European Commission

Desertification in Europe : mitigation strategies, land use planning

Proceedings of the Advanced Study Course,
held in
Alghero, Sardinia, Italy,
from 31st May – 10th June 1999

Edited by:

G. Enne, C. Zanolla, D. Peter

Directorate – General for Research
Environment and climate programme

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Foreword

The training of scientific personnel and the development of a highly qualified scientific community are, and have always been among the important concerns of the European Commission. Advanced training is an important prerequisite for the implementation of a common EU policy in science and technology.

The Advanced Study Courses activity consists of a series of courses on specialised subjects within the general theme of research related to the EU. Under the Environment Research Programme (Accompanying Measures) support is provided to graduate and post-graduate students to attend such courses.

Each of the courses is organised in cooperation with a European Institution involved in the current research programme, and is aimed at giving the students new perspectives and insights in the specialist subject areas through formal lectures and participation in informal discussions with leading researchers.

The Key Action on Global Change, Climate and Biodiversity includes a specific theme: Fighting Land Degradation and Desertification. The present volume is based on lectures given at the course held in Alghero, Sardinia, Italy, from 31 May to 10 June 1999 on 'Desertification in Europe: Mitigation Strategies, Land Use Planning'. It also contains presentations, given by the participating students, on their own research activities and interests.

With the adoption of the International Convention to Combat Desertification, which represents a follow up of the Rio recommendations, this publication is timely. It highlights the specific situation of the Southern European regions and provides a comprehensive and state-of-the-art review of this complex issue. I am convinced that it will stimulate further interest in this field of research.

A. GHAZI
Head Biodiversity and Global Change Unit
Research Directorate General
European Commission
Brussels, Belgium

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School Programme
Alghero,Italy

Opening of the School

Dr. E. Cossu Major of Porto Torres and chairman of "National Observatory on Desertification"
Prof. G. Enne Coordinator of N.R.D. University of Sassari

Opening Conference

Chairman: Prof. G. Enne
The history and development of desertification in the Mediterranean and its contemporary reality. *(Prof. N. Yassoglou - Laboratory of Soil and Agricultural Chemistry, Agricultural University of Athens)*
Students' contribution *(Roberto Sabatini, Antonio Barberis, Alexandra Weldon)*
Discussion

Lectures

I. Desertification indicators: how to measure desertification and degradation processes

Chairman: Prof. G. Pulina
I.1 How to measure desertification and degradation processes. *(Prof. F. Lopez-Bermudez – Instituto del Agua y Medio Ambiente, Universidad de Murcia, Murcia Spain)*
Students' contribution *(Sara Bernia, Dimitrios Triantakonstantis)*
Discussion

Chairman: Prof. N. Yassoglou
I.2 Indicators of land degradation in the Mediterranean basin. *(Prof. A. Imeson – Department of Physical Geography and Social Science, University of Amsterdam, Amsterdam, The Netherlands)*
Students'contribution *(Teresa Carvalho, Antonella Deriu, Stefano Loddo)*
Discussion

II Understanding and modelling degradation processes and desertification risk

Chairman: Dr. S. Sommer
II.1 Criteria and instruments to halt soil erosion. *(Prof. J. Poesen – Laboratory for Experimental Geomorphology, K. U. Leuven, Belgium)*
Students' contribution *(Fabio Manfredini, Maria Adabovskaya, Stavroula Panagea)*
Discussion

Chairman: Prof. J. Poesen

II.2 Rain, rivers and floods in relation to desertification. *(Prof. J. Thornes - Department of Geography, King's College London, University of London)*
Students' contribution *(Marco Scozzafava, Justin Taplin)*
Discussion

Chairman: Prof. A. Giordano

II.3 Modelling ephemeral channels and groundwater recharge. *(Dr. S. Burke - AmbioTEK Technology for Environmental Knowledge, London UK and Prof. J. Thornes – University of London)*
Students' contribution *(Marijke Ghesquiere, Stefano Di Fabio)*
Discussion

III Remote sensing to support mitigation action planning

Chairman: Prof. F. Lopez-Bermudez

III.1 Advanced technologies to support mitigation action planning. *(Dr. S. Sommer - DG JRC, European Commission, Space Application Institute (SAI), Environment and Geo-Information Unit TP, Ispra (VA) Italy)*
Students' contribution *(Chantal De Jaeger, Marco Motta)*
Discussion

IV Land evaluation and land use planning to mitigate desertification

Chairman: Prof. A. Imeson

IV.1 Land evaluation to mitigate desertification. *(Prof. A. Giordano - DEIAFA Department of Economy and Agricultural Forestry and Environmental Engineering, University of Torino, Italy)*
Students' contribution *(Maria Sarnataro, Marta Maggi)*
Discussion

Chairman: Prof. S. Van der Leeuw.

IV.2 Land use planning to mitigate land degradation. *(Dr. L. Stroosnijder - Department of Environmental Sciences, Erosion and Soil & Water Conservation Group, Wageningen University)*
Discussion

V **Methodologies to prevent and mitigate land degradation phenomena in Mediterranean agrosilvopastoral systems**

Chairman: Amb. Antonio Marongiu

V.1 Methodologies to prevent and mitigate land degradation phenomena in Mediterranean agrosilvopastoral systems. *(Prof. G. Pulina - N.R.D. Department of Zootechnical Science, University of Sassari, Italy and Prof. V. Papanastasis - Faculty of Forestry and Natural Environment, Aristotle University, Thessaloniki, Greece)*
Students' contribution *(Antonio Barberis, Claudio Zucca)*
Discussion

VI **Restoration strategies and actions in Mediterranean degraded lands**

Chairman: Dr. L. Stroosnijder

VI.1 Restoration strategies and actions in Mediterranean degraded lands. *(Prof. R. Vallejo - Centro de Estudios Ambientales del Mediterraneo, CEAM,* Parc Tecnologic, *Paterna, Spain)*
Students' contribution *(Raquel Moreno Penaranda, Juliet Rose, Andreas Persson)*
Discussion

Chairman: Prof. V. Papanastasis

VI.2 Mitigation actions in desertified areas of Northern Europe. *(Dr. A. Arnalds - Soil Conservation Service,Iceland)*
Students' contribution *(Ranneveig Olafsdottir, Sara Bernia)*
Discussion

VII **Policy-related aspects: the CCD implementation and the National Programmes to Combat Desertification**

Chairman: Dr. M. d'Angelo

VII.1 Managing desertification in a national context. *(Dr. L. Rojo Serrano - Dirección General de Conservación de la Naturaleza Ministerio de Medio Ambiente., Madrid Spain)*
Students' contribution *(Teresa Carvalho, Rosanna Salvia, Joaquin Lavado Contador)*
Discussion

Chairman: Prof. G. Enne

VII.2 International aspects of desertification: towards the implementation of the CCD Annex IV. *(Prof. S. Van der Leeuw - Université de Paris I, UFR 03 - Histoire d'Art & Archéologie and Amb. Antonio Marongiu - Former EU Ambassador Loc. S. Andrea, Quartu S. Elena (CA), Italy)*
Students' contribution *(Zhong Zhang)*
Discussion

VIII Open session on Political and socio-economical aspects of desertification

Chairmen: Prof. G. Enne, S. Van der Leeuw and L. Rojo Serrano
General discussion

Field trip to the NRD-MEDALUS III study area
Presented and organised by *Dr. M. d'Angelo, Regional Forestry Administration*

Irgoli – **First stop**
Welcome from the Major and brief presentation by the NRD - University of Sassari of the main desertification topics dealt with in the field trip.
Irgoli – Second stop.
Topic: The overgrazing problem and the "pasture improvement"actions.
Poster presentation by *Dr. Claudio Zucca and Dr. Salvatore Madrau*
Irgoli – Third stop.
Topic: The role of forest fires on land degradation
Siniscola – Fourth stop
Visit to the Capo Comino sand dunes

Field trip to Is Arenas and Tharros
Is Arenas *(Narbolia Municipality)* **- First stop**
Visit led by *Dr. Giuseppe Delogu, Regional Forestry Administration.*
Topic: Mitigating land degradation: afforestation in arid environments. The case study of Is Arenas sand dunes fixation.
Tharros – Second stop
Visit to the ancient town of Tharros (Phoenician period).

Closing of the school and certificate conferring

Prof. G. Enne Coordinator N.R.D. University of Sassari
Prof. A. Mastino Deputy Rector University of Sassari

HISTORY AND DEVELOPMENT OF DESERTIFICATION IN THE MEDITERRANEAN AND ITS CONTEMPORARY REALITY

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Abstract. Pre-historic land degradation events are not accurately documented. They are inferred from past geological and hydrological evidence and they have a certain degree of bias and uncertainty. Available information seems to be more dependable after the Bronze Age, when man's impact on the natural systems starts to become obvious.
Physical and anthropogenic process have acted on the land and caused extensive but spatially and temporally discontinuous degradation of the natural ecosystems. Catastrophic soil erosion, flooding, deposition and climatic aridity cycles had taken place before human action started interfering with nature. Physical land degradation has been reversible and natural ecosystems reestablished themselves during periods climatic optima.
Land degradation advanced to the state of desertification, following a localized pattern, during periods that climatic aridity and excessive human pressure coincided. Such periods began around 8,000 years BP, but most of the land remained in natural and semi-natural condition until 4,000 years before present. During this period population grew, agriculture was extended to vulnerable lands and diversified. Coastal forests were cleared for shipbuilding, pottery kilns and ore smelting. This intense human action on the land coincided with major drought around 3.500 years BP. The fall of the Mycenean Civilization and a sharp decline in the population of Greece followed this period of strong human interference with nature.
Exploitation of vulnerable marginal land, modification of environment and population movements were accentuated during the Roman Era and continued until present with two major interruptions: Bubonic Plague in 747 AD and the Black Death about 600 years ago. Depopulation during these two periods may have allowed natural ecosystems to recover. Technological advancement, industrialization of agriculture and subsidy policies have accelerated the rate of land degradation during the last 50 years.
Man's actions have not been only destructive to land. Land protection was practiced in several locations. Land terracing in the Mediterranean is about 2, 500 years old.
Desertification has been prominent in two landforms: the limestone slopes and the marly hills.

Key words: Desertification history, land degradation.

Introduction

The analysis of the past events and causes of desertification is a valuable tool for understanding the factors and processes involved, for predicting future events and for designing and implementing prevention and mitigation measures.

The exact description and documentation of past events is not always feasible, particularly for time periods lacking historical evidence. Many of the projections concerning past natural and anthropogenic land degradation processes and causes are based on inference and they are not entirely free of personal bias. Thus, the assessments of the historical evolution of desertification in the European Mediterranean in this presentation may not be entirely correct.

The causes of desertification in the Mediterranean fall within two major groups: Physical and anthropogenic. The history of desertification actually follows the course of evolution of these two groups of causes and of their interactions.

Desertification according to the definition of the United Nations Convention is confined to areas affected by drought. This definition is somewhat biased since the phenomenon may also take place under humid climates as in Scotland and Iceland. Thus, this phenomenon will be treated, in this presentation as, an extreme case of land degradation.

Land degradation has no spatial and temporal confinement. It has taken place at various times and under a variety of physical conditions, with and without the intervention of man. Catastrophic degradation of land resources has taken place in all climatic regions of the Earth.

The causes of degradation are variable and quite complex. Similar sets of conditions and circumstances may produce different results. It seems that a severe and permanent decline of land's productivity, that will result in the desertification and desertion of an area, would require a certain conjunction of natural and social circumstances (van de Leeuw, 1998). It occurs as soon as one or more variables accelerate or slow down out of proportion, not allowing the other ones to keep up with them, thus leading to different dynamic equilibria of the system. One may add that at the new equilibria, the life and diversity support capacity of the system is sequentially diminished.

According to the above reasoning, one may conclude, that in the course of history, land resources follow with time a declining path. This might be true in some occasions and not in others. Land resilience, through positive feed back and self-reinforcing mechanisms, can interrupt the declining course and repair the damages if they have not crossed the critical thresholds. Intensive soil erosion episodes during the Quaternary denuded higher slopes but at the same time created collouvial and large alluvial deposits, which had much greater biomass productivity than the original sloping lands. These lands have supported the proliferation of the human communities.

While desertification in the Mediterranean does not occur without irrational human activity, there are many cases where man's interference with nature has produced new socio-ecological systems that contribute to his welfare more than the natural ones. Such a case is the sustainable agriculture, which may have, through the ages, decreased biodiversity but it has provided livelihood for a greater number of inhabitants than the natural system.

Irrational land use practices have, in several occasions, desertified areas that as natural systems were productive. Such cases are the desertification of large areas in Mesopotamia through man induced soil salinization and erosion, and in southeastern Spain through cultivation and overgrazing of sloping lands.

The history of natural events and the episodes of human interference that caused major degradation in the European Mediterranean land will be discussed in the following sections of this presentation.

Evolution of the physical environment

Climatic fluctuations have been changing the landscapes and the vegetation on Earth ever since the Pliocene. Geological evidence shows that these fluctuations occurred in periodic cold-warm an dry-wet cycles. As a result we see in a given point at a given moment a mixture of landscapes, the succeeding inheriting the preceded one, which are difficult to unriddle. Holocene sediments in Attica, Greece indicate the occurrence of about 12 humid-dry cycles repeating themselves every 1,000 years until 3,550 BP. The periods that followed had cycles of 500 years (Van Overloop, 1986).

The evolution of the physical environment in the Mediterranean has been examined by many authors such as Gilman and Thornes, 1985;Verheye 1991; Tzedakis, 1993; Runnels, 1995; Grove, 1996; several researchers of the ARCAEOMEDES Project, 1998, (summaries by van der Leeuw; McGlade and van der Leeuw). The main physical events that occurred during the later period of Earth's life in the European Mediterranean Region can be summarized as in Table 1.

The descriptions indicate that natural events that could trigger physical processes such as soil erosion, sediment transport, gullying, cooling, aridification and biological changes, capable of extensive land degradation, have occurred even in the absence of human interference.

The Epirus landscape, in northwestern Greece, has been affected by large- scale erosion episodes throughout the 1,000,000 years of the Quaternary, which should be attributed to the absence of an efficient tree cover, but more fundamentally to slope angles and chronic tectonic activity (Bailey et. al.1998).

Pollen analysis in cores taken from the bottom of Lake Ioannina in Epirus, has revealed that, in the period between 423,000 to 10,200 years BP, there had been several cycles of open vegetation separated by shorter cycles of forest (Tzedakis, 1993). Epirus, like almost all of the Mediterranean was covered by an open low biomass producing steppe-type vegetation during the cold stages of the Quaternary. This type of vegetation accounted for about 70% of the land use for 2 million years and was associated with unstable landscapes and low rates of soil development, erosion and formation of colluvial deposits and large alluvial fans during the middle Pleistocene. The advance of forests, which occurred during the temperate interglacial times, interrupted the periods of land instability.

It seems that soil erosion had been more intensive on the colluvial and alluvial deposits than on the higher slopes because the former were in the path of the waterways (Bailey et al., summary by van der Leeuw, 1998).

Studies in the Vera basin in southeastern Spain (Bailiff et al. 1998) indicate that an overall stability prevailed during the Late Pleistocene to Middle Holocene. Aggradation was the dominant physical process, which was interrupted by short dissectional episodes that did not reverse the general trend of reduction in the erosion rates and fluvial transport capacity. Decrease in rainfall intensity warmer temperatures and sea level rise contributed to higher rates of soil development.

During the last 5,000 years, the Mediterranean climate became drier and an increase in the amplitude of its fluctuations increased the risks of soil erosion. Thus, weakly developed soils with high sensitivity to erosion predominated during this period. Human intervention, during this period became a significant factor, which contributed to the instability of the land systems.

5 million years BP.	Salinity Crisis, sea level drop, closure of Gibraltar straits, Evaporation fault displacement, tectonic uplifting, exposure of Soft rocks, catastrophic erosion.
300,000-25,000 BP	Sedimentation of basins during cold periods, formation of fluvial terraces in Greece. Southern Europe covered by Artemisia steppes with scattered forest stands.
15,000 BP	Glaciers retreated. Pine-Juniperus forest appeared followed by Oak forest.
11,000 BP	Strong cooling, lower precipitation. Deposition of wind blown silt from Africa. Juniperus-Pinus-Amygdalus-Pistacea forest and steppe predominate.
10,000-0,00 BP	Higher temperatures and more precipitation than present, arid conditions declined. Deciduous forests expanded, Appearance of wild olive tree. Torrential rainfalls between 10,000 and 8,000 BP
Arround 8,500 BP	Major dry crises
8,400-7,500 BP	Climatic optimum
7,400- 0,00 BP	High-level glaciers expanded in southern Europe. Climatic fluctuations until a few centuries ago (Little Ice Age) caused vertical shifts of snow and tree lines had no significant effects On the Mediterranean ecosystems. Major drought crises around 3, 500. Wild fires occurred also prior to agriculture

Table 1: Chronological sequence of natural events.

Human intervention

Man has been on the Earth for about 1.6 million years. However, his actions started having marked effects on the European natural ecosystems since the Neolithic Age and became quite prominent during the Bronze Age. The human interference has not been linear. It shows maxima and minima that coincided with periods of population increase and decline respectively.

An approximate outline of the human impact on the natural systems is given in Table 2 It is based on the estimates provided by the authors: McDonald, 1972; Van Wersh 1972; Yassoglou and Nobeli, 1972; Gilman and Thornes, 1985; van Andel and Runnels, 1987 Coccosis, 1991; Rubio, 1995 Grove, 1996; researchers of the ARCHAEOMEDES project, 1998 (summaries by van der Leeuw; McGlade and van der Leeuw).

The history of man's intervention on the land of the Mediterranean Europe suggests that human pressures have followed a non-linear increasing trend since the Neolithic Age with several interruptions. Periods of low human activities allowed the recovery of some natural ecosystems. These interruptions show spatial and temporal variability throughout the region. Human pressures have been enormously intensified during the last 50 years so that there are no remaining pure natural ecosystems in the Mediterranean Europe today.
The study of the human activity on the Earth has provided substantial evidence of its periodic fluctuations. Population increases and decreases may be attributed both to physical changes of the environment and to man's own activities. An exponential increase in population has been taking place during the last centuries. At the same time the effects of the natural episodes on the human communities diminishes as technology advances. Whether we are at metastable equilibrium or not and what will be its duration will be seen in the future.

Interactions between physical and human events

There is no evidence in the Mediterranean Europe of physical degradation leading to desertification without human action. According to findings of the ARCHAEOMEDES project, land degradation is immediate when physical degradation is in phase with agro-pastural activities.
On the other hand long time human impact fragilizes the ecosystem, so that minor oscillations in the physical parameters might bring about severe land degradation. Under these assumptions periods of possible desertification and resilience may be traced along with the history of physical and human evolution.
Results, obtained by studies conducted in Epirus in northwestern Greece (Bailey et al. 1998), have shown that pastural activities, forest clearances, seasonal movement of people and animals and a detectable interference of man with nature began around 9,000 BP. However, intensive man induced land degradation started much later.
Desertification may have occurred after the Neolithic Age. The first might be traced in the period 4,000- 3,000 years BP when intense human activities such as population growth, expanded agriculture and cutting of forest trees coincided with periods of aridity. The Mycenean Civilization collapsed and depopulation took place during this period.
The distribution of settlements in the period of 4,500 to 2,500 years BP is certainly related to the land degradation in the coastal areas of ancient Greece. During the early Helladic Period (4,600-4,000 BP) settlements and cultivation were mainly confined to the prime bottomland, which is resistant to degradation. During the Middle and Late Helladic and the Archaic periods (3,900-2,500 BP) most of the settlements and cultivated fields had been moved to second and third quality class hilly lands, which were quite vulnerable to soil erosion. These areas were severely eroded and lost most of the soil horizons, that were formed during the preceded climatically optimum period. Pine forest disappeared from populated areas during this period.
The collapse of the Mycenean Civilization around 3,200 BP (end of late Helladic) may be attributed, among other unknown causes, also to the desertification of land. The decline of population most probably allowed the recovery of land's productivity. The cultivation of olive trees, that followed and continue until today, prevented further deterioration of land.

In the Middle East man started affecting the natural vegetation patterns around 10,000 BP.	
8,000-5,000 BP	Man begins to change the natural ecosystems during the Neolithic Age. Cultivation starts around rural settlements. Grazing, burning and land clearing start to interfere with natural ecosystems.
5,000 BP	Cultivators and herdsmen were established and small villages appeared on low ground and near the coast in the Copper-Bronze Age. Wide spreading of cultivation in highly resilient productive land. However, most of the land remains in natural or semi-natural condition. Land degradation is not intense.
4,000 BP	Poly-culture is established. Population growth. Cutting of coastal pine forests for ships, pottery kilns and smelting ores. Olive trees widely grown. Fortification of inland hilltop sites, aggressive political unification. Trojan War around 3,300 BP. Decline of Mycenean Civilization, severe decline of population around 3,200 BP.
2,500 BP	Population increase, Greek colonies established in the north and south coasts of the Mediterranean
2,100 BP	Roman control imposed. Growth of population and cities. Marginal land came under cultivation. Modification of environment by drainage, river damming, and water transfers. Highland people came down to low lands
1,700 BP	Decline of the Western Roman Empire. Invasion of Visigoths.
1,500-1,300 BP	Dark ages. Reduction in population. Bubonic Plague. Invasion of Germanic tribes, large scale immigration of Slavs in the East Abandonment of rural estates, destruction of hydraulic works. Piracy drove people to the interior.
1,330- 650 BP	Expansion of agriculture, improved irrigation practices, introduction of new crops by the Moor invaders of Iberian Peninsula. Movement of people to larger villages. Agriculture is characterized by subsistent agrarian systems.
650-500 BP	Black Death, severe depopulation, number of people and settlements nearly halved.
250 BP- Present	Recovery of population, land shortage, overgrazing, forest clearing, intensive erosion, floods. Changes in the land tenure systems, individuals acquire free holdings. During the period of Industrial Revolution, agriculture is further expanded, arable land increases, agricultural practices intensified, land degradation advances. Abandonment of marginal land and population shift toward the urban centers becomes apparent. After the Second World War new technologies are applied to agriculture land exploitation increases encouraged by economic expansion policies and produce subsidies. Land deterioration becomes an important issue.

Table 2: Chronological sequence of human impacts on natural systems.

Hilly lands and plateaus were first used for the cultivation of rainfed crops because winter rainfall was sufficient. Later, around 4,000 BP, irrigated agriculture was practiced in the basins of Euphrates and Tigris and along the banks of the Nile. Population increase and the consequent intensification of land exploitation resulted in severe soil erosion on the hills and salinization in the irrigated lands. A manifestation of the desertification processes that took place in the area is the reduction of population in Mesopotamia from its peak of 25 millions to the present of four millions.

In Spain, land degradation periods can be traced from 2,500 BP to present. Theophrastus and Pliny had described the conditions in southeastern Spain as desert like. Spanish writers have referred to land and forest degradation since 850 BP and expressed concern about its consequences and prescribed methods of mitigation.

Studies in the Vera basin in Spain have shown that, in the period 6,000-5,000 BP, pines were extensive in the uplands, whereas deciduous species dominated the lower slopes and valleys. Human communities were sparsely distributed and were engaged in a subsistence agro-silvo-pastural exploitation. People and animals moved across the landscape following the seasonal oscillations of vegetation and of a more humid than present climate. Some man induced slow soil erosion had started during this period but the land was for the most part resilient.

Low human influence prevailed until Colonization (2,800 years BP). Then began a long period of high interference of man with nature, which lasted about 1,000 years. However, low intensity winter rainfall and probable warm summers caused rill erosion and sheet floods on low stability land. During the Andalusian Era that followed (1,300- 500 years BP) man's exploitation of land was moderate and contributed toward the stabilization of the landscapes.

The Arabs, after their conquest of the area around 1250 years BP, had established a sustainable agricultural system based on irrigation and terraced farming. This system collapsed when the population declined after the expulsion of the Arab around 450 years BP. Irrigation systems were left unattended, terraces were destroyed, soil erosion was intensified and badlands were formed.

Social dynamics, in the Vera basin, played an important role in the deterioration of land.

They caused the decline of the roman settlements, which ended the maintenance of the irrigation channels and expanded the badlands on the slopes. The interactions among climate soil and man from the beginning of the Chalcolithic period are summarized in Table 3 according to Baliff et al. (1998)

In the Rhône Valley, the natural landscape was transformed during the period of 6,800-5,200 BP by clearing the oak forests, development of settlements on the hills and on the bottomlands and practicing agriculture and stock breeding. During the next 1,000 years, there was a decline of the human impact on nature. A rapid spreading of settlements begins around 3,300 BP associated with a heavy impact on the environment as a result of firewood cutting for melting and working bronze. Intensive human activities such as building of roads, drainage systems an expansion of agriculture caused a significant change in the landscape during the Roman period (Audouze et al. 1998).

The experience in the Vera and the Rhône valleys and elsewhere in the Mediterranean, both in the past and in the present time, shows that a sustainable equilibrium attained by a man affected artificial landscape may quickly be destabilized and degraded when it is abandoned. It must be stressed, however, that this is true only in cases, where man has strongly affected the

natural environment and established a metastable equilibrium, which could be maintained only through his conservation practices. There are many cases of degraded lands that followed a recovery course after their abandonment. Such cases are overgrazed pastures and cultivated forest lands. It is necessary, therefore, thar authorities should analyze all of the past and present conditions, when they are faced with land abandonment.

Man's action on the land has not always been destructive, in many occasions he practiced soil conservation by terracing sloping land since ancient times. There is also some evidence that man knew how to evaluate the capability of land and use it accordingly since the Bronze Age (Yassoglou and Nobeli, 1972). One of the most land protective and improving agricultural systems has been the olive grove with understory vegetation (Kosmas et al. 1996).

In contrast winter cereals, such as wheat, are the least protective crops, because they leave the soil surface bare and exposed to erosion during the beginning of the rainy season (Enne, 1996).

Prominent cases of desertification

Prominent cases of desertification in Mediterranean Europe are those on limestone slopes and on marly tertiary and quaternary hills. These two landforms are particularly sensitive to human impact and have been under pressure for several thousand years.

Desertification on Limestone slopes

Irreversible desertification of limestone slopes is quite extensive in the Mediterranean, particularly in the eastern regions. Land on limestone is very vulnerable for the following reasons:

a. The high permeability of the bedrock induces a more arid microclimate than other rock formations.
b. Soils developed on this parent material are thin because the residue that remains upon its weathering is very small, usually less than 2%. Actually some of the soil material consist of wind blown silt from Africa. Such an extensive deposition occurred around 10,000 years before present and continues until today.

These two conditions are responsible for the low erosion tolerance of the soils and the low rate of recovery of damaged vegetation. Thus land degradation and desertification proceed faster on the sloping limestone lands than on other landforms.

Deforestation of coastal areas has been going for 4,000 years and has resulted in accelerated erosion on the limestone slopes, critical reduction of soil volume and in desertification. This is documented in Attica, Greece by Plato's writings in Critias; "Soil has been carried to the bottom of the sea.. Earthy high mountains, that in the past carried tall forest and large pastures, have become rocky lands and look like the bones of a sick body... In the past rain water was utilized and did not run on the barren land to the sea as it does now. It infiltrated and was stored into the soil and it was distributed in springs, fountains and river streams".

These processes continued to expand in the mainland until now desertifying a large portion of the limestone formations, especially on southern slopes of the semi-arid and dry-subhumid zones.

Cultural period	Sediment budget	Soil dynamic	Inferred climate	Human influence
Chalcolithic (5,000-4,300 BP)	Progressive sediment loss in uplands and midland, aggradation in the lowlands	Structural stability at regional level	Strong seasonal variations	Low
Agric (4,300-3,500 BP)				
a. Early agric	High discontinuous sediment flux	Destabilization of vegatative cover by , forest fires, gullies and mudflows	Warming, frequent torrential rains	Low
b. Late agric	Low sediment flux	Stability	Rainfall increase	Low
Post agric (3,500-2,700 BP)	Low sediment flux	Moderate stability	Low intensity winter Rainfall	Low
Colonization to Visigothic-Byzantine (2,700-1,450 BP)	Soil erosion in up-lands, aggradation in Lowlands	Permanent rill ero- sion and sheet floods on lands with low stability, rapid regeneration of soil cover	Low intensity winter rainfall, possibly warm summers	High
Andalusian (1,300-500 BP)	Low sediment yields	Improved stabilization by shrubland expansion, ground Water recharge	Warming	Moderate
Modern 500- 50 BP	High rates of sedi-mentation in the low- lands	Permanent rill ero- sion controlled conservation ploughing and terracing		Exponential increase
Agricultural revolution 50- 0,00 BP	Very low sediment flux	Moderate rill ero-sion abandoned terraces on marls, slow restoration of structure on other soils		None to weak on abandoned lands, very strong on irri- gated

				fertile lands

(Source: Baliff et al. 1998, ARCHAEOMEDES)

Table 3: Landscape dynamics in the Vera basin.

Desertification on Marly slopes

Marly formations when undisturbed form deep fertile soils (Mollisols), characterized by a thick, dark, well structured and rich in organic matter surface horizon. Their productivity was early recognized and were intensively cultivated mostly with cereals until the Archaic times and then with vine, olive trees and orchards. The Goddess of Agriculture was called "Melaina Dimitra (Dark Ceres)".

In spite of their productivity, marly lands are sensitive to desertification because:

a. They are hilly and therefore subject to water erosion

b. The texture of the parent material is silty and mostly structureless. Once the rich in organic material and well structure top soil is removed, the exposed underlying horizons acquire high rates of erosion because of their high erodibility.

c. The surface crust that usually forms on the subsurface horizons reduces water infiltration, increases runoff and inhibits the emergence and the rooting of the young plants. The recovery of protective vegetation is very slow and erosion is further accelerated.

d. Biomass production on these soils is very sensitive to soil moisture. It is high when the available soil moisture is sufficient, but drops quickly when it diminishes. Thus, under conditions of drought, these soils are more sensitive than even shallower soils on other parent materials.

The above conditions prevail in the semi-arid and arid zones, where desertification is extensive on the marly landforms. It is particularly extensive in Southeastern Spain. Desert like conditions in this area were described by Theophrastus (ca 370-280 BC) and Pliny (23-79 AD). The former writer described Greece as arid and Italy as green. Since then, both countries have experienced man-induced desertification. Deforestation followed by cereal cultivation, over grazing and land abandonment have desertifyied large sections of land. Due to the adequate depth of the friable parent material, desertification in many cases is reversible.

The contemporary reality

Desertification in Europe is a reality today. It is estimated that European farmers loose annually about 1.5 billion of US dollars (Dregne, 1991). The physical and socio-economic factors, which are responsible for this loss are described below.

The physical setup. Steep slopes, a sequence of Pliocene to contemporary erosion and aggradation surfaces, characterize the present landscape of the Mediterranean Europe; man altered vegetation, and over-exploited soil and water resources.

The contemporary climate of the area follows a warming and drying path. Statistics indicate that a general warming trend started around 100 years ago and it has not been reversed

(Berger, 1986). The period of 1931-60 had been one of the warmest in Europe during the last 500 years. There are also long periods of drought. Yearly rainfall is irregularly distributed, particularly in the drier zones. The variation increases with decreasing mean annual rainfall. Global Circulation Models predict that greenhouse gases will cause changes in the temperature and rainfall, which will be unfavorable in the desertification sensitive areas. Although, the accuracy of the predictions is not satisfactory at present, they indicate a general trend that is widely accepted and raises concern.

The above described physical conditions make a large part of the Mediterranean lands vulnerable to desertification. The primary processes are soil erosion by water, drought, and secondary salinization .

Factors responsible for the high rates of soil erosion are those, which apply all over the World. Some of them are particularly adverse in the Mediterranean:

- The steep slopes particularly on the extensive Tertiary and Pre-Tertiary surfaces.
- The insufficient protection of the land by a disturbed perennial plant cover and vegetation structure, and its low resilience in the desertification sensitive areas.
- The low erosion tolerance of the lands on limestone slopes.
- The high erodibility of the of soils on Pliocene formations.
- The high erosivity of rainfall due to its irregular temporal, spatial and intensity distribution.
- The long history of intensive human interference.

Country	High risk area		Moderate risk area		Low risk area		Excluded area		Total area
	Km2	%	km2	%	Km2	%	Km2	%	Km2
France (S)	16, 355	9	37,900	20	93, 443	49	42,463	22	190,161
Italia	82,368	27	85,211	28	122,416	41	11,303	4	301,278
Hellas	57,414	43	27,436	21	27,027	21	20,113	15	131,990
España	202,101	41	205,157	41	69,662	14	20,598	4	497,518
Portugal	61,120	68	21,890	25	4,918	6	1,000	1	88,928
EU (South)	419,338	35	377594	31	317,466	26	95, 477	8	1,206,875

(source CORINE, 1992)

Table 4: Potential erosion risk in the southern EU countries.

Table 4 shows that large sections in each of the EU Mediterranean countries are at high and moderate soil erosion risk. The total area at risk amounts to 66% of the total area that these countries occupy. Thus, if man does not restrain himself from irrationally interfering with the physical environment land degradation and desertification, through soil erosion, will be extensive.

Drought is a normal climatic feature of the Mediterranean countries, which has no predictable patterns of occurrence and has serious ecological, economical and sociological effects. There are various types of drought (Llamas, 1997): weather, agricultural, hydrological, ecological, technological and psychological. The classical is the agricultural on non-irrigated land that has brought famines described by human history as disasters or plagues.

Salinization and sodification of soils have been ongoing old natural processes that turn productive lands into deserts. It takes place in land depressions and coastal plains, where

salts are transported by surface runoff and/or capillary rise of ground water. Land in the arid and semiarid zones with inadequate drainage are those that are mostly affected by this phenomenon. There are two paths followed by the processes of soil salinization:

- Addition of soluble salts to the soil by converging surface waters, by rising ground water and by irrigation waters.
- Distilative removal of soil water by evaporation.

A desertification threat that dates back to 5,000 years BP in Mesopotamia and continues through contemporary time, is secondary salinization, which is caused by the irrational application of irrigation, such as the use of water with elevated soluble salt content and / or the failure to meet the leaching requirements.

Modern technology leads to low rates of irrigation water application that does not meet the requirements of leaching the accumulated salts. Tricle irrigation poses greater salinization threat than surface irrigation (Yaron, et al.1973).

Abstraction of ground water from coastal aquifers frequently results in the intrusion of seawater into them. The use of such waters has quickly damaged the soils and reduced their productivity on many occasions. Aru et al. (1996) has classified the coastal soils in Sardinia according to their salinization risk due to this phenomenon.

Desertification due to soil salinization is not as extensive as that which is caused by erosion. The economical loss that it inflicts per degraded unit area is much greater, because it affects high valued productive land, whereas erosion affects mostly marginal lands. The continuing expansion of irrigated agriculture in the Mediterranean is bound to increase the salinization risk and deserves special attention.

The socio-economic context. Since 1950 the world is experiencing a dramatic increase of human interference with nature. This is mainly due to the rapid technological advancement, which enables man to inflict major changes on the natural systems in a short time. Desire for quick economical growth, policy regulations, trade expansion, population explosion in some places, large scale migration, tourism, urban expansion and land use competition are some of the driving forces, which are changing nature in increasing rates by the over-exploitation of its resources. Vegetation, soil and climate are the main components of the environment that are being affected. We are now living in era, during which man has for the first time succeeded in modifying the climate. The principal processes that are followed and the conditions that are conducive to the artificialization of the environment are:

- The low level of the perception on the part of the authorities and the public about the processes and the impacts of desertification.
- The industrialization and mechanization of agriculture, which actually consumes more energy than it produces. This, fact by itself, poses a question about the long-term sustainability of this human activity.
- The reduction in the quantity and diversity of natural vegetation by overexploitation and clear-cutting of forest lands, overgrazing the pastures, burning forests and shrublands and by military actions.
- The overexploitation of the water resources and especially the groundwater of which the level has dropped significantly in the desertification sensitive areas.

- The soil sealing by urban expansion in to productive lands, which has acquired high rates in the recent years.
- The abandonment of marginal agricultural lands that had been brought by man to an unstable equilibrium. These are lands on sloping terrain, which were protected by erosion control by erosion control structures and practices. Protection ceases and erosion accelerates when they are abandoned.
- The over-pumping of coastal ground water and improper irrigation practices that cause intrusion of seawater into the aquifers and secondary salinization of the soils.
- The tourist influx in sensitive area has become a problem since it promotes urban expansion to the expense of natural landscapes and contributes to the overexploitation of the water resources
- The emission of green house gases that generally increase temperatures and decrease rainfall in the sensitive areas of the Mediterranean.
- Remedial actions taken by governmental an non-governmental organizations

The industrialization and mechanization of agriculture has enabled the farmer to bring into cultivation sensitive sloping lands and enjoy a temporary profit from them. Technological advancement and subsidies are concealing the damage done to the land by organic matter loss and soil erosion, until a threshold is reached, after which desertification will becomes inevitable. The areas most vulnerable to degradation are the tertiary marly hills of the semiarid and dry subhumid zones.

Vegetation in forests and shrublands has been declining in recent years in favor of cultivated lands and pastures. The area covered by forests and brushes in the Guandalentin basin in Spain has declined by 50 % since 1947 (Lopez-Bermudes et al. 1998). In other cases forest show a comeback trend to the abandoned and deserted lands.
Wild fires have been causing an extensive damage to forested areas they are detrimental in the sensitive climatic zones, especially when they are followed by grazing or if they re-occur before the trees reach the fruiting stage. Pine forest has been subjected to frequent and extensive fires, which show an upward trend during recent years. In Greece the burned areas show a general increasing trend in the last 20 years. A significant number of them (25%) have been intentional criminal acts, whereas negligence accounts for another 28%. The area of forest land that has been burnt in the last 25 years amounts to approximately 1, 500, 000 ha, which is almost 50% of the total forested area of the country. The average annual number of forest fires, that have occurred during the decade 1981-1900. Table 5 shows the gravity of the problem.

Portugal	Spain	France	Italy	Greece
8,397	10,210	4,475	10,999	1,275

(Source: Eurostat, 1995)

Table 5: Average annual number of wild fires in the EU Mediterranan countries during the decade 1981-1990.

Forests have been expanding in parts of the countries of European Mediterranean, during the last decades. During the period 1965-1984, the total forested area of the region has grown by 6,462,000, which represents a 14% increase (Le Houérou, 1990). The advancing forests have occupied abandoned marginal agricultural lands and pastures. However, most of the naturally afforested areas are located in climatically favorable and moderately damaged lands. Natural afforestation of abandoned lands in the desertification threatened areas is not always possible because of climatic limitations and advanced degrees of soil degradation.
National and international military activities have been widespread in Europe during the last century. Newly developed war technologies are quite effective in destroying vegetation and contaminating soil, water and air.

Water resources, considered at the country level, are at present sufficient in all the countries of the Mediterranean Europe, but there are asymmetries in their seasonal and spatial distribution in all of them. Serious supply-demand imbalances are the result of climatic irregularities, irrigated agriculture, urban sprawl in coastal areas and increase in tourism.
In the semi-arid regions, the water cycle is discontinuous. As a result water channels and rivers may be dry for much of the year. There is a deficit between the locally available water and the consumption needs in the desertification sensitive areas. This deficit is growing as consumption increases, while available resources do not increase. It reached dramatic dimensions in the Guadalentin basin and in Murcia during this decade (Lopez-Bermudes, 1998).
The negative gap between precipitation and potential evapotranspiration is very large. Consequently, the principal user of water is irrigated agriculture. The amounts of irrigation water that are consumed annually are given in Table 6.

Country	Millions of hectares irrigated	% of total national farmland	Billions of m3/yr consumed
Spain	3.3	12	20.0
France	1.2	4.0	3.6
Italy	3.6	21.0	13
Greece	1.2	34.3	3.5

(source: Collin, 1995)

Table 6: Average consumption of irrigation water in four Mediterranean countries.

Over- pumping of water may have broad adverse influences on the land, because not only exhausts the underground aquifers but it also reduces channel flow and causes sea water intrusion in the former. In La Mancha, Spain , the extracted water is twice as much as the recharge. According to Chabart et al (1996), Spain will have consumed more than half of their water resources in 30 years. The accelerating effect of water over-pumping on the rate of desertification has been recognized and restrictions are being imposed by the states.
There is a tendency for increased consumption also for the non-agricultural uses of water, such as urban, and industrial. The sharp increase in the influx of tourist, who seem to prefer the desertification sensitive coastal areas poses a new serious threat to the water resources. It is expected that several hundred millions of tourist will arrive in the Mediterranean basin by the

first quarter of the next century. An uncontrolled influx of economic immigrants in the near future may also contribute to the threat of desertification in the region.

Abandonment of marginal agricultural lands started during the decade of 1950 due to the industrialization of the countries involved, the increase in the cost of cultivation, the decrease of profits and the changes in the trade regulations among the countries. There have also been social incentives, which encouraged the farmers to move to urban centers, which are more attractive to them. By 1990 between 10 and 20 percent of agricultural land in the Mediterranean countries was abandoned (Grove and Rackham, 1996.

Land abandonment has been considered as important cause of desertification, but in reality this is not always true, because in many cases recovery of the natural systems follows it. Whether an abandoned agricultural land will move towards recovery or desertification depends on the state of the land at the time of its abandonment and on what follows afterwards.

The most vulnerable lands to further degradation are those on sloping terrain and shallow soils, which have been stabilized by erosion control terraces. These lands are at metastable equilibrium, which exists only as long as the terraces are attended and damages are repaired. Upon abandonment, terraces brake and accelerated erosion begins to remove the soil from them.

Desertification may proceed on sloping land when intensive grazing follows agriculture. The grazing animals consume the vegetation that tries to establish itself on the abandoned fields, the soil is left unprotected and erosion degrades it rather quickly. The system moves toward desertification if the soil productivity and erosion tolerance is low, and the bioclimatic conditions do not allow a speedy recovery of vegetation.

The degradation of abandoned agricultural land is most extensive and frequently leads to desertification on limestone slopes within the semi-arid zone and especially on southern and southwestern aspects.

In cases where the above landscape and climatic limitations are not severe, the system moves toward the recovery of the natural environment. However, this recovery may not be economically as profitable as the agricultural exploitation. This is why some people consider afforestation of abandoned agricultural lands as “degradation”, a position that in most cases is shortsighted.

Remedial and preventive actions to combat desertification have been taken by all the Mediterranean countries. Some of actions had been taken before desertification was recognized as a threat to societies. They were technical and legislative measures that targeted toward the control of soil erosion, and salinization, water supply, forest protection and reforestation. At the present, both governmental and non-governmental agencies are involved in the battle against desertification. Efforts are made both at the national and international levels. Actions taken could be classified into the following categories:

- Development of strategies through the formulation of the National Action Plans for Combating Desertification and the establishment of coordinating National Committees.
- Policy regulations towards the sustainability of the land resources.
- Legislative measures securing better protection of the environment in general.

- Public awareness activities aiming at improving the level of perception on the existing threat and at securing public consent and support for the action.
- Adoption of incentives for public participation.
- Technical actions such as soil and water conservation practices and works, forest protection and expansion, soil reclamation and irrigation, protection of natural ecosystems and drought mitigation.
- Research and development.

The specific description of the above measures is not within the scope of this presentation. The interested reader is referred to Sophia Burk and John Thorns edited "Action taken by national governmental and non governmental organizations to mitigate desertification in the Mediterranean. Concerted Action Report 1. European Commission EUR 18490 EN".

It is worth mentioning the tremendous research that was conducted by several multinational research projects, supported by the European Commission. These projects have studied in depth the factors and the mechanisms of desertification. The results have been presented in conventions and made available to the public in numerous publications. They are important tools in mitigating the phenomenon.

Conclusion

Catastrophic land degradation effects had taken place before human presence had any effect on the natural ecosystems. Desertification as it is defined in the respective United Nations Convention can presently take place in the semi-arid and dry sub humid regions of European Mediterranean only through irrational human action.

The destructive effects of human action on the natural ecosystems began at local scales during the Neolithic Age, covered large areas during the Roman Time and continue to the present. Catastrophic human actions have been intensified during the last 50 years as a result of the over-exploitation of land and water resources and the industrialization of agriculture. There have also been land protection activities since ancient times. The degradation has been discontinuous, interrupted by depopulation that was followed by the resilience, to various degrees, of the natural ecosystems. Degradation maxima occurred in periods of intense human actions that coincided with climatic aridity. Desertification in the Mediterranean Europe has occurred on local scale when land degradation crossed the critical thresholds.

Mediterranean countries are facing the threat through policy, legislative socio-economic and technical actions supported by research projects.

References

Aru, A. (1996). Salt water intrusion, waste disposal. Field site Santa Lucia, Sardinia. MEDALUS II. Managing desertification, Final report. Medalus Office, 20a High str., Thatcham, Berkshire UK, 1-38

Audouze,F., Argant, J. Ballais, J.-L., Beeching A, Bel, V., Berger, J.F., Bois, M., Brochi, J.L., Chouquer, G., Favory, F., Fiches J.L. Gazenbeek, M. Girardot, J.J., Jung, C., Mgnin, F., Meffre, J.Cl., Odiot, T., Raynaud, C. Thiebault, S., Tourneux, F.P., Tschanz, X., Verhagen, Ph. and Zannier, M.P. (1998). Land use, settlement pattern and degradation in the Ancient Rhone Valley (Summary by van der Leeuw). In: S.E. van der Leeuw (ed.)

Archaeomedes.Understanding the natural and anthropogenic causes of degradation and desertification in the Mediterranean Basin. European Communities, EUR 18181 EN, Luxembourg.

Bailey, G.N., Ioakim, Chr., King, G.P.C., Turner, C., Sanchez-Goni, F., Sturdy, D., and Winder, N.P. (1998). Norwest Epirus in the Palaeolithic. (Summary by van der Leeuw) In: S.E. van der Leeuw (ed.) Understanding the natural and anthropogenic causes of degradation and desertification in the Mediterranean Basin. European Communities, EUR 18181 EN, Luxembourg.

Ballif,I., Bell, J.,Castro, P.V., Colomer, E., Courty, M. a., Deve, L., Escoriza, t., Fedoroff, N., Fernandez-Miranda, M. Fernandes Posse, D. Carcia, A, Gili, S., Girard, M.C.. Gonzalez Marcelen, P. Jones,M.K., King,G.P.C., Lopez Castro,J.L., Lull, V., Marlin, C., Martin, C. McGlade, J. Menasanch, M., Mico, R. Monton, S., Olmo, L., Rihuete, C., Risch, R., Ruize, M., Sanahuja Yll, E. and Tenas, M. (1998). The environmental dynamics in the Vera Basin (Summary by van der Leeuw). In: J. McGlade and S.E. van der Leeuw (eds.) The Archaeomedes project. Understanding the natural and anthropogenic causes of degradation and desertification in the Mediterranean Basin. European Communities, EUR 18181 EN, Luxembourg.

Berger, A. (1986). Desertification in a changing climate, with a particular attention to the Mediterranean countries. In R. Fantechi and N.S. Margaris [Eds] Desertification in Europe, Com. Eur. Comm. D. Reidel Pub. Comp., Dordrecht, 15-34.

Chabart, M., Collin, J.J. and Marshal, J.P. (1996). Modelling short-term water resources trends in the context of a possible desertification of Southern Europe. In C.J. Brandt and J.B. Thornes [Eds]. Mediterranean desertification and land use. John Willey and Sons Ltd., 398-429

Coccosis, H.N., (1991). Historical land use changes: Mediterranean Regions of Europe. In: F.B. Brouwer, A.J. Thomas and M.J. Chadwick (eds), Land use changes in Europe. Processes of change, environmental transformations and future patterns. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Collin, J.J. (1995). Some aspects of desertification seen from the ground water viewpoint. In R. Fantechi, D. peter, P. Balabanis and J.L. Rubio [Eds] Desertification in a European context:Physical and socio-economic aspects. European Commission EUR 15415, 111-121.

CORINE (1992). Soil erosion and important land resources in the southern regions of the European Community, European Commission, EUR 13233 EN, 96p.

Dregne, H. (1991). A new assessment of the Wold status of desertification. UNEP, Desertification Control Buletin, 6-18.

Enne, G., Mancini, F., Bullittta, P and co-wrkers. (1996). MEDALUS II, Research and policy interfacing in selected regions. Final report. Medalus Office, Berkshire, UK, 599-642.

EUROSTAT, (1995). Europes Environment. Statistical Compendium for the Dobris Assessment. European Environment Agency, Copenhagen.

Gilman, A and Thornes, J.B. (1985). Land use and prehistory in southeastern Spain. Allen & Unwin, London.

Grove, A.T. (1996). The historical context: Before 1850. In: C. Jane Brandt and J.B. Thornes (eds) Mediterranean desertification and land use. John Wiley & Sons, Chichester, UK.,13-28.

Grove, A.T., and Rackham, O. (1996). Physical, biological and human aspects of environmental change. MEDALUS II. Final report. Medalus Office, Berkshire, UK, 39-64.

Kosmas, C., Yassoglou, N., Moustakas, N. and danalatos, N.G. (1`996). Field site Spata, Greece. Basic field programme. MEDALUS II . Final report. Medalus Office, Berkshire, UK, 129-163.

Le Houérou, (1990). Ecological guidelines to control land degradation in European Mediterranean countries. In Rubio. J.L.and Rickson, R.J. [Eds] Strategies to combat desertification in the Mediterranean Europe. Comm.Eur. Comm. EUR 11175 EN/ES, 3311-360.

Llamas. M.R. (1997) Consideraciones sobre la sequia de 1991 a 1995 en Espana. Ingenieria del Aaqua 4, no1, 39-50.

Lopes-Bermudes, F., Tobar P., Javier Pardo,F and Romero, A. (1998). Regional economic and social approaches to desertification. MEDALUS III Regional indicators, second annual report 65-80.

McDonald, W.A. (1972). The problems and the program. In: W.A. McDonald and G.R. Rapp, Jr. (eds) The Minnesota Messinia Expedition. Reconstructing a Bronze Age regional environment. University of Minnesota Press. Minneapolis.

Rubio, J.L. (1995). Desertification: Evolution of a concept. In: R. Fantechi, D. Peter, P Balabanis and J.L. Rubio (eds). Desertification in a European context: Physical and socioeconomic aspects.

Runnels, C.N. (1995). Environmental degradation in ancient Greece. Scientific American, March: 72-75.

Tzedakis, P.C. (1993). Long term tree population in northwestern Greece through multiple climatic cycles. Nature, 364: 437-40.

UNCCD. (1997). United Nations convention to combat desertification in those countries experiencing serious drought an/or desertification, particularly in Africa. Secretariat of the Convention, Bonn, DPSD/CCD/97/1.

Van Andel,T.H. and Runnels, C.N. (1987). Beyond the Acropolis. A rural Greek past. Stanford University Press, Stanford, California.

Van Wersch, HJ. (1972). The agricultural economy. In: W.A. McDonald and G.R. Rapp, Jr. (eds) The Minnesota Messinia Expedition. Reconstructing a Bronze Age regional environment. University of Minnesota Press. Minneapolis.

Van Overloop, E. (1986). Comparison of climatic evolution during the post-glacial times in Greece, tropical and subtropical regions, in relation to desertification. In R. Fantechi and N.S. Margaris [Eds] Desertification in Europe, Com. Eur. Comm., D. Reidel Pub. Comp., Dordrecht, 59-72.

Verheye, W.H. (1991) The role and impact of biophysical determinants on present and future land use patterns in Europe. **In:** F.B. Brouwer, A.J. Thomas and M.J. Chadwick (eds), Land use changes in Europe. Processes of change, environmental transformations and future patterns. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Yaron, B, Shalvet, J., Shimshi, D. (1973). Patterns of salt distribution under tricle irrigation. In A. Haadas, D. Swartzendruber, P.E. Rrijtema, M. Fuchs and B.Yaron [Eds] Physical aspects of soil water and salts in ecosystems. Springer-Verlag, New York, 389-394.

Yassoglou, N.J. and Nobeli, C. (1972). Soil studies. In: W.A. McDonald and G.R. Rapp, Jr. (eds) The Minnesota Messinia Expedition. Reconstructing a Bronze Age regional environment. University of Minnesota Press. Minneapolis.

INDICATORS OF LAND DEGRADATION IN THE MEDITERRANEAN BASIN.

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Background

This paper introduces the topic of land degradation indicators in the Mediterranean Basin. It describes some of the concepts that lie behind the indicator methodologies being applied in southern Europe. Some brief illustrations will be given as well as references in which fuller explanations can be found.
It is useful to briefly consider the problem of land degradation in The Mediterranean Basin and the need for indicators. Most of the indicators put forward in this paper are in some ways related to the effects that land degradation has on soil-vegetation-water interactions at different scales. Enne et al (1998) recently reviewed indicators for assessing desertification in the Mediterranean and this book is an important source for obtaining an overview of the main issues involved in a broader context. In considering land degradation indicators it is important to appreciate that "Benchmarks and Indicators" were prioritised by the Committee of Science of Technology of the Convention to Combat Desertification (see for example Mendizabal 1998). An indicator should summarise the targeted impacts of complex ecosystem processes. Although on the one hand they may be useful for conveying ideas, on the other they involve the risk that key points will be misunderstood. As Landres (1992) points out they may be more of a liability than a panacea.

Land Degradation in the Mediterranean

The history of land degradation in the Mediterranean region is very long and it has has been extensively studied in many countries (Brandt and Thornes 1996 and Groves 1996). The simple view is that following, thousands of years of human activity, the soil and land resources of The Mediterranean have become degraded in comparison with what they once were. If we want evidence or indicators of this long-term land degradation we can find this in the areas of thin soils, in the deposits of Holocene colluvium and in the declining well levels and increasing salt concentrations in coastal aquifers.
Whilst this simple view may be true, it is also true that this perception of land degradation is culturally biased by our present day perspective The agricultural practises of 750 or even 1500 BC and earlier involved enormous geo-ecological impacts as water-tables were lowered by irrigation works, and grazing improved by fire. Many ecologists have argued that the present-day Mediterranean landscape has co-evolved with man, grazing and fire. DePloey and Yair (1985) demonstrated that erosion in dry regions can under certain circumstances have beneficial effects because less water is lost to evaporation and so that there is a subsequent increase in either percolation to groundwater or runoff. The degraded and shallow soils that are an indicator of land degradation may also be an indicator of a high rate of groundwater recharge.

The contrast between these two views of land degradation illustrates at least two issues that are important for land degradation indicators. The first is scale the second cultural bias. Different indicators have to be used at different spatial and temporal domains of scale. In the methodologies mentioned later, this is always the case. The second is that the problem of bias can be avoided if indicators are based on soil or land resource functions. This enables different soils to be compared on the basis of how they are performing a specific or a range of functions. Functional approaches are being increasingly advocated in soil and land resource investigations (de Groot 1992 Kimpe and Warkentin 1998 and Shaxson 1998). One of the sets of functions provided by the landscape are the land degradation control functions. Land degradation indicators should be able to provide early warning or evidence that these functions are being lost. During the remainder of this paper historic land degradation will not receive attention. Land degradation will be considered in the context of indicators for the degradation of present–day Mediterranean geo-ecosystems. As some processes are slow, present-day must sometimes be treated as the present decade.

The publication (Kosmas et al 1999) present a methodology for "key indicators " of what is in fact historic desertification. This manual refers to indicators of existing desertification identified in the Medalus target areas across Europe. The emphasis in this review is somewhat different because it considers the existing landscape as the starting point The question is how can we see which areas are losing valued ecological functions as a result of desertification at the present time.

An indicator is required to summarise specific aspects of the effects of complex processes and also to be easy to measure and relate to critical conditions. A major problem is that simple universal indicators are impossible to find because properties of the soil and vegetation, and processes that are dependent on chemical or physical threshold conditions (for example frost action or salt accumulation) usually limit the validity of an indicator to a specific geo-ecological domain. This is exemplified by soil depth.

Soil depth has been often proposed as a god indicator of desertification (Reining 1984). Research by Kosmas (1997), however, illustrates how the effects of soil depth is conditioned by lithology. He demonstrated that although loss of soil depth is a major factor explaining the disappearance of vegetation, the presence of -> ?which becomes limited by lack of soil moisture storage capacity, different critical values and relationships existed for the different parent materials. Consequently, although soil depth, can be used as a global indicator of degradation for large areas (Reining 1984), at the scale of the land manager, the actual values that are critical depend on the same factors that influence *sensitivity.*

In other words, because the real point of interest is not the soil depth but whether or not the soil retains after erosion its productive capacity, the type of parent material, and the resilience must be known to establish critical values of sensitivity. Therefore, to calculate and compare the sensitivity of different areas, soil depth is evaluated in its context as a function performance indicator.

Function performance indicators are required which not only tell us how well an area is performing its function but also give early-warning of a risk. With respect to the example of soil depth in Lesbos mentioned above, Kosmas (1997) does this by relating soil depth to identifying areas that are at various degrees of risk.

Functional Indicators

Land degradation processes affect the functions that are being fulfilled by the environmental system. (De Groot 1992) Land degradation results in a decline of the performance of a particular function. A function or service of the environmental system has been defined as:

- *Properties of the environmental system which are maintained by components, interactions and processes of the system. The function can be seen as a potential or actual supply of the environmental system (Landres 1992).*

According to De Groot (1992), the functions of an environmental system can be subdivided in four main groups (namely production, regulation, carrier and information functions). Such functions are initially defined for "a systematic assessment and evaluation of natural and semi-natural ecosystems, in order to achieve the conservation and sustainable utilisation of nature and natural resources" (De Groot, 1992; Braat et al., 1979).

The functions performed by the soil have been recently summarised as biochemical and geo-chemical cycling, partitioning of water storage and release, buffering and energy partitioning (Kimpe and Warkentin 1998). One aspect of this is the soil and water conservation function (SWC*f)*. The performance of functions can be evaluated by *function performance* indicators. A detailed example of how desertification affects soil functions and its indicators has recently been described in the Alentejo (Imeson 2000)

Previous Studies of Land degradation and desertification indicators

Indicators have been used in many ways in environmental research. Mabutt (1986), for example, subdivided desertification indicators, 1986 into direct and indirect indicators. A direct indicator will generally form a diagnostic element in the system of phenomena specifically constituting the environmental condition in question. The indirect indicators on the other hand, may reflect secondary or consequential interactions within related adjoining or encompassing systems. Using an indirect indicator brings with it the risk of responding to processes other than desertification or to another condition that is being monitored. An indirect indicator has the potential advantage of integrative monitoring a range of processes over a broad spectrum. Although all indicators can be classified as direct or indirect indicators such classifications do not explain how an indicator methodology should be applied.

Most problems in applying indicators arise from the identification of indicators and the temporal or spatial scales of processes they reflect. One of the problems is the selection of indicators for which many measurements may be needed.

Another problem is that different temporal and spatial scales are often not accurately linked with the identified indicators. Within an indicator study, indicators are sometimes selected at one scale. In this way the research strongly concentrates at one single scale. This often occurs with flux- or process-oriented indicators. Processes and fluxes are usually analysed at one scale (fine-scale). However, an apparently unfavourable property of the system at a fine scale could be beneficial for the system at a coarser scale (Imeson and Cammeraat 2000).

Indicators at different scales are often selected in such a way that relationships between different scales in the environmental system become unclear. This results in a set of indicators that cannot be combined to evaluate the degradation of an environmental system.

UNEP developed a programme of desertification indicators during the 1970's and this research and its results are analysed by Reinig (1987). The indicators that were proposed included such things as soil erosion and soil depth. Although in general the assumptions made were reasonable at the time, today indicators such as this, for reasons explained above are not practical as they are context specific and non-comparable.
Finally, in many recent publications emphasis is given to the distinction between indicators that relate to either the "driving stresses" or to the impacts or responses to these stresses. Land degradation is indeed being driven by both climate and various land use impacts.
This idea is illustrated in Table 2 for a study of land degradation resulting from grazing in Lesbos. The pressure of grazing is related to the evidence described in the left of the table and the impact to the phenomenon on the right.
However, within the framework of this paper land degradation will be mainly treated as an impact or "response" so that the types of indicator used could be described as "functional response" indicators of land degradation.

Indicators and the CCD

The Scientific and Technology Committee of the CCD (Mendizabal 1998) expressed the need for a methodology that could be used for determining impact indicators. These were needed for representative locations and should provide baseline data (benchmarks). The indicators were required to identify key issues at the appropriate scales. The following requirements and future tasks were mentioned. The indicators should be:

- Minimum in number, only one per issue, with expected results.
- It was necessary to identify the required data, data availability and method of collection.
- Defined with a consistent terminology.
- Enable the represented issue to be reliably evaluated, with an adequate spatial coverage.
- Capable of being replaced with proxy data if the specified data is not available

For each indicator it would be necessary to

- Collect and analyse data
- establish a baseline
- define performance criteria
- present results
- Combine and aggregate indicators to provide decision makers with a few clear messages.

These requirements clearly set the research agenda but they do not describe specifically what should be done.

Key functions, processes and indicators

In order to identify indicators it is necessary to have knowledge of a) the main processes of land degradation and b) how these affect the functions of the ecosystem that prevent desertification from occurring.

With respect to the main processes, this is a huge field of investigation. Nevertheless three critical functions can be singled out where the complexity of the can be summarised in key indicators The indicators are:

1. Indicators of loss of water regulating functions.
2. Indicators of loss of ecosystem restorative (production) functions
3. Indicators of loss of soil and water conservation function

An indicator is required to summarise specific aspects of the effects of complex processes and also to be easy to measure and relate to critical conditions. A major problem is that simple universal indicators are impossible to find because properties of the soil and vegetation, and processes that are dependent on chemical or physical threshold conditions (for example frost action or salt accumulation) usually limit the validity of an indicator to a specific geo-ecological domain. This is exemplified by soil depth.

Water regulation functions that are degraded at different scales.

The first set of indicators proposed are those that relate to the water regulation functioning of the soil –vegetation system because these provide a sensitive indicator of land degradation.

It is possible to consider a landscape as being composed of hydrological or ecological response units within which there are distinct relationships between the soil-water and vegetation. Within each unit there are characteristic ecosystem responses to both top down influences and bottom up processes. At different scales within the unit (sub-patch, patch, response unit and slope or catchment) there are positive feed-backs between the vegetation, soil and water that reinforce the redistribution of rainfall and runoff (see for example Imeson 1996 and Imeson and Cammeraat 2000). Processes of water, nutrient and sediment transport on slopes generate patterns or three-dimensional structures. It is these relationships and patterns that are disturbed by degradation and that give an early warning of desertification.

In semi-natural ecosystems patterns are present everywhere all of the time. On cultivated soils they form around weeds or crops but they are usually destroyed by tillage.

Land degradation at this scale manifests itself in the loss of these structures, The loss or development of these structures, if monitored enable the soil and water conservation function to be monitored at the catchment scale.

At the finer scale, the soil structure or aggregation plays a similar role. It has been shown that a “water stable” aggregation promotes water penetration, resists erosion and is indicative of a good functioning soil system. The loss of this capacity through a number of degradation processes that can occur in the soil can lead to the formation of crusts. When this is local, as is the case on semi-natural areas, then this is simply the mechanism by which the water redistribution mechanisms of the response unit are formed. At the coarser scale, if the soil-vegetation structures are disturbed, there is a greater connectivity between bare patches on slopes so that emergent runoff processes occur at this scale. When this occurs, there is a greater differentiation between up and downslope areas.

Key indicators of the soil and water conservation functions

Key indicators of the soil and water conservation function can be simply obtained from a) measurements of soil structure infiltration rates and patterns. Critical values can be

related to losses of target function values and to biological indicators. Examples of how this can be done are described by Lavee et al for Israel. Lavee shows how different vegetation patterns characterise north and south facing slopes from arid to subhumid Mediterranean conditions.
Information about the rates of change of structures and patterns can be obtained from investigating the changes that take place when systems are disturbed. Very good examples are found on abandoned land in SE Spain and in the Alentejo region of Portugal. The advantage of monitoring patterns is that these can be related to the hydrological functioning of a watershed. Some examples of this are described later.

The restorative capacity of the system.
The second set of indicators relate to the restorative capacity of the land following disturbance, The indicators employed reflect various aspects of the inertia and resilience of the system (for a full account see Westmann 1986). Various biological indicators can be very useful for this purpose but so also are many of the soil aggregation and infiltration indicators that can be used with respect to 2.1

Degraded and non-degraded or healthy and unhealthy
The disappearance of key functions leads to a degraded state that is clearly different from that which is found on non-degraded reference locations. One way of approaching the restorative capacity therefore is to compare indicator values for degraded and non-degraded systems.
Land degradation indicators may be at the same time indicators of ecosystem health and soil quality. Indicators can be related to thresholds separating healthy from unhealthy systems
Using the above concepts, hierarchical function response indicators were sought that could be linked to the soil and water conservation. Some premises need to be made about the nature of a healthy functioning systems (Pellant 1997). To evaluate the soil and water conservation function (SWC*f*) it could be assumed that a healthy system is one that can retain the maximum amount of water and moisture as is possible under the specific circumstances. A degraded system would retain less water so that runoff and erosion measurements could be used to derive indicators of the *SWCf* performance.
In the example from Portugal mentioned below, it had been found that the SCW*f* at the fine scale was could be studied by at least three easy to measure indicators. (soil dispersion index, soil depth and surface crust permeability) . Field validations of these and other indicators could be obtained by:
a) measuring actual and simulated runoff and erosion patterns after and during rainfall,
b) from comparing grazed and non grazed sites and
c) by looking at the changes that had occurred on abandoned land in time .

Changes on Abandoned Land
The soil and water conservation functions of cultivated, semi-natural areas and abandoned land.
Agriculture in the dryer Mediterranean regions of Europe was traditionally characterised by cultivation practises that optimise the use of water, which is usually the major limiting factor for plant growth. This has traditionally been achieved by tillage practises that enhance water storage and reduce evaporative losses but also by the use of terraces and other structures that trap or harvest runoff and increase infiltration. Weed control,

manure, mulching, crop selection and rotation are also geared to maximise water availability and prevent runoff, soil and nutrient loss. Cultivation and water conservation practises such as these may be thought of as the essential activities that are required for sustainable agricultural production in dryland regions and as being essential for the maintenance of the *soil and water conservation* function.

Recent research into the hydrology of relatively natural areas in semi-arid areas has also shown that these also are organised to optimise the use of water. Although at the scale of metres, runoff may occur on bare areas, this never travels far and it usually infiltrates in vegetated areas beneath which the soil has a high infiltration rate. Interactions between vegetation, soil organisms and the mineral soil create structures at different scales that can rapidly trap and accumulate rainfall at depth in the soil surface. Runoff trapping mechanisms vary from location. Even when natural vegetation is destroyed, the runoff intercepting mechanisms in the soil may persist. After a few years of cultivation they have probably disappeared. These mechanisms may be though to as maintaining the *soil and water conservation function* of semi-natural areas analogous to that provided by human activity on agricultural land.

When land is no longer cultivated, the human inputs needed to sustain the soil and water conservation functions are stopped. On the other hand, although the succession of vegetation by begin with the colonisation of annuals and perennial shrubs, the naturally occurring soil and water conservation mechanisms present in semi-natural areas are absent. These may take many years to develop.

The changes in soil, vegetation and surface properties following abandonment has been studied at many locations in order to calibrate indicators. In the example from Portugal areas were selected areas that had been abandoned for: (a) 1 to 5 years, (b) 5 to 10 years, (c) 10 to 15 years, and (d) 15 to 20 years. On north and south facing slopes, detailed surveys of surface properties and descriptions of soil profiles were made at five slope positions: summit, upper slope, middle slope, bottom and valley. Soil samples were taken for chemical analysis and to determine soil stoniness, soil bulk density and root biomass.

Key Indicators of restorative capacity

The rate at which structures and patterns re-establish themselves forms the basis for selecting indicators. In addition however, it is possible to target specific biological indicators.

The loss of the soil and water conservation function

Under natural conditions the structures and patterns mentioned above trap and conserve water and sediment . It is much more effective to monitor the patterns than to try to measure erosion rates. It is necessary, however, to sometimes measure erosion in order to verify and calibrate structure or pattern indicators. In the table , the soil and water conservation functions are compared for cultivated and non cultivated land.

Conclusion

Land degradation can best be compared with respect to loss of valued functions. Three key functions are nutrient water regulation, the restorative capacity and function and the ability to prevent erosion. All of these functions can be monitored by indicators that can be observed either on the ground or in many cases from remote sensing. These are indicators related to the patterns that are found and which develop at different scales in the landscape as a result of interactions between soil-water and vegetation. Such indicators have been calibrated along climatological transects and on abandoned land.

References

Braat L.C., Van der Ploeg S.W.F. & Bouma F. 1979 Functions of the natural environment: an economic-ecological research, Institute for Environmental Studies, Free University Amsterdam, Amsterdam: 73 pp.

Brandt, C.J. and Thornes, J., 1996. Mediterranean Desertification and Land Use. Wiley and Sons, London, 600pp.

Cammeraat L.H and A.C. 1998 Imeson Deriving indicators of soil degradation from soil aggregation studies in SE Spain and S. France, *Geomorphology 23 2-4, 307-321*

De Groot R.S. 1992 Functions of nature: evaluation of nature in environmental planning, management and decision making, Wolters-Noordhoff, Amsterdam: 315 pp.

Doran J.W. and A.J. Jones (editors) 1996 Methods for Assessing Soil Quality SSSA Special Publication 49, Madison, 410 pp.

Doran J.W. and T.B. Parkin, 1996. Quantitative indicators of soil quality: A minimum data setin Doran J.W. and A.J. Jones (editors), Methods for Assessing Soil Quality. SSSA Special Publication 49, Madison, p. 25-38.

Enne G, M,D'Angelo and C.Zanolla .1998 Indictors for assessing desertification in the Mediterranean Proceeding of the International Seminar in Porto Torres Italy 18-20 September 1998 Nucleo Ricerca Desertificazione Universita di Sassari

Grove A.T. 1996 The historical Context in Brandt, C.J. and Thornes, J., 1996. Mediterranean Desertification and Land Use. Wiley and Sons, London, 600pp.

Harris R.F, D.L Karlen and D.J. Mulla 1996. A conceptual framework for assessment and management of soil quality and health. In: Doran J.W. and A.J. Jones (editors), Methods for Assessing Soil Quality SSSA Special Publication, p. 61-82.

Imeson A.C. 2000 Functional Indicators for Evaluating the Effect of Desertification on Soils, Mediterranean In Press

Imeson, A.C. and L.H. Cammeraa 2000 Scaling-up from filed measurements to large areas using the desertification response unit approach and indicator approaches in Advances in Vegetation Science 19 (Rangeland Desertification issue Kluwer)

Kimpe C.R.de & B.P Warkentin 1998 Soil Functions and the Future of Natural Resources Advances In GeoEcology 31, 3-10

Kirkby, M.J., Imeson, A.C., Bergkamp, G., and Cammeraat, L.H., 1996. Scaling up processes and models from the field plot to the watershed and regional areas. Journal of Soil and Water Conservation, 51(5):391-396

Landres, P.B., 1992. Ecological indicators: panacea or liability. In: D.H. McKenzie, D.H. Hyatt and V.J. McDonald (editors), Ecological Indicators. Elsevier Applied Science, London&New York, p.1295-1318.

Karlen D.L, M.J. Mausbach, J.W. Doran R.G. Cline, R.F. Harris and G.E. Schuman, 1997. Soil Quality: A concept, definition and framework for analysis. Soil Sci. Soc. Am. J. 61 :4-10.

Kosmos, C Kirkby M and N.Geeson (eds) Mannual on key indicators pf desertification and mapping environmentally sensitive areas to desertification EUR 18882 DGXII Brussels 87 p.

Mabutt J.A. 1986 Desertification Indicators, Climatic Change, 9: 113-122.

Mendizabal T 1998 Comments of the medthodology for determining impact indicators pp Indictors for assessing desertification in the Mediterranean pp 1-4 in Proceeding of the International Seminar in Porto Torres Italy 18-20 September 1998 Nucleo Ricerca Desertificazione Universita di Sassari

Mouat D., Fox C.A. & Rose M.R. 1992 Ecological indicator strategy for monitoring arid ecosystems. In: Ecological indicators, vol. I, McKenzie D.H., Hyatt D.E. & McDonald V.J. (Eds.), Elsevier Science Publishers Ltd, Essex: 717-738.

Puigdefabregas, J. and Sanchez, G., 1996. Geomorphological impplications of vegetation patchiness on semi-arid slopes. In: M.G. Anderson and S.M. Brooks (Editors), Advances in hillslope processes. John Wiley & Sons, London, pp. 1027-1060.

J de Ploey and A.Yair 1985 Promoted erosion and controlled colluviation: A proposal concerening land management and landscape evolutionm Catena, 12 105-110

Reining, P. 1987 Handbook on Desertification Indicators, AAAS Publication no 78-7, 141 p

Shaxson, T.F. (1998) Concepts and Indicators for Assessment of Sustainable Land Use Advances in Geo-Ecology 31, 11-19

Westman. W.E. 1986 Resilience Concepts and Measures in Dell, B. Hopkins A. J. M. and Lamont B.B. (eds) pp. 5-19 The *Resilience of Mediterranean ecosystems*. Junk The Netherlands.

Tables

Main type	Category of indicators	Example of indicator	Scale-level	Used by (author)
Desertification Indicators	Direct indicators	frequency of dust storms	Global	Mabutt, 1986
	Indirect indicators	human well-being	National/local	
	Physical indicators	Crusts	field/local	Reining, 1978
	Biological indicators	Biomass	field/local	
	Social indicators	Migration	National	
stress-response system indicators	Exposure indicators	Accumulation of toxics	Regional	Hunsacker et al., 1990
	Stress indicators	pollutant emissions	Regional	
		acidification of the environment	National	Adriaanse, 1993
	Response indicators	Vegetation diversity	Regional	Hunsacker et al., 1990
		information provision	National	Adriaanse, 1993
	state indicators	air composition	National	
scale indicators	Broad-scale indicators	lightning distribution	Regional	Gosz et al., 1992
	fine-scale indicators	species distribution	field/local	
Agroecosystem indicators	Indicators addressing sustainability	crop productivity	field/ regional	Meyer et al., 1992
	Indicators addressing contamination of natural resources	lichens, mosses	field/local	
	Indicators addressing quality of agricultural landscapes	land use	Regional	
various indicators	Retroperspective indicators	Dendrochronology	Regional	Mouat et al., 1992
	Synoptic indicators	fire occurrence	Regional/ National	
	Sample-based indicators	Vegetation cover	field/local	

Table 1: Frequently used indicators of desertification.

Level	Scale (m^2)	Grazing Features	Effects Related to Grazing	Erosional features
Patch	**10^{-1} – 10^{1}**	Hoof marks	Erosional ledge; Compaction by hooves	Bare soil
Slope	**10^{2} – 10^{4}**	Preferential direction of browsing; Shelter stones	Trampling paths; Compaction of top soil by trampling	Sheetflow; Rills
First order catchment	**10^{5} – 10^{6}**	Gathering and Watering points	Uneven Distribution of Trampling Effects Within Catchment.	Degraded Patches with respect to Soil Properties
Second order catchment	**10^{6} – 10^{8}**	Fences	Uneven Distribution of Grazing Activity between first order catchments.	Degraded Catchments with respect to Soil Properties
Region	**10^{8} – 10^{10}**	Differences in Land Use	Uneven Distribution of Grazing Densities between Regions	Degraded regions with respect to Soil Properties

Table 2: The Expected effects of grazing on degradattion that can be seen at different scales (modified from Levelt and Oortwijn 1998).

	Semi-natural areas	*Cultivated Soil*
Physical degradation	Compaction, infiltration and water holding capacity, wetting front irregularity, aggregate size and stability; soil depth	Organic matter; bulk density/porosity; infiltration and water holding capacity; soil aggregation, compaction, soil depth

Table 3: Examples of indicators used to study soil degradation at the patch scale on cultivated and semi-natural areas.

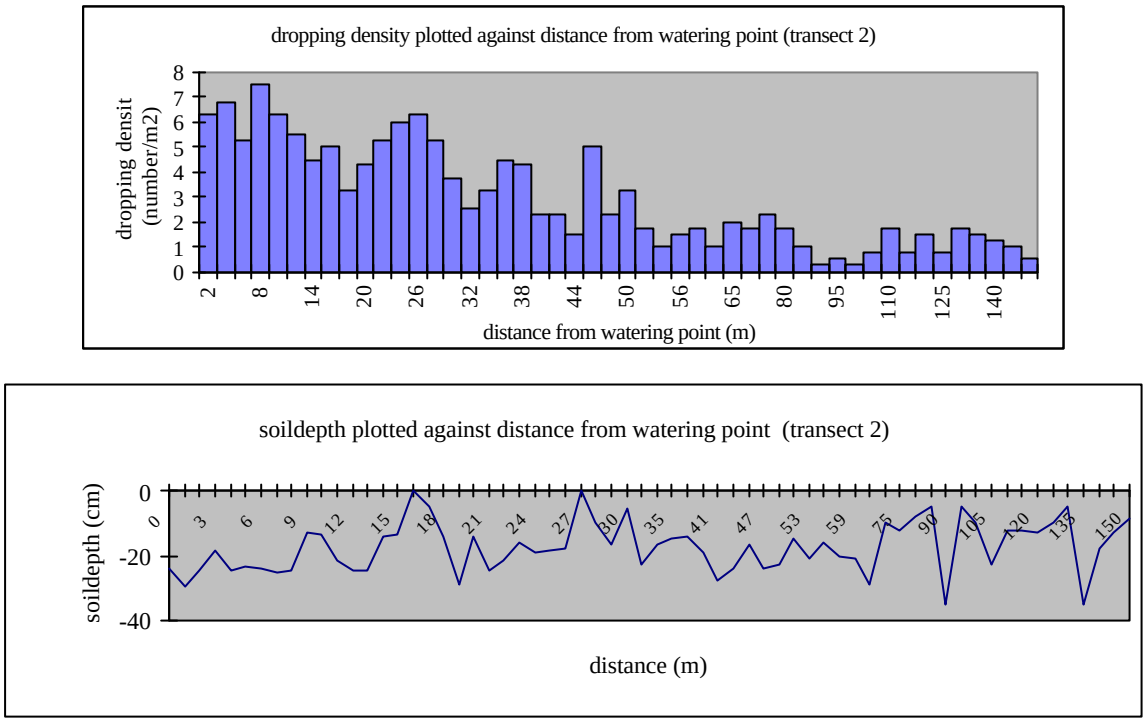


Figure 1: Examples pressure and possible response indicators indicator from west Lesbos. Differences in grazing pressure are indicated by establishing the dropping density and the depth of soil reflects soil water conservation function

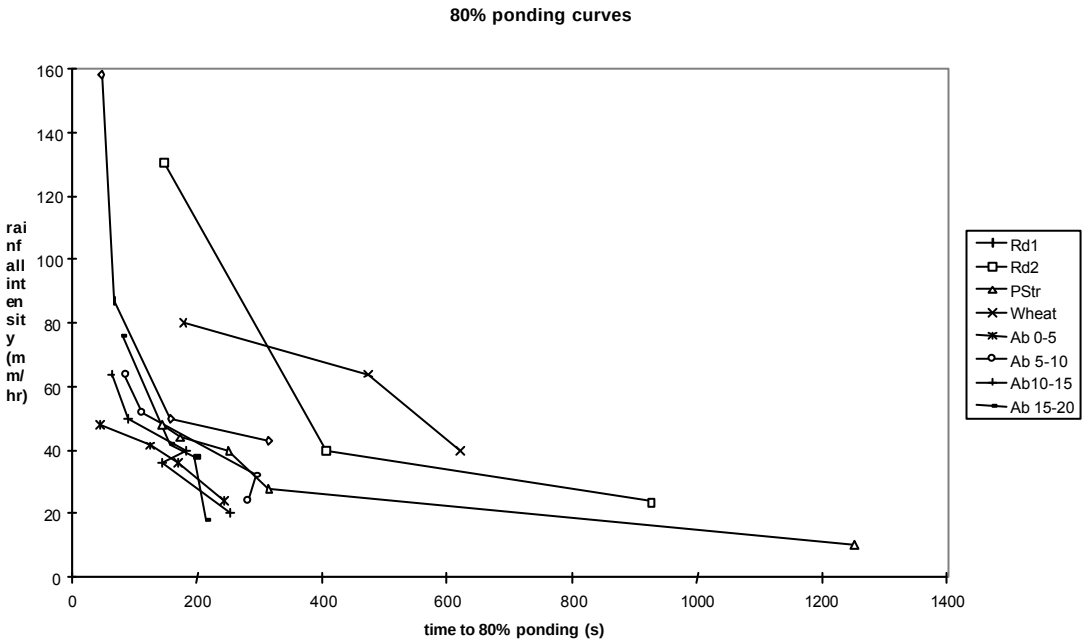


Figure 2: This figure illustrates an important property of the soil that can be used for deriving and testing indicators. This is the time required for rainfall at different intensities to pond the soil. Note the differences between the land abandoned for different amounts of time (Ab =abandoned, the numbers refer to time of abandonment). Rd is a tracj and wheat a cultivated wheat field.

HOW TO MEASURE DESERTIFICATION AND DEGRADATION PROCESSES

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Abstract. The desertification is a dynamic and complex system of land degradation. To understand its behaviour it is necessary to begin identifying their elements and interrelations. The problem is one of multiple degradation processes overlapping at different scales and over different systems. To measure desertification they are required a lot of data as well as to identify where and how it occurs using indicators. Several strategies for measuring degradation processes are carried out at different scales: from experimental fields to the whole Earth.
It is proposed a new strategy for integrating measurements of degradation in order to have more comprehensive and reliable schemes. This strategy is based in the creation of Desertification Focal Points, that work as collectors of information of very different aspects and contribute to its dissemination both globally and locally, as well as would produce updated assessment of the degradation in the threatenned areas.

Key words: Desertification, land degradation, monitoring, measurement

Introduction

Desertification is a land degradation problem of major importance in the dry regions of the world. The UN Conference on Environment and Development defined desertification as: "*land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climate variations and human activities*" (UNCED, 1992; CCD,1994). The desertification is the impoverishment of terrestrial ecosystems under the impact of man. He is the man who brings about the conditions for the desertification of landscapes. The climate, more or less arid, and the recurrence of droughts are only favourable conditions (López-Bermúdez, 1997). The degradation of soil, water, vegetation cover and the spread of desertification are the result of multivariate processes that contribute to the loss of productive capacity of land. The desertification is a dynamic and complex system, and to understand the behaviour of the system it is necessary to begin identifying their elements and interrelations.
The events that produce desertification are the response of a positive feedback (Fig.1), not easy to break, that amplifies the natural processes as a result of human intervention (Charney *et.al.*, 1 975; Mainguet, 1990; Scoging, 1991; Thomas *et.al*, 1994; López-Bermúdez, 1995, 1996; Barberá *et.al.*, 1997). Accordingly, any simplifying interpretation of desertification distorts the reality of events. The desertification has both physical and social-economic dimensions. The causes of desertification are many and complex and it is necessary to find out the sinergic action of a large set of environmental and anthropic multiscaled processes in space and in time not easy to be mesured.

Degradation implies a loss of value. In this sense, the assesment of degradation is a value judgement. Science deals with fact judgements, and consequently the definition of the degradation is, in some extension, extrinsic to science itself. Therefore, it is necessary to accept that *degradation* is not a clear-cutting concept, preexisting to perception, preconceptions, cultural, educational and political backgrounds, etc. It would be philosophically wrong to consider that degradation is a concept independent of man. Preconceptions, especially when dealing with values are unavoidable. For example, degradation by overgrazing will be feel in a different way if studied by an agricultural expert that if studied by a conservation biology one. The first one could stress the decrease of available biomass and the changes on infiltration, and the second one the local extinction of several species, that could change the dynamics of ecosystem.

Nevertheless, the definition of degradation is not so a difficult problem as it could be inferred from previous paragraph. It there is a wide consensus about what can be considered as degraded and what can not. However, it is possible to work in a different way to circumvent the problem of a definition of degradation previous to the measurement. In fact, degradation, wichever it was, occurs into systems. Therefore, that we measure when studying degradation is the level of one or several variables of the system in order to determine the state of the system, because it is assumed that degradation changes the state of the system.

The purpose of these short comments is to avoid unending discussions about the nature and results of degradation. It is clear that it would be absurd to think that the degradation processes we know, and how they are known, are not influential in the way we gather data, they are. But finally, we are constrained to observe a set of variables that are usually important. It is more important to concentrate on the description and observation of each degradation process as a *process* and to make value judgements after.

Ocurrence of desertification: General measurements

The desertification has become a major environmental issue in scientific, political and even general public circles and the term captures a sense of moving deserts, drying lakes and starving people (Thornes, 1996). The international community has long recognized that desertification is the most important economic, social and environmental problem of concerning to many countries in all regions of the planet. Spoiling in soil and plant cover have adversely affected nearly 50 percent of the land areas as the result of human mismanagement of cultivated lands and rangelands.

Desertification affects to nearly all of the arid regions, in varying degrees, except for the extremely arid climatic deserts such as the Sahara. The high correlation between aridity and desertification and the global status of desertification in the world (Fig. 2) shows that areas effected by at least moderate desertification comprised 3,100 million ha of rangelands (80 % of their total area in drylands), 335 million of rainfed croplands (60 % of their total area in drylands), and 40 million ha of irrigated croplands (30 % of their total area in drylands), in all, up to 3,475 million or 70 % of total area of drylands (Dregne, 1986, 1991).

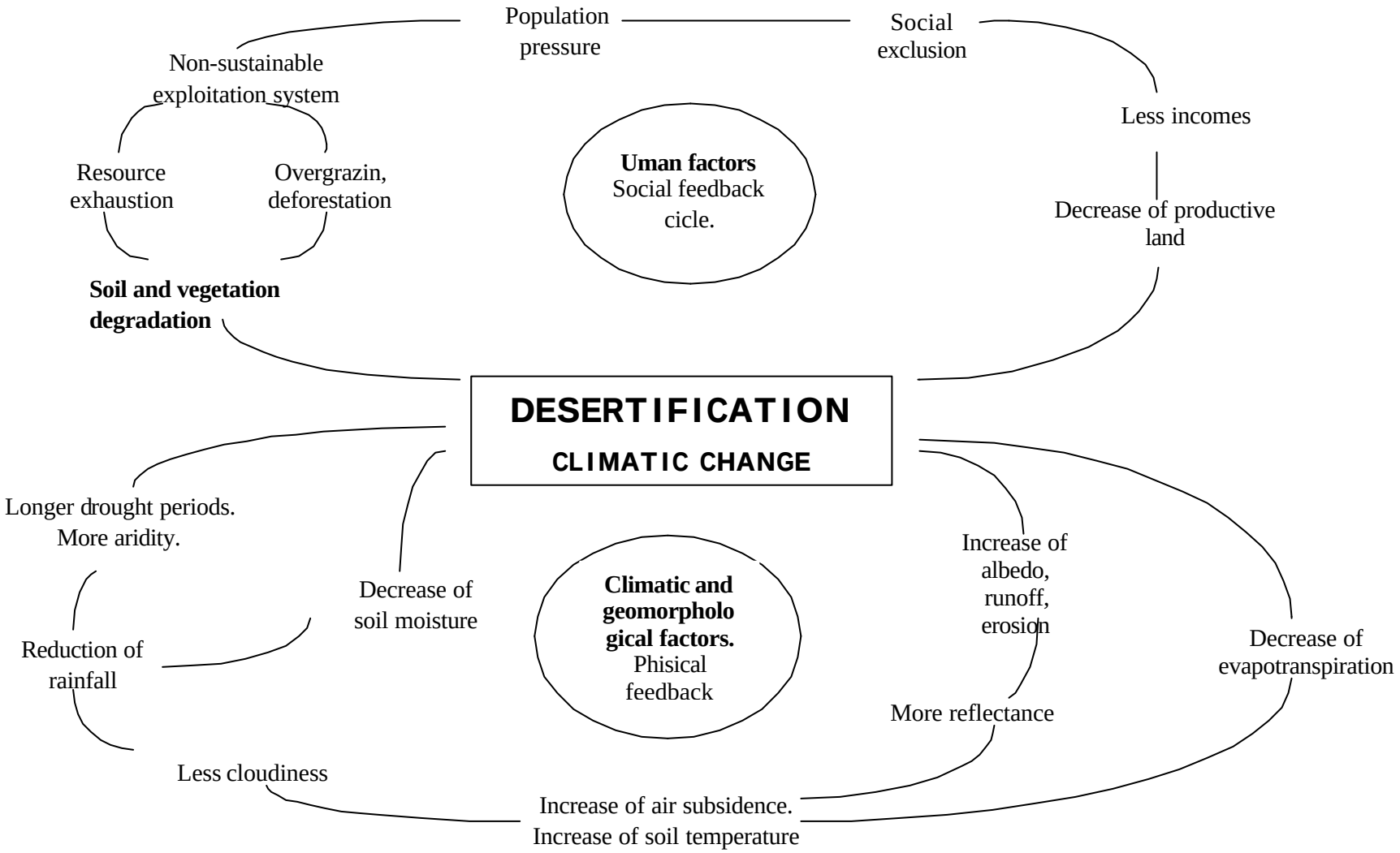


Figure 1: Social and physical feedbacks in desertification.

The first indication of the extent and intensity of the desertification in the world was prepared by FAO, UNESCO and WMO for UNCOD, in fact it was an estimation of desertification hazard rather than actual occurrence (UN, 1977). Since the UN Conference on Desertification (Nairobi, 1977) a great number of studies have been done about the global extent of the problem, using different criteria for classifying desertification.

The classification system used for estimating of desertification is based on four classes of desertification: slight, moderate, severe and very severe. The criteria for each class are as follows (Dregne, 1984, 1986; Thomas *et.al.*, 1994):

Slight: Little or no degradation of the soil and plant cover has occurred; the salination of water for irrigated land less of 4,000 mmhos of electrical conductivity (ECc). The crop yield is reduced by less tha 10 percent.

Moderate: (a) 26 to 50 percent of plant cover consists of climacic species, or (b) moderate sheet erosion, 25 to 75 percent of original topsoil lost, shallow gullies or (c) the salination 4,000 to 8,000 mmhos (ECc), soil salinity has reduced crop yields 10 to 50 percent.

Severe: (a) Poor range conditions class, 10 to 25 percent of plant community consists of climacic species, or (b) severe sheet erosion, the erosion has removed all or practically all of the topsoil, gullies common or (c) salination 8,000 to 15,000 mmhos (ECc), crop yield reduced by 50-90 percent;

Very severe: (a) Land is essentially denuded of vegetation, less than 10 percent of plant community consists of climacic species, or (b) land has many sand dunes or deep gullies, the badlands are generalised or (c) salt crusts have developed on very slow permeable irrigated soils, the crop yields reduced by more than 90 percent.

The *very severe* category represents the extreme condition that many people associates with desertification. It is a completely degraded land, which utility for man or animals is virtually zero and the degradation is ecologically and economically practically irreversible.

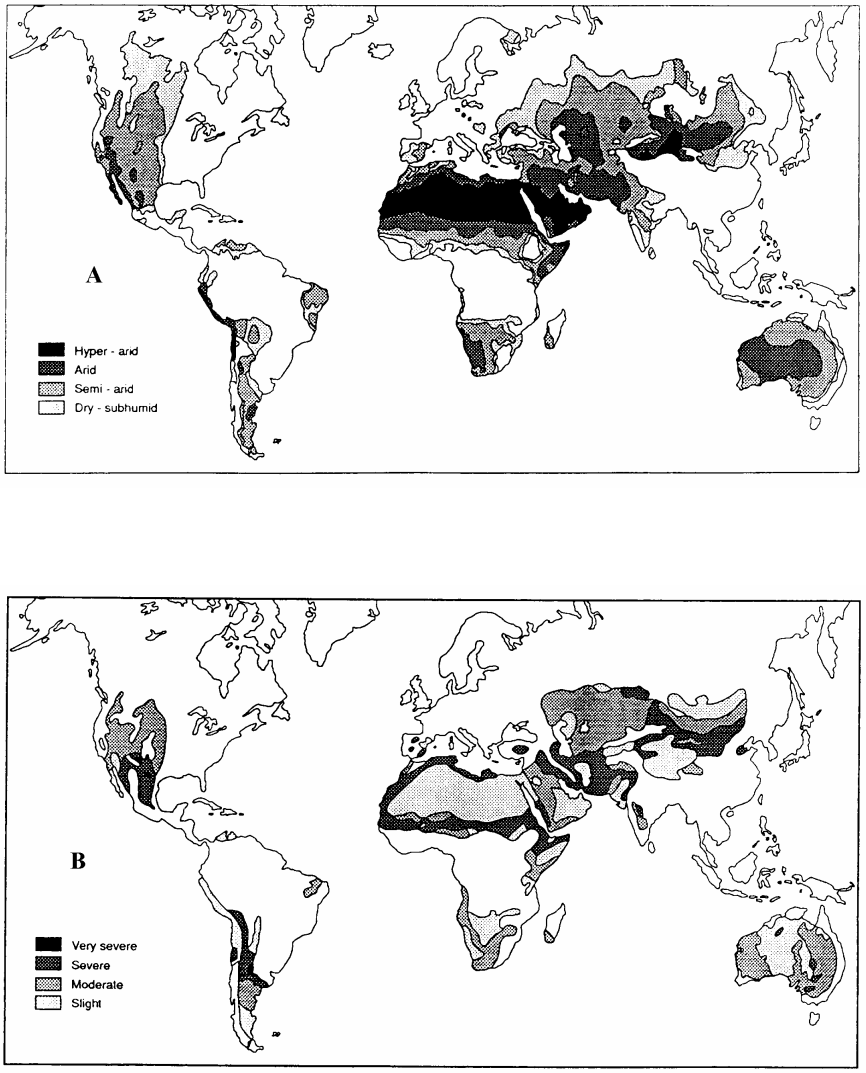
Observe that the measurements proposed concentrate on three different areas: vegetation cover, soil erosion and salination of agricultural lands. Apart of the difficulty of assessing what is a climacic species, a very controversial topic in Ecology, these three aspects give a good idea of wich kind of measurements are proposed to assess degradation. Measurements about vegetation cover and soil erosion are very related as both elements get related in a positive feedback. The measurement about salination is linked exclusively to irrigated agricultural lands. Also it can be pointed out that the scale of measurements is relatively simple and can be assessed virtually "by eye" except those referred to salination.

The conclusions that can be infered from the former are:

i. Systems wich dynamics is different because of differences of management could need specific measurements of degradation (vegetation cover and soil erosion *vs.* salination). The suitability of a set of *Indicators for Assessing Desertification in the Mediterranean* was the core of a International Seminar held in Porto Torres, Italy (Osservatorio Nazionale sulla Desertificaziones, 1998). Concerning to agroecosystems were identified several key points in order to measure desertification in these systems. (López-Bermúdez & Barberá, 1998).It was stated that practical constrictions (i.e. economic resources, development of the country, etc.) and singularities of the dynamics of the systems (more or less influenced by human management) can have repercussions on how to measure desertification. It

was argued that no one scheme for desertification state assesment is independent of these two factors. There, it was advocated for accepting the necessity of flexible strategies. In summary, no one 'unique' system for measuring desertification is 'naturally' acceptable. Degradation of a complex system by multiple and overlapping degradation processes could need multifaced approaches not exclusive each other.

ii. The scale of measurement proposed is simple and virtually applicable on all the spatial scales. However, there are some doubts about the accuracy of the sources of information to estimate these variables all over the world (look at Figure 2). It seems more a rough guesswork that data based on firmly established and reliable measurements. Later it will be reviewed the possibilities of estimating degradation at the planet's scale.



(From Dregne, 1986, 1991)

Figure 2: A) The extent of arid , semiarid and subhumid lands in the world. B) Status of desertification.

The assessment desertification of arid and mediterranean lands

In Europe, desertification is widespread in the mediterranean semi-arid and dry subhumid regions (Perez-Trejo, 1994; Brandt & Thornes, 1996; Mairota *et al.*, 1998). This includes the southern and eastern parts of the Iberian Peninsula, parts of Mediterranean France, most of the Mezzogiorno in Italy, Sardinia and Corsica and most of Greece, including the islands, especially Lesvos. Generally the most critical areas were identified as having less than 600 mm of rainfall per year, distributed over a few months, with a long dry hot summer. The *World Atlas of Desertification* (UNEP, 1992a), CORINE (1992) and the second edition of UNEP´s *World Atlas of Desertification* (1997) which summarizes the current state of scientific knowledge on the drylands of the globe, shows that desertification is one of the world´s most pressing environmental problems, and that it is a global issue which is speeding up. On the other hand, most of the Mediterranean has been identified as having "very high", "high" or "medium" levels of soil degradation severity.

The Fourth Annex to the International Convention on Desertification (UNEP, 1992b) identified Portugal, Spain, Italy and Greece as countries with a marked problem of desertification because of the occurrence of particular conditions over large areas:

(i) Semi-arid climatic conditions affecting large areas, seasonal droughts, very high rainfall variability and high-intensity rainfall.
(ii) Poor and highly erodible soils, prone to develop surface crusts.
(iii) Uneven relief with steep slopes.
(iv) Intensification of soil use, which can lead to the destruction of essential soil properties due to intensive mechanical ploughing and increasing exposure of soil without vegetation to soil erosion.
(v) Extensive forest coverage losses due to frequent wildfires, increasing the exposure of the forest soil, washing nutrients and soil away, reducing soil depth and fertility.
(vi) Overgrazing, leading to a reduction of the biomass of the vegetation cover and soil compaction, that decrease the infiltration of water into the soil.
(vii) Crisis conditions in traditional agriculture with associated land abandonment by rural populations and deterioration of soil and water conservation structures, increasing runoff and related erosion problems, especially in the first years after abandonment.
(viii) Unsustainable exploitation of water resources linked to expansion of irrigated land, leading to serious environmental damage, including chemical pollution, salination and exhaustion of aquifers.
(ix) Concentration of econonomic activity in coastal areas as result of urban growth, expansion of industry and tourism activities The results have been the reduction of natural areas along shorelines and the loss of wetlands.
(x) The national and Agrarian Community Policy of subsides is also a problem, especially in not irrigated areas because it will lead to land abandonment, will increase the marginalisation and the risk of hydric erosion. Land degradation is particularly important on agroecosystem of marginal hilly areas.

From the ten factors, or complexes of factors, it can be deduced again how many aspects should be considered in a scheme for measuring and monitoring desertification. There are natural climatic, geological, etc., factors (i-iii), agricultural practices (iv, viii), purely socioeconomic aspects (vii, ix), exploitation of non-

agriculture lands (v, vi), political issues (x), etc. Thus, in comparison to the measurements and scales showed in the previous section it is suggested a more complex system of measurement and monitoring in order to relate all the causes, outcomes, relationships, etc., implied in degradation.
Recently (Mairota *et.al.*, 1998), the *Atlas of Mediterranean Environments in Europe. The Desertification Contex,* based on the findings of the European Community´s MEDALUS project, have confirmed these issues and exposes the desertification as a environmental crisis at the end of millenium.
This overview about of the desertification around the Mediterranean, shows the importance of the problem and the necessity of mitigating the environmental, economic and social problems arising from desertification in the southern European countries. The threat of Climate Change and the indication of deeper and more sustained future droughts may make heavier the problem (Duplessy *et.al.*, 1991; Fantechi *et.al.*, 1991; Imeson *et.al.*, 1992). Combating desertification is essential to ensuring the long-term productivity of inhabited drylands, but to do this it is necessary to know and to mesure processes, and to carry out national, and regional action programmes. Combating desertification, is just a part of a much broader objetive: the sustainable development of countries affected by drought and desertification.

Principles for sustainable land management in regions threatened by desertification

The problem of desertification, as stated in the Introduction, is one of multiple degradation processes, overlapping at different scales and over different systems. The first prerequisite for any sucessful amelioration project or programme to combat desertification is an accurate diagnosis of the problem, followed by a careful identification of the physical and human causes of degradation. The range of actions has two time dimensions: (i) short-term remedial programmes for dealing with immediate problems such as soil erosion, salination, overgrazing, etc., are designed to alleviate their more immediate manifestations; (ii) of far greater ultimate value are longer term strategies which aim to attack the root causes underlying dryland degradation.
Such long-term strategies must fulfil at least four main requirements (Williams *et al.*, 1997):

- Any community action must be suited to the ability of the people directly affected by the degradation to finance and carry out conservation and restoration programmes with appropriated local technologies.
- The nature of the degradation process must be thoroughly understood, the problems clearly diagnosed and a careful initial assessment made of the most suitable options for prevention and rehabilitation.
- Long-term ecological sustainability must be paramount.
- Maintenance of soil quality is essential. If the soils become degraded, so too will the the dryland ecosystems. The viability of the human communities in the arid, semi-arid an dry sub-humid areas, depends ultimately on the quality of the soils and water resources which sustain the natural ecosystems and the agrosystems.

Sustainable land management in regions threatened by desertification requires to combine technologies, policies and activities aimed at integrating socioeconomic principles with environmental concerns, so as to simultaneously (Ciesin,1998):

- To protect the potential of natural resources and prevent degradation of soil and water quality *(protection*).
- To reduce the level of production risk, and to enhance soil capacity to buffer against degradation processes (*stability/resilience*).
- To maintain and to enhance production (*productivity*).
- Be economically viable (*viability*)
- Be socially acceptable, and to assure access to the benefits from improved land management (*acceptability/equity*).

Monitoring desertification.

The desertification acts over two different systems: the socioeconomic one and the biophysical one. Each one has very different components and processes, is studied with different tools, measurements and concepts, and by scientists of very different background.

The understanding desertification requires a lot of data on land degradation. In monitoring drylands it is necessary to identify where desertification is occurring, and to give indicators about how and why it is happening. Nevertheless, the task is not easy. One obstacle is the absence of an interdisciplinary approach between the biophysical and social sciences. The lack of an integrated approach is another problem, and extends to questions of project formulation, participatory processes, funding, long-term political decissions and making the results known to decision-makers and local communities.

The definitions and selection of indicators for multi-scale assessments use measurements that reflect the behavior of the indicator. They have been studied and discussed for many authors (Berry *et al.*, 1977; López-Bermúdez, 1997, 1999; Kirkby, 1997; Rubio *et.al.*, 1998; Osservatorio Nazionale sulla Desertificaziones, 1998).

The steps for monitoring and assessing desertification could be:

- To identify the problem. In this repect the measurements and perceptions of degradation problems by experts may differ markedly from those of the local people who lives with the problem.
- To distinguish between the information that it is desirable to have and that which it is practical to obtain.
- To identify the appropriate scale of the work. It is relatively simple to collect degradation data from experimental fields but it is another matter to do so for whole regions or countries. Both levels of data are necessary.
- To determine the appropriate indicators and how to measure them with the given technology.
- To identify the costs and resources and who will do the work.
- To evaluate the results

The measurement of degradation at the present.

At the present several strategies for measuring degradation processes are carried out. They range from the very little but intensely researched experimental fields to very rough assessment of degradation at the scale of the whole Earth. Every one of this strategies has got its own strong points and weaknesses, but as a whole they are not, probably, satisfactory enough for measuring degradation with the necessary detail in time and space as well as for mitigation necessities.

Experimental fields

Experimental fields are permanent points where basic research is carried out in different sciences. They are usually reduced in extension (several ha) and are equipped with a high number of gauges and other devices for studying continuosly processes (Slaymaker, 1991; López-Bermúdez *et.al.*, 1993). A good example are the network of experimental fields across the Mediterranean run by the MEDALUS project (Brandt & Thornes, 1996) financed by EU, or the spanish network RESEL financed by the Ministry of Environment of Spain (Rojo *et al.,* 1996).

In fact, two of the main aspects studied in experimental fields is the runoff and sediment yield processes. They are, certainly, intimately associated with the change of land uses and the desertification as soil erosion is a major threat for sustainable land management. Soil erosion is a very widespread process, usually irreversible, and occurs over a range of time and space scales, from the plot in which individual measurements are made, up to regional or national scales where they can influence major planning decisions. A number of approaches to the problem of upscaling have been developed in the context of climate and soil erosion, within projects of the EU Environment Programme (MEDALUS, EFEDA and ERMES; Kirkby *et al.*,1996). Once the nutrient-rich surface soil has been lost, the ability to sustain plant growth is severely reduced, and increased runoff from the more impermeable subsoil results in reduced plan-available water. Furthermore, erosion brings associated off-site problems, including reduced water quality from increased sediment loads and poorer air quality due to dust. Erosion processes are both varied and complex and, in consequence, long-term erosion monitoring, experimentation and modelling are essential to observe possible transient and non-equilibrium responses to climatic, land use changes and desertification (GCTE, 1997).

Monitoring of soil erosion may be rather arbitrarily defined as field based measurement of erosional and/or depositional forms for a period longer than two years (Bordman, 1994). Most experimental reseach on soil erosion by water has concentrated on the runoff at the plot scale. Relatively few studies have been done at either smaller or larger scales. Monitoring of soil erosion over larger areas (more than 10 km^2) relies on detecting volumetric or area changes in geomorphic features such as rills and gullies or alluvial fans using field observations or aerial photographs. The important processes and factors related to hydric erosion at four scales ranging in size from a squared millimeter to a catchment are shown in Table 1 (Poesen *et.al.*,1996)

Ideally, an experimental field should serve as a focus point where the effort of researchers of different sciences converge, so they can complement each other. Other strong point of experimental fields is that they are usually run for long periods, letting to know in depth the dynamics of processes and the influence of the time

variability of climate. This is very important in dry areas where intearnnual variability of climate, especially the alternation of dry and humid periods, is essential for the correct understanding of ecosystem behaviour. Also, it is important to remark that experimental fields run for long periods are excellent for assessing the influence of Global Change on the dynamics.

In summary, experimental fields provide insight in the 'micro' view of ecosystems, setting a firm basis for the assessment of degradation processes, especially in respect of the identification of relevant variables of the ecosystem that should be measured.

On the contrary, the usefulness of experimental fields in order to actually measure the degradation or desertification is very reduced:

Firstly, experimental fields are very reduced in extension, at least in the european context if compared to the LTER (Long Term Ecological Research) network in USA. It makes that these fields have a very reduced represetativity of the regions they are located. This reduced representativity affects both to the geographical dimension and the ecological dimension. So, their data hardly can be useful for assessing the evolution of degradation.

Secondly, although some experiments simulating degradation processes are carried out, most of the research is devoted to basic studies of structure and dynamics of geoecosystems.

Scale	Key processes sensitive to environmental change
Micro scale (< $1m^2$)	Dynamics of soil aggregation Biological soil degradation Litter production Soil moisture Infiltration Splash erosion
Plot scale (1-10^2 m^2)	Soil surface dynamics Biological processes Physical degradation Interrill and microrril Subsurface erosion (piping)
Field scale (10^2-10^4 m^2)	Interril and rill erosion Gully erosion Ephemeral channels Deposition Mass movements Vegetation cover
Hillslope-Catchment scale	Interrill and rill erosion Gully and ephemeral channels Deposition Mass movements Channel processes Anthropic erosion

Source: Poesen *et.al.*, 1996, with additions.

Table 1: Relevant spatial scales at which various soil degradation processes, sensitive to changes in climate, land use and desertification.

Particularly, long monitoring of degradation processes (or human mangement in general) at realistic scales (scales over the field size like landscapes, etc.) are rarely carried out. The upscaling of the results, both in time and space, is difficult even from a conceptual point of view.

Studies at the basin scale

Hydrological basins are probably the best organization level for studying geoecological processes as water fluxes impose dynamic constraints and the very important off-site effects are better understand. However, the hydrological basin is a organization level which spatial scale is very varied since microcatchments under 1 ha to huge semicontinental basins like the Amazonian one. The most reduced basins, no more than several hundreds of hectares are usually included in the kind of studies referred above as *experimental fields* (ICONA, 1988), while the largest basins fit better on continental studies. For the actual measurement of degradation they are more appropriated basins ranging from 10^4 to 10^6 hectares, because they match with the scale of regional planning.

Although they are possible diverse type of measurements of degradation, the typical application of the studies at the basin scale are related to hydrology as a synthetic indicator of basin dynamics. So, this kind of studies look at variation of water flows or sediment charges and deposits measured in gauging stations and reservoirs (Mon *et.al.*,1981; López-Bermúdez *et.al.*, 1982; Clotet-Perarnau *et.al.*,1988; Romero-Díaz *et al.*, 1992; Poesen *et.al.*, 1996; Morgan *et.al.*, 1998). The advantage is that they deal with a set of variables (water and sediments) that have a very tight relationship to the management of the area and take advantage of usually expensive systems of gauging that water authorities have to install, maintain and monitor continously. On the other hand, the weakness is just the synthetic indicator character of these variables. Even with a complete record of all the management factors and changes of the basin (that is never got) it is usually impossible to discern what is exact cause of the output (in water flow and sediment terms) that is observed, apart from general appreciations. This impossibility is based on the lack of replication of the basin as in a experimental design, and in the lack of detailed studies at spatial scales under the basin's one.

Regional studies of indicators

This type of work is very related to the basin studies, although they do use an administrative entity or a natural region which borders, are not defined by the catchment ones. It can also be collected information related to water flows, but the stress is not so important.

The main sources of information can be provided by GIS (ideally coupled to remote sensing) and standard statistical records. The first is the updated version of traditional thematic cartography works with the unvaluable capacities of a GIS for environmental modelling. The second is especially important because let to work with the socioeconomic side of degradation processes. One of the most quickly growing areas in this kind of work is the study of land use structure and dynamics as a synthetic indicator of interaction between the biophysical and the socioeconomic systems and their relation to degradation processes.

The weaknesses here are related to the lack of accurate thematic cartography, and especially to the slow updating of this cartography. This updating could be made by remote sensing but, in practice, it is not so usual to have research or administrative bodies that had implemented such a task as a routine of work. So, the measurement of degradation is severely hampered by large uncertainties about the present state of the indicators. For instance, in Spain there is a nation-wide land use cartography at 1:50000 scale that is implemented in a GIS for planning in many administrative bodies or for research or consulting when data back to the first seventies, and therefore are unsuitable for any real assesment of degradation at the present.
On the other hand, statistical records were not thought for their application to environmental monitoring and many of them are too much indirect indicators for being useful in degradation assessment. Other disadvantage of these records are that their sampling units are administrative entities, and therefore neither necessarily match to homogeneous landscapes nor the spatial level of resolution is usually adequated for project scale, the scale relevant to restoration.

Mediterranean to Earth scale studies
Very large scale studies have been produced, as for example those presented previously about figures of degraded land in dry areas of the world (Figure 2). They use sources of information that are qualitative similar to those used in regional studies, but here uncertainties about quality of data are larger. In fact, many of these data should be used very carefully and it has to be assumed that are very rough. Continous monitoring using remote sensing of coarse resolution (over 1 km, like that of NOAA satellites) open a hope to an effective monitoring and degradation measurement at the Mediterranean basin and planet scale (Lacaze, *et.al.*, 1996).

Restoration projects
Restoration of degraded (agro)ecosystem is an activity that has been carried out by administrative bodies since decades. For instance, in SE Spain the first large scale restoration of severely deforested mountains were carried out more than 100 years ago (Gómez Mendoza, 1992; Paula Juanes *et.al.*, 1998) with an important success. In general, this activity has increased continously in the last 50 years.
Apart of the discussion about the suitability of techniques used and the relation between objectives pursued and those actually achieved, it is clear that, unfortunately, no one scheme of monitoring has been routinely implemented in order to know the changes in structure and dynamics of the system produced by the restoration project, or over the region as a whole. This can be considered a huge loss of information on the measurement of degradation processes. It is remarkable that while much attention have been paid in measuring degradation in one way or another, few works evaluate the human's agradation attempts. This is conceptually wrong as agradation is the other side of degradation and technically wrong because an indispensable empiric feedback is lost.

New strategies for the measurement of degradation?

As reviewed in the former section, the set of techniques for the measurement of degradation and desertification is wide but uncompletely developed for providing the accurate and updated information that is necessary for mitigation.
The first common problem is that every one of the techniques reviewed works at a different spatial scale. This can be considered an advantage because it lets to know processes that actually occur at every scale form plot to the whole planet. However, the effort to link all this information across scales is, maybe, too scarce. There are basic theoretical problems to this problem, but also there are other more practical. For instance, only a part of the regions where we would like to measure degradation have got experimental fields providing basic information. It can result of a complete lack of information about important processes of representative ecosystems of a particular region. At higher spatial scales information is too sparse and disorganized.
Other important problem is that information is usually collected to assess some particular aspect or degradation process related to desertification like soil erosion or overgrazing, depending on the interest of the researcher. Not integral mesurement attempts seem to have been carried out. This is a drawback when working in a physically and socially complex issue.
The last two paragraphs touch upon the necessity of vertical and horizontal integration of schemes for measuring degradation and desertification. This integration is the jump that is needed to go from academic exercises to real-world routine monitoring. The outcomes of this kind of monitoring would be of direct application for problem solving. As real-world application, a monitoring system for assesing the state and trends of degradation should concentrate on scientific based measurements and rigorous analysis but not attempting a complete perfect picture of reality. It stresses the necessity of designing a continous data recording system that incorporates the available and reliable information that may be directly or indirectly related to degradation.
This kind of system for measurement of degradation could be based on the following points:

- Spatial scale for gathering information should go from the planet to the region. Lower spatial scales are not useful for planning and action, although they are indispensable for improving the knwoledge about processes. In some sense it is necessary to distinguish between the technical side and the scientific side. The scientific side can could provide insight for updating and improving what data and how can be collected and analysed.
- The ways the information should be collected would be similar to Statistical Offices of administrative bodies. Actually, it can be seen that it is basically the same to collect information for economic purposes that for environmental ones. That one intends is to have a continous measurement of the state of the system in order to implement policies at short, medium and long term.
- As spatially distributed information, a GIS implementation is indispensable.
- It should be gathered information related to biophysiscal factors as well as to socioeconomic ones.
- The continous updating of information is, probably, the most complex issue. It does not present special difficulties for socieconomic data as they are presently well covered by Statistical Offices. Not so the biophysical data. In respect of this

kind of data a link to remote sensing should be necessary. However, not all the information relevant to degradation processes is capable of being collected by this method. Therefore, as in statistical offices some information is collected exhaustively (*e.g.* the number of cars sold), other is estimated by sampling (indices of prices), thus it should be in collecting environmental information. While remote sensing or several statistics will be available for estimating for instance land use changes, other like relatively detailed soil erosion measurements will have to be obtained by sampling.

A possible scheme to carry out this project is the creation of *Desertification Focal Points* (Figure 3), at the national and/or the regional scales, that would work as collectors of all the information relevant to degradation processes, would analyse it and would disseminate data, results and predictions. They could be operated at different levels of complexity depending on funding and human resources they will get:

- A first level would be simply storing all the thematic cartography relevant to desertification, the scientific and technical papers, reports, etc. carried out in the area, and recording all the information that is continously updated by other bodies (economic statistics, water flows, groundwater levels, etc). All this information should be accesible by Internet, and would be in standard interchange formats. On the other hand the desertification focal point, could organize workshops, seminars, etc. oriented to technicians, scientists, administration officials, social organizations, etc.
- In a second level of development, the desertification focal point could implement continous updating of spatial information through standarised remote sensing methods, using this information to publish periodic reports about the monitoring of degradation.
- The third level of development would be the implementation of a sampling scheme over representative areas in order to obtain information about variables that are not able to be measured by remote sensing or other methods.
- Finally, a complete design of the desertification focal point would be a collaboration with other entities in order to implement pilot demosntration projects to combat degradation, where a continous monitoring of the results would be achieved. At the same time it would be implemented, by sampling, a parallel scheme to monitor the results of other restoration activities carried out in the past or in the present by administration (forest, nature conservation, water management, etc.).

Acknowledgements

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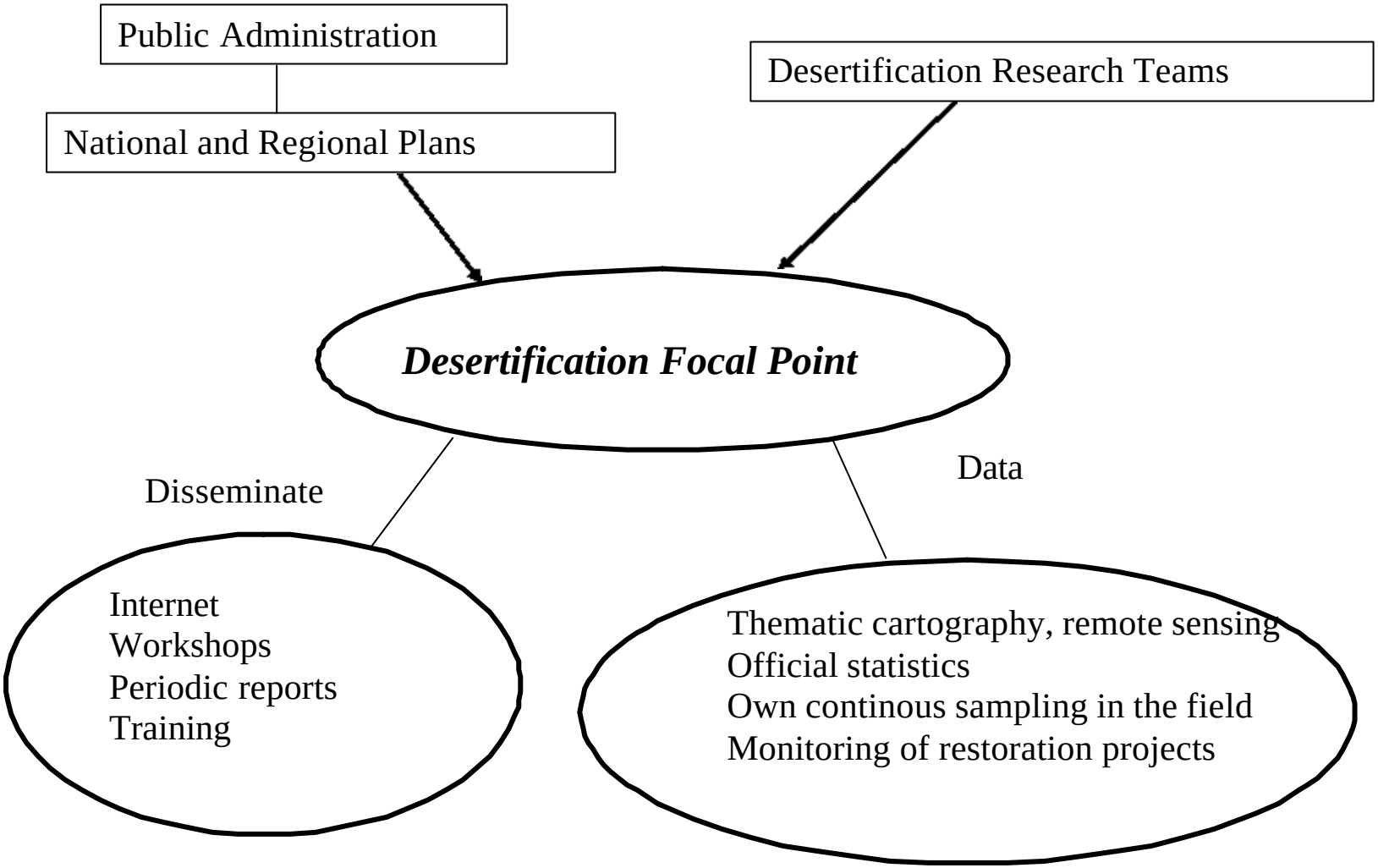


Figure 3: Organization of Desertification Focal Point for monitoring of degradation and desertification.

References

Barberá, G.G.; López-Bermúdez, F.; Romero-Díaz, A.(1997). Cambios de uso del suelo y desertificación en el Mediterráneo: el caso del Sureste Ibérico. In *Acción humana y desertificación en ambientes mediterráneos,* J.M.García-Ruiz & P.López-García, Eds. CSIC. Instituto Pirenaico de Ecología. Zaragoza: 9-39.

Berry, L.; Ford, R.B. (1977). *Recommendations for a system to monitor critical indicators in areas prone to desertification.* Worcester, MA: Program for International Development, Clark University, 66 p.

Brandt, C.J.; Thornes, J.B., Eds. (1996). *Mediterranean Desertification and Land Use.* Wiley & Sons. Chichester: 554 p.

CCD (1994). *United Nations Convention to Combat Desertification. In those Countries Experiencing Serious Drought and / or Desertification, particulary in Africa.* Interim Secretariat for the Convention to Combat Desertification. Geneve Executive Center-C.P.76-1219. Châtelaine/Geneve, 71 p.

Charney, J.G.; Stone, P.H.; Quirk, W.J.(1975). Drought in the Sahara: A biophysical feedback mechanisme. *Science*, 187: 434-435.

CIESIN (1998). *Land and Water Knowledge Management Node.* CIESIN User Services, supported by World Bank, NASA, FAO, UNEP, 6 p.

CORINE. (1992). *CORINE soil erosion risk and important land resources in the southern regions of the European Community.* Commission of the European Communities. EUR 13233 EN. Brussels, 97 p.

Dregne,H.E.(1984). Combating desertification: evaluation of progress. *Environmental Conservation*,11: 115-121.

Dregne,H.E. (1986). Desertification of Arid lands. In *Physics of desertification.* F. El-Baz & M.H. Hassan, Eds. Dordrecht. The Netherlands: Martinus, Nijhoff, 16 p.

Dregne, H.E. (1991). A New Assssment of the World Status of Desertification. *Desertification Control Bulletin*, 20: 6-38. United Nations Environment Programme (UNEP).

Duplessy, J.C.; Pons, A.; Fantechi, R., Eds.(1991). *Climate and global change*. Commission of the European Communities. DG-XII. Report EUR 13149. Brussels, 357 p.

Fantechi, R.; Maracchi, G.; Almeida-Teixera, E., Eds.(1991). *Climatic change and its impacts: A general introduction.* Commission of the European Communities. DG-XII. Report EUR 11943. Brussels, 453 p.

Gómez Mendoza, J. (1992). *Ciencia y Política de los Montes Españoles.* ICONA. MAPA. Madrid, 260 p.

ICONA (1988). *Mapas de Estados Erosivos. Cuenca Hidrográfica del Segura.* Ministerio de Agricultura, Pesca y Alimentación. Madrid, 75 p.

Imeson, A.C.; Emmer, J.M. (1992). Implications of climatic change on land degradation in the Mediterranean. In *Climatic change and the Mediterranean,* L. Jeftic, J.D. Milliman, G. Sestini, Eds., 95-128.

Kirkby, M.J. (1997). *MEDALUS III: Regional Indicators Project. Coordinator´s Summary.* First Annual Report Covering the Period January to December 1996. MEDALUS Office, King´s College London. Departement of Geography. University of London (U.K.) London, 186 p.

López-Bermúdez, F. (1995). Desertificación: Una amenaza para las tierras mediterráneas. *El Boletín*,20: 38-48. Ministerio de Agricultura. Madrid.

López-Bermúdez, F. (1996). La degradación de tierras en ambientes áridos y semiáridos. Causas y consecuencias. En *Erosión y recuperación de tierras en áreas marginales.* T.Lasanta & J.M. García-Ruiz, Eds. Instituto de Estudios Riojanos. Sociedad Española de Geomorfología. Geoforma Ediciones. Logroño: 51-72.

López-Bermúdez, F. (1997). Gli indicatori della desertificazione nei Paesi Mediterranei dell´Europa. *Genio Rurale*, 6: 36-39.

López-Bermúdez, F. (1999): Indicadores de la desertificación: Una propuesta para las tierras mediterráneas amenazadas. *Murgetana*,100: 113-128. Real Academia Alfonso X El Sabio. Murcia.

López-Bermúdez, F.; Barberá,G.G.(1998). Indicators of degradation in semi-arid Mediterranean agroecosystems of Southeastern Spain. In *Indicators for Assessing desertification in the Mediterranean.* Proceeding of the International Seminar. Osservatorio Nazionale sulla Desertificazione. Porto Torres, Italy: 173-184.

Mainguet, M.(1990). La desertification: una crise autant socio-économique que climatique. *Sécheress*, 1-3: 187-195.

Mairota, P.; Thornes, J.B.; Geeson, N, Eds.(1998). *Atlas of Mediterranean Environments in Europe. The Desertification Context*. Wiley. Chichester, 205 p.

Osservatorio Nazionale sulla Desertificazione (1998). *Indicators for Assessing Desertification in the Mediterranean.* Proceeding of the International Seminar. Porto Torres, Italy 18-20 September 1998. Nucleo Ricerca Desertificaziones- University of Sassari, 355 p.

Paula Juanes, F.; Gonzalez Rincón,A.(1998): Memoria de los trabajos realizados durante el año 1891 en Sierra Espuña. *Monte Bravo*, 2: 2-7.

Pérez-Trejo, F. (1994). *Desertification and land degradation in the European Mediterranean.* European Commission. DG-XII. Report EUR 14850 EN.Brussels: 63 p.

Rojo, L.; Sánchez Fuster, M.C.(1996). Red de estaciones experimentales de seguimiento y evaluación de la erosión y desertificación. Proyecto LUCDEME (RESEL). Ministerio de Medio Ambiente. Dirección General de Conservación de la Naturaleza. Madrid, 121 p.

Rubio, J.L.; Bochet, E. (1998). Desertification indicators as diagnosis criteria for desertification risk assessment in Europe. *Journal of Arid Environments*, 39: 113-120.

Scoging, H. (1991). Desertification and its management. In *Global Change and Challenge. Geography for the 1990s*. In R.Bennet & R.Estall, Eds. Routledge. London: 57-79.

Thomas, D.S.G.; Middleton, N.J.(1994). *Desertification Exploding the Myth.* Wiley & Sons. Chichester: 177 p.

Thornes, J. (1996). Introduction. In *Mediterranean Desertification and Land Use*, C.J.Brandt & J.Thornes, Eds. Wiley. Chichester: 1-11.

UN (1977). *World map of desertification.* UN Conference on Desertification (UNCOD). Nairobi, Kenya. Document A/CONF.74/2

UNCED (1992). *Report of the United Nations Conference on Environment and Development at Rio de Janeiro. Managing Fragile Ecosystems. Combat Desertification and Drought*. Chapter 12. U.N. New York.

UNEP (1992a). *World Atlas of Desertification.* Edward Arnold. Sevenoaks.

UNEP (1992b). *United Nations Convention to Combat desertification in those countries experiencing serious drought and/or desertification, particularly in Africa.* Interim Secretariat for the Convention to Combat Desertification. Geneve Executive Center-C.P.76-1219 Châtelaine/Geneve,71 p.

Williams, M.A.J.; Balling, R.C.(1997). *Interactions of Desertification and Climate.* Arnold. London, 270 p.

MODELLING GROUNDWATER AND RECHARGE UNDER VARIABLE MEDITERRANEAN CONDITIONS

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Abstract. The overexploitation of groundwater for mainly agricultural purposes in recent decades has caused substantial drawdown of the water table in many areas of the Mediterranean. This has ecological and economic costs. In order to define sustainable levels of groundwater abstraction it is necessary to quantify the aquifer balance. One of the most difficult components to quantify is the recharge component, because it is highly variable in time and space. Recharge is highly dependent on rainfall input and irrigation. In this paper, the effects of rainfall variability at all timescales on the recharge component in the Upper Guadiana catchment, Spain, are discussed.

Keywords: Groundwater, recharge, hydrological modelling.

Groundwater is a ubiquitous part of the hydrological cycle but due to its low visibility to human society the consequences of exploitation on the cycle are often not considered. Groundwater is recharged by infiltrated rainfall and from riparian zones and discharged through natural sources such as springs, rivers, lakes and the coast and human-made sources such as wells and drains. Groundwater plays a key role in ecological processes at the surface as groundwater discharge maintains river and spring base flow, wetland levels and phreatophyte communities. If the groundwater regime is altered in some way this may change flow patterns, water table levels, outflow levels and the chemistry of the discharge. Groundwater is also susceptible to salinisation and contamination, which, in view of its long turnover time may limit the resource exploitation for many years.

Groundwater movement is very slow (of the order of mm per day to mm per year). Therefore the system is extremely sensitive to large-scale extraction of water for human use over a short time scale. Groundwater is extracted for industrial, agricultural and domestic use. The over-exploitation of water resources results from regional and temporal imbalances in water supply and water demand. This has put present water resources under pressure of competition. Although this water extraction is essential for human society, extraction often takes place at an unsustainable rate. Extraction rates are sometimes orders of magnitude larger than input recharge rates. Water is removed from the groundwater system and drawdown of the water table occurs. Discharges may therefore be reduced.

In order to predict the effects of exploitation on the groundwater system, a good understanding is needed of the hydrogeology, hydrology and flow processes in operation. These factors will govern the magnitude, speed and location of any drawdown. In order to define sustainable levels of groundwater abstraction it is necessary to quantify the aquifer balance. Groundwater models have been developed for this. One of the most difficult components to quantify is the recharge component, as it is highly variable in time and

space. For this we need a model that effectively describes recharge processes at all timescales. Recharge varies according to a number of controls including climate change and variability. Given the past and future changes in these controls, we can use the model to estimate future changes on the aquifer balance, and use this information for planning and decision making. One such study has taken place in the Upper Guadiana catchment, Central Spain, as part of the EU EFEDA II project (Thornes et al. 1996).

The Upper Guadiana catchment is c. 18,000km^2, and groundwater is the main source of water for agriculture in this climatically marginal area. Average annual rainfall is 460mm between 1956 and 1991. The area has almost flat topography (slopes of less than 3 degrees). Groundwater levels have been declining by up to 1m per year since 1974 in some parts. Most of this decline has occurred in Aquifer 23 (Lopez Geta et al. 1989), located in the centre of the catchment. It is assumed that over-exploitation by intensive irrigation since 1974 is the principal cause, but changes in climatic inputs and land use over the long term may also have contributed. Modelled estimates of potential recharge from the non-riparian zone[1] at the surface have been produced (Burke 1998) using the PATTERN model (Mulligan 1996), a 2- dimensional grid-based SVAT model, constructed, parameterised and validated for Mediterranean environments. Potential recharge (figure 1) is the water transmitted downwards below the soil zone (Rushton 1988). This may take many years to percolate through the unsaturated zone to reach the deep aquifer. Estimates of these residence times in Castilla-La Mancha are in the region of three centuries (Llamas et al. 1996), which suggests the groundwater decline may have been the result of changes in potential recharge many centuries ago. If the impact of past and present climate and land use changes on potential recharge can be assessed, decisions can be made on the long-term sustainability of aquifer abstractions in the light of estimates of recent and future land use and climatic changes (Mulligan and Burke 1999).

The PATTERN model conceptualises the soil zone as a leaking bucket, with infiltration and evaporation at the surface and recharge leaking from the bucket. It uses the Campbell equation (Campbell, 1985) for recharge (equation 1) which is then modified for stone content at the base of the profile.

$$K = Ksat \,.\, (\theta/\theta sat)^{2b+3} \qquad [1]$$

where:

K	= instantaneous recharge rate (mm/hr)
$Ksat$	= saturated hydraulic conductivity (mm/hr)
θ	= soil moisture (m3water/m3porespace)
θsat	= saturated soil moisture (m^{3}water/m^{3}porespace) [=1.0]
b	= decay constant of soil moisture characteristic.

This equation describes the recharge as the vertical rate of movement of water through soil. During rainfall events, recharge takes place at a rapid rate because soil moistures are high and water drained from the profile is being continuously replenished by infiltration. Recharge occurs at an ever-decreasing rate according to the K-θ curve and the soil moisture characteristic curve in the dry periods between rainfall events.

[1] Recharge from the riparian zones is not considered (see Thornes, J. B., this volume).

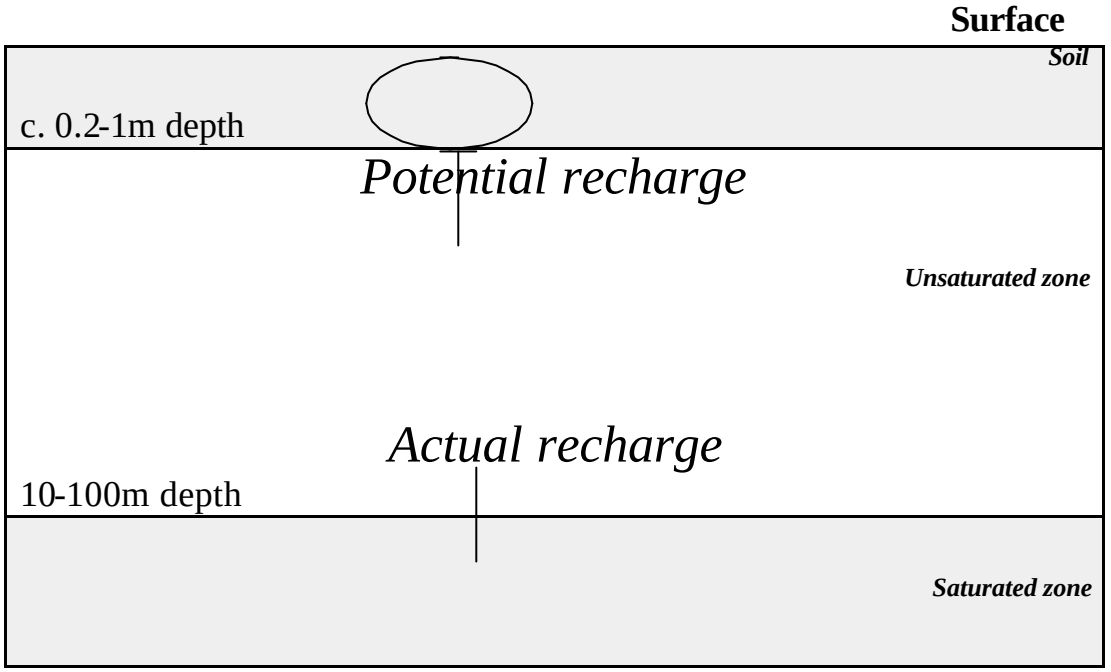


Figure 1: Potential recharge from the soil zone.

It assumes that the permeability of the bedrock is greater than the soil (it is highly fractured) and therefore this rate of movement at the soil-bedrock interface is equivalent to recharge.

Rainfall is extremely variable in Mediterranean environments, as discussed by Thornes (this volume). In temperate zones precipitation is distributed reasonably uniformly in both space and time. However, the distribution of rainfall in semi-arid zones is very irregular and Castilla-La Mancha is no exception (Burke and Thornes, in press). Between 1956 and 1991 average annual rainfall over the whole catchments (using data from 60 rain gauges) varies from 326 mm / year to 642 mm / year, a range of 316mm. There is also strong seasonal variability - monthly rainfall can vary by as much as 200mm between consecutive months. Finally rainfall storm intensities can vary greatly, with long periods of drought interspersed by substantial rainfall events. Mediterranean environments also exhibit spatial variation in rainfall, even in areas of low relief such as Castilla-La Mancha. Between October 1968 and September 1969, annual rainfall varied between 200mm and 1200mm over 50 kilometres of flat topography. This variability is often considered a major source of uncertainty in catchment modelling, and the development of distributed modelling technology is hampered by the lack of understanding of the spatial variability of rainfall and the lack of data to characterise it (Lopes 1996). This uncertainty is particularly significant in large catchments. Detailed analysis of the temporal and spatial patterns of rainfall are essential for estimating catchment recharge. As rainfall exerts a strong control over recharge, groundwater recharge is highly variable (figure 2). When recharge does take place the recharge is usually only very small fraction of the rainfall amount, where soil

storage and evapotranspiration demands are high. With such small flux values the estimation of recharge is prone to high errors. We can conclude that recharge events are sparsely distributed and episodic in nature, according to the rainfall characteristics. This provides difficulties for modelling recharge.

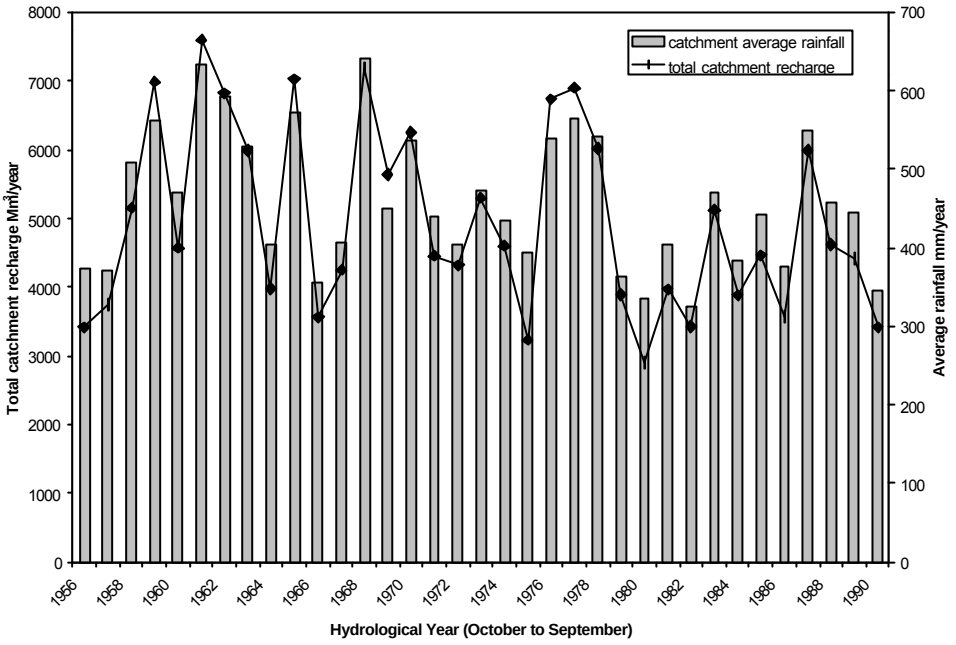


Figure 2: Total catchment recharge under a fixed land use scenario.

We should therefore model recharge using rainfall data at the fine scale over a long time period using rainfall data from as many rain gauges as necessary. The model used in the Upper Guadiana catchment simulates recharge at the automatic weather station bucket-tip timestep from 1956 to 1991 using rainfall data from 60 gauges. The model is applied across the catchment in a semi-distributed grid (Burke 1995). Figure 3 shows the regression results between average annual rainfall and average annual recharge. R^2 varies from 0.888 to 0.965 where the same rainfall is applied across the different land uses. These relationships can be used by resource planners in the catchment to understand recharge under these same soil and vegetation conditions given the annual rainfall.

Figure 3 also shows that the regression intercepts vary between different land uses. A shift in the regression intercept implies that non-meteorological processes are affecting the proportion of rainfall that becomes recharge. By examining the modelled recharge output it is possible to define a threshold of annual rainfall below which recharge never occurs. For example, Bredenkamp (1988) used regression to define the relationship between recharge and rainfall in South Africa, where recharge was estimated from the average rise of groundwater level using an estimate of effective porosity.

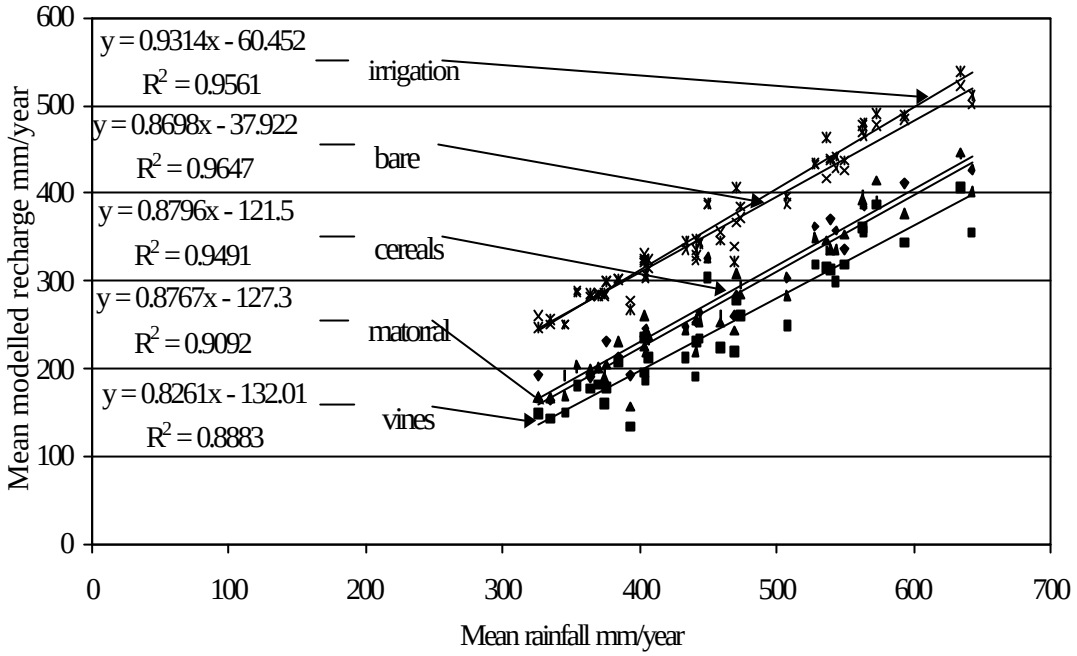


Figure 3: Regression analysis of rainfall versus recharge under different land uses.

The regression intercept (395mm rainfall in quartzite, 313mm in dolomite) was then interpreted as a threshold rainfall for recharge to occur. Kennet Smith et al. (1994) found the critical limit was approximately 150mm rainfall for loamy sand and 250mm rainfall for sandy loam in Australia. Sandström (1995) found the limit to be 400mm in degraded land in Tanzania. The intercepts on the x axis in figure 3 (which represents rainfall where recharge is zero) range from 43.6mm (bare) to 159.8mm (vines). This suggests that land use exerts a powerful control on the minimum rainfall required for recharge in times of drought.

The minimum threshold value of rainfall before recharge takes place also occurs at the storm scale. This is affected by the magnitude of the storm intensity and frequency. Only under higher intensity (and/or high frequency) rainfall events does the soil moisture increase faster than it drains away or evapotranspires. Eventually the proportion of the rainfall that becomes recharge is higher under these conditions because the soil moisture content is maintained at a high level.

In this paper we have explored the impact of rainfall variability on recharge at a number of timescales. Modelled recharge has been shown to be responsive to the inter-annual changes in rainfall experienced in the Upper Guadiana (figure 2). More long-term analysis of aquifer inputs are also important when there has been long-term shift in climate. Using modelled results over 35 years, the recharge was calculated from the whole Upper Guadiana catchment assuming that land use (which also controls recharge, see figure 3) is held constant according to the land use scenario from taken satellite data in 1990. After smoothing the data with a five-year running mean, a linear downward trend is significant at

the 99% probability level. We can therefore conclude that past climate changes may have caused the decline of groundwater levels, and due to the long residence times in this area, the groundwater level will continue to decline into the future.

However, the estimated decline in recharge due to this climate change is only 39.4 Mm^3/year, or 2.11mm/year on average. Assuming the bedrock porosity is 5%, the measured decline in groundwater levels is equivalent to 42.2mm/year of water loss. Therefore, on average, the decline in groundwater due to present day climate change is 21 times less than the groundwater losses being experienced today. We therefore have to conclude that the main cause for the present day groundwater decline is due to the unsustainable rate of abstractions.

We can therefore conclude the following points:

- Modelled estimates of recharge are needed for an assessment of sustainable levels of exploitation
- Recharge events are small, sparse and episodic
- The most important control on recharge is rainfall, which is extremely variable at all timescales and is unpredictable
- Groundwater abstraction rates are unsustainably high in the Upper Guadiana catchment, Spain.

References

Bredenkamp, D. B. 1998. Quantitative estimates of groundwater recharge in the Pretoria Rietondale area. In: Simmers, I (ed) Estimation of natural groundwater recharge, pp461-476, D. Reidel Publishing Company.

Burke, S. 1995. Land Surface Parameterisation: Regionalised versus distributed approach to groundwater recharge. Phys. Chem. Earth 20, 3-4, pp. 331 -337.

Burke, S. 1998. Modelling surface and near surface controls on groundwater recharge in Central Spain. PhD (unpublished), University of London.

Burke, S. and Thornes, J. B. *(in press)* EFEDA II desertification and groundwater: Regional estimation of recharge in the Upper Guadiana catchment. In: Balabanis, P. and Peter, D. (eds) Proceedings of International Conference on Mediterranean Desertification: Research Results and Policy Implications, Volume 2, Office for Official Publications of the European Communities, Luxembourg.

Campbell, G. S. 1985. Soil Physics with BASIC. Elsevier, The Netherlands.

Kennet-Smith, A., Cook, P.G. and Walker, G. R. 1994. Factors affecting groundwater recharge following clearing in the south western Murray Basin. Journal of Hydrology 154, 85-105.

Llamas, M. R., Cruces, J., Casado, M, de la Hera, A. And Martinez, L., 1996. Groundwater modelling and estimation of recharge using a one-dimensional soil water models. In: Bromley, J (ed) EFEDA II: Hydrology Group Contract No. EV5V - CT93 - 0282 Final Report. European Commission.

Lopes, V. L. 1996. On the effect of uncertainty in spatial distribution of rainfall on catchment modelling. Catena 28, 107-119.

Lopez Geta, J. A., Fabregat Ventura, V., Olivares Talens, J. F. 1989. Mancha Occidental Sistema Acuifero No. 23. Serie: Manuales de Utilizacion de Acuiferos, Instituto Tecnológico de Espana, Spain.

Mulligan, M and Burke, S. 1999. Modelling the future of groundwater resources in Central Spain. Environmental Management and Health 10/1 41-51.

Rushton, K. R. 1988. Numerical and Conceptual Models for recharge estimation in arid and semi-arid zones. In: Simmers, I (ed) Estimation of natural groundwater recharge, p223-238, D. Reidel Publishing Company.

Sandström, K. 1995. Modeling the effects of rainfall variability on groundwater recharge in semi-arid Tanzania. Nordic Hydrology 26, 313-330.

Thornes, J. B., Burke, S. Harrison, A., and Lopez Bermudez, F. 1996. Regional estimation of groundwater recharge and the role of changing land use. In: Bromley, J (ed) EFEDA II: Hydrology Group Contract No. EV5V - CT93 - 0282 Final Report. European Commission.

CRITERIA AND INSTRUMENTS TO CONTROL SOIL EROSION

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Abstract. Mediterranean soils are threatened by various soil erosion processes: i.e. mainly by water erosion, tillage erosion, mass movements and erosion due to land levelling. Various criteria must be considered before planning appropriate soil conservation measures. An overview of the most important techniques for soil conservation is given with particular attention to Mediterranean environments. Although many techniques are available, the implementation of these techniques by farmers remains the bottleneck of the problem.

Key words: Water erosion, tillage erosion, mass movements, land levelling, soil conservation techniques.

Introduction

Soil erosion is defined, in a strict sense, as detachment, entrainment and transport of soil particles (sediment) by a moving fluid (e.g. water or wind). In a larger sense, soil erosion also includes mass movements, which cover various kinds of processes leading to a downslope movement of soil or rock due to the pull of gravity, as well as net soil losses due to tillage operations (tillage erosion) or due to land preparation (e.g. land levelling operations before crops are grown) or due to rootcrop harvesting (Poesen et al. 1996).
Which soil erosion processes are important in Mediterranean environments ? From a spatial point of view and in decreasing order of importance, water erosion (i.e. interrill, rill, gully and piping erosion), mass movements and wind erosion are degrading our soil resources in Mediterranean environments (Poesen 1995). More recently, attention has also been drawn to tillage erosion in these environments (e.g. Revel et al. 1990, Poesen et al. 1997, Poesen and Hooke 1997) as well as to soil losses caused by land preparation works in Spain and in Italy (e.g. Poesen and Hooke 1997, Dazzi and Monteleone 1999, Torri 1999). All these soil erosion processes must be regarded as significant desertification processes since they are threatening the biological or economic productivity of Mediterranean soils.

Criteria to control soil erosion

Various criteria exist to decide whether soil erosion rates should be reduced or not. These can be subdivided into « on site » criteria and « off site » criteria.
Before discussing these criteria in more detail, it is important to briefly review the various soil functions. The quality of a soil is determined by several functions it can perform.

Among the many soil functions, the following are usually recognised : 1) plant growth function (food and fiber production), 2) water filter function (surface water, groundwater), 3) ecological function (e.g. storage of nutrients, genetic pool, shelter for soil organisms), 4) function as source of raw material (e.g. for production of bricks) and 5) archive function, particularly in Mediterranean environments where soils are key elements for unravelling our history since they store artefacts or pollen or they have soil horizons which teach us about past environmental conditions. In fact, soils are part of our natural heritage. In order to allow a soil to perform all these functions, it needs to be protected from excessive erosion through the use of soil conservation techniques.

Too often, conservation of nature is focussing on biotic aspects (i.e. plants and animals) and not at all at abiotic (i.e. mineral) parts. Killing a bird or cutting a tree is considered to be more of a crime than truncating a soil profile, e.g. in the framework of a land levelling operation. Yet a bird or a tree can be replaced in a relatively short time span, whereas a complete soil profile needs hundreds to thousands of years to develop, in some cases the soil profile can even not develop anymore because of changing environmental conditions.

The rate of soil erosion is usually expressed as soil loss per soil surface unit and per time interval : e.g. ton/ha/y. Erosion rates are often compared to a soil-loss tolerance level (T-factor) in order to decide whether soil loss rates are excessive. T-factor values are defined based on on-site and/or on off-site considerations of soil erosion.

On-site criteria

A T-value for cropland productivity (see soil function 1) equals a maximum rate of soil erosion that can occur and which still permits crop productivity to be sustained economically (Renard et al. 1997). These T-values range between 0 and 13 ton/ha/year (= 1 mm/year). A T-factor of 13 ton/ha/y has been accepted for deep medium-textured soils under temperate humid conditions since this soil loss rate is believed to keep pace with the corresponding weathering rate. But T-values may be much less for many soils in the Mediterranean belt because these soils are often shallow (hard unweathered rock is at limited depth in the soil profile) and because of lower weathering rates under Mediterranean climatic conditions.

Off-site criteria

T-values considering off-site effects of soil erosion may be less than those considering on-site effects. Among the most important off-site criteria used the following can be listed : 1) reduction of sediment deposition on cropland and infrastructure (e.g. roads), reduction of sediment input to water bodies (streams, lakes and reservoirs) because of water quality (drinking water and fisheries), water quantity and economic considerations (e.g. treating surface water polluted with very fine clay particles in suspension is quite expensive). Other off-site effects may include flooding and channel management problems.

More recently, attention has also been drawn to the fact that the application of soil conservation techniques such as crop residue management, conservation tillage, restoration of degraded soils through afforestation and other proven technologies, leads to the sequestration of carbon (C) in the soil. As such, the application of these soil conservation techniques is producing unanticipated benefits by letting soils become major sinks for

atmospheric carbon dioxide (CO_2), thereby reducing concentrations of this greenhouse gas (Lal et al. 1999).

Cost-benefit analysis

Before soil conservation measures are taken, a cost-benefit analysis is needed taking into account the long-term benefits resulting from soil conservation. Overall, there is a need for cheap, simple and efficient techniques which have, if possible, also other beneficial effects, such as for instance soil water conservation. Particularly in the light of Agenda 2000, whereby subsidies for crop production in the European Union will be reduced, cheap techniques are required given that farmers will be less inclined to spend a lot of money for reducing soil erosion rates.

Instruments to control soil erosion (soil conservation techniques).

Given that water erosion, mass movement and tillage erosion are caused by different processes and controlled by different factors, we will discuss the most important soil conservation techniques to reduce the rate of these land degradation processes separately in the following sections.

Water erosion

Protecting the soil against water erosion can be achieved by applying some basic principles (Morgan 1995) :

1. Protect the soil surface as much as possible in space and time through vegetation cover (both canopy cover and contact cover). This follows from the fact that ma ny researchers found a negative exponential relation between (vegetation) cover (C, %) and sediment production (SY) by water erosion processes (i.e. interrill and rill erosion processes) ;

$$SY = a\, e^{-bC}$$

where a = SY for a vegetation cover equalling 0 %,
b = a coefficient indicating the effectiveness of the vegetation cover in reducing sediment production. From a detailed literature review, Bochet (1996) concluded that b usually ranges between 0.020 and 0.085.

2. Increase infiltration rates of rain and runoff into the soil ;
3. Improve the structural stability of the soil (i.e. soil aggregate stability) ;
4. Increase soil surface roughness in order to increase surface detention, depression storage and overland flow energy dissipation on roughness ele ments (in doing so, this energy can not be used anymore to detach, entrain and transport soil particles).

Techniques to control water erosion rates are usually grouped in crop and vegetation management, soil management and mechanical or physical methods (Morgan 1995). Crop and vegetation measures make use of the important role of vegetation to protect the soil against erosion. Soil management deals with ways of preparing the soil to promote plant growth and improve its structure so that it is more resistant to erosion. Mechanical or physical methods manipulate the surface topography so as to control the overland flow

velocity and discharge. In what follows, we briefly review the most important techniques with a special attention to Mediterranean environmental conditions.

Crop and vegetation management

The most important crop and vegetation management techniques used to control soil losses due to water erosion are crop rotation, cover cropping, multiple cropping, mulching, revegetation and agroforestry.

Crop rotation

Crops are usually grown consecutively in rotation (e.g. wheat – fallow rotation in southern Portugal). During years where particular crops are grown (e.g. wheat), erosion rates may be high (because of a low vegetation cover) whereas during years with other landuses (e.g. fallow) erosion rates will be low so that averaged over several years, mean annual soil losses due to water erosion remain less than the tolerance level.

One should keep in mind that soil losses caused by the growth of agricultural crops in a rotation scheme can also be caused by soil sticking to rootcrops (e.g. potatoes, onions). When harvesting rootcrops, this soil leaves the field plot and seldom returns to the same plot. Consequently, the soil loss due to rootcrop harvesting (SLRH) should also be taken into account when assessing mean soil loss rates.

Rotation schemes can also be found on rangelands in the Mediterranean where shepherds move herds around in order to allow the grass to recover and where controlled burning is practised regularly for the removal of undesirable plant species (e.g. Sarcopoterium Spinosum bushes in Greece). Overgrazed areas or freshly burned pastures have a large extent of bare ground, resulting in serious erosion during the subsequent rainy season.

Cover cropping

Cover crops can be grown in order to cover the soil during the off season or below trees. A typical example is the establishment of a permanent grass cover in vineyards so as to reduce soil losses (in between the rows) drastically. However, since the grass competes with the vines for moisture during spring and the hot dry summer period, the grass is killed by a herbicide so that the dead biomass still covers the surface.

Multiple cropping

The objectives of multiple cropping are to increase soil productivity and to protect the soil surface both in space and in time. This can be achieved by, for instance, growing several crops on the same piece of land at the same time (intercropping). Multiple cropping has been traditionally practised in Tuscany (Italy) where it is known as « coltura promiscua ». Coltura promiscua involves the growth of cereals or vegetables, vines, olives, fodder or fruit trees on the same plot of land (Lebeau, 1972). However, due to the limited possibilities for mechanisation, the area under coltura promiscua is decreasing in favour of monocultures (Chisci 1986).

Mulching

Mulching involves the covering of the soil with organic or mineral material. Examples of organic mulches are crop residues (straw, maize stalks, standing stubble, leaves or twigs),

woodchips or pieces of bark, forest litter (needles of conifers or leaves from deciduous trees) or city compost. Gravel, lapilli or shells are examples of mineral mulch materials. Mulches simulate the effects of a vegetation cover. Mulches will, provided that the ground is sufficiently covered, reduce the intensity of surface sealing and splash erosion which will lead to reduced surface runoff production, sheet and rill erosion. The latter is also attained by the reduced overland flow velocity because surface mulches absorb part of the overland flow energy (mulches increase hydraulic friction factors).
Similar to vegetation covers, various mulch types have various efficiencies in reducing soil loss. For a given soil cover, a mulch consisting of small mulch elements is more efficient compared to a mulch consisting of large mulch elements (Poesen and Lavee 1991). In semi-arid to arid environments, mulches also have other beneficial effects such as the reduction of evaporation rates (= water conservation, e.g. van Wesemael et al. 1996) or soil temperatures.
Some examples of mulches used in southern Europe are crop residues, vine twigs (in vineyards), gravel (e.g. in Switzerland, Nachtergaele et al. 1998) or lapilli (e.g. in the Canary Islands, Caldas and Salguero 1988).

Revegetation
Because of the crucial role of vegetation (cover) in soil erosion control, disturbed or sparsely vegetated areas are revegetated. For instance, throughout the Mediterranean, many examples of afforestation programmes can be found. The success of such schemes depends among others on the land preparation before replanting, the soil type and the introduced plant species.

Agroforestry
The practice of integrating trees with crops or animals is defined as agroforestry. The role of trees is to preserve soil fertility by returning organic matter, and to improve the soil's structure which favours high infiltration rates, low runoff rates and low erosion rates Young 1997)
A typical example for the Mediterranean is the Dehesa (Spain) or Montado (Portugal) system, also described as Mediterranean savannas, which denote the land-use system in rural areas, mainly rangelands, which are occupied by scattered oak trees (Quercus rotundifolia, Q. suber, Q. faginae). This system has been known for many centuries for its multiple mainly silvopastoral, use of renewable resources, and its strong linkages to recurrent cereal cropping in rangelands (Joffre et al. 1988).

Soil management
The main objectives of soil management are the conservation of the fertility and the structure of the soil (Morgan 1995). Well-managed soils produce a large biomass, and hence an important vegetation cover, and are less erodible resulting in low erosion rates (see above). The most important soil management techniques are the management of soil organic matter content (SOM), tillage practices and the application of soil conditioners.

Soil organic matter (SOM)

SOM plays various important functions in the soil. One of these is to act as a glue (like for instance clay) which binds primary particles into soil (micro-)aggregates. The efficiency of SOM in stabilising soil aggregates depends among other factors on the amount and type of organic matter added to the soil (e.g. crop residues, manure, compost). Consequently, by incorporating organic matter to the top soil, one can control the resistance of the soil aggregates to breakdown by erosive forces.

Tillage practices

Tillage of the topsoil is performed to control weeds and to provide suitable seedbeds for plants to develop. However, through tillage operations, farmers have a control on soil surface roughness and depression storage and therefore on runoff and erosion rates.

Through **conventional tillage**, farmers can create rough soil surfaces which are less susceptible to surface sealing and therefore have high infiltration rates and low runoff and erosion rates.

Alternatively, through **conservation tillage**, farmers leave the soil surface still covered with crop residues for at least 30 %. In doing so, soil erosion rates are cut to at least 50 % of those for similar surfaces without crop residues.

In a **no tillage** farming system, tillage is restricted to that necessary for planting the seed. In other words, drilling is performed directly in a compact topsoil which is covered by stubble and weeds (which are killed by a herbicide).

By creating **ridges and furrows** parallel to the contour, farmers increase surface roughness and depression storage. In order to prevent rainfall excess to flow along the contour in the furrows, small furrow dams (in earth) can be created (basin tillage)(Agassi et al. 1986).

Ploughing, drilling and cultivation on the contour, i.e. **contour tillage**, can reduce soil loss from sloping land compared with cultivation up and down the slope. However, this way of working the land is only efficient within a certain slope range, typically between 0.5 and 20 % depending on the height difference between furrow bottoms and ridge tops (Renard et al. 1997) and for rains characterised by a low to medium intensity. Field observations clearly indicate that contour tillage may increase the risk of ephemeral gully erosion during intense rains by storing runoff in the furrows which will then flow subparallel to the contour towards the lowest point in the furrow. At this point, depression storage capacity may be rapidly reduced because of sediment deposition which than will lead to flow overtopping and breaching the ridge. Once this happens, the same process will repeat itself downslope (similar to a domino effect) leading to the rapid development of a concentrated flow erosion channel (i.e. an ephemeral gully).

Recently conducted field and laboratory experiments clearly indicate that when dry stony topsoils, which are typical for the Mediterranean, are tilled with tines or tine-like tools, **kinetic sieving** takes place, i.e. most of the largest rock fragments concentrate at the soil surface whereas the finest soil fraction concentrates in the bottom of the tilled layer (Oostwoud Wijdenes et al. 1997, Poesen et al. 1997). This indicates that one or two tillage operations can greatly increase rock fragment cover at the soil surface. As shown by numerous studies, these rock fragments behave like natural soil surface stabilisers (mulch elements) protecting the soil surface from surface sealing, interrill and rill erosion (Poesen et al. 1994).

Soil conditioning

A soil conditioners (soil stabiliser) is a substance – natural or manufactured – that has the ability to improve the physical properties of the soil so that the application of a soil conditioner will enhance the quality of the soil for many of its functions (Wallace and Terry, 1998). Gypsum, lime, compost, biosolids (sewage sludge, olive mill effluents), and polymers have been used in various studies to control surface sealing, infiltration, runoff and soil erosion rates (Agassi, 1996). Soil conditioners are often used in the hydroseeding technique which is applied to erosion prone-sites for rapid establishment of a vegetation cover. A mixture of seeds, fertilisers, water and soil conditioners is sprayed onto the erodible, bare soil surface. The soil conditioner has to create a stable environment where the seedlings can develop before being eroded. Over time, the plants take up the stabilising role of the soil conditioner.

Mechanical methods

In order to control the movement of overland flow, various techniques are being applied in conjunction with agronomic measures. The most important ones are contour bunds, terraces, waterways and stabilisation structures (Morgan 1995).

Contour bunds

In order to avoid runoff concentration from long and gentle hillslopes, the latter are being divided into sections each of them separated by an earth bank (contour bund). These earth banks act 1) as a barrier to overland flow and 2) create water storage areas on their upslope sides.

Terraces

Throughout the Mediterranean, many types of earth embankments have been constructed (across the slope) on steep hillslopes in order to intercept surface runoff, to irrigate and to till the land without losing the soil by erosion (Ambroise et al. 1989). However, the construction and maintenance cost of these structures is high. Some of these terrace banks have developed over time because of tillage erosion at the top end of agricultural plots and tillage deposition at the bottom end of these plots (Poesen et al. 1997).

Waterways

In order to convey runoff at a non-erosive velocity to a suitable disposal point, carefully designed waterways are constructed. Various types of waterways exist (Morgan 1995). In order to reduce the risk of (ephemeral) gully erosion, grassed waterways can be established. However, in Mediterranean areas, soil water deficit during the summer causes a problem in that it will be difficult to maintain a full grass cover in the waterway without irrigation. Alternatively, waterways in these environments can be covered by large rock fragments incorporated in concrete so as to prevent them from being transported during peak flows.

Stabilisation structures

Stabilisation structures are used in gully erosion control or when reclaiming gullies. These usually consist of (small) checkdams constructed across the gully using locally available

earth, loose rock or brushwood. Very often gabions are used to construct these dams. The efficiency of these structures depends on various factors including soil type or lithology in which the gullies developed. For instance, field observations in Southeast Spain indicate that many stabilisation structures installed in gullies, which developed in marls (badlands), have failed because of intense piping in the gully walls or gully beds, bypassing these structures.
Attempts to control gully head development in very erodible materials by installing these structures have often failed. However, the installation of a geomembrane, preventing concentrated overland flow to come directly into contact with the erodible soil at the gully head, has proven to be a cheap and successful technique (Poesen, 1989).

Mass movements
In order to reduce the risk for mass movements, two basic techniques are usually applied: i.e. drainage of hillslopes and reforestation (Flageollet 1989).
The development of a (temporal) watertable in hillslopes contributes significantly to the lowering of the shear strength of the soil mass (buoyancy effect) and hence the instability of the hillslope. By draining such hillslopes, susceptible to mass movements, the probability of a water table built up is being reduced leading to a higher degree of stability. Additionally, diversion canals can be built in order to avoid overland flow produced elsewhere, to saturate the hillslope.
Forests have various effects on the stability of hillslopes. One of them is the reinforcement of the soil mass by their roots and the increase of the shear resistance of the soil which contributes significantly to the increase of the factor of safety. Consequently, reforestation is often applied to reduce the risk of (shallow) landsliding.

Tillage erosion.
Over the last years, it has become clear that frequent tillage operations on steep slopes throughout the Mediterranean leads to significant net downslope soil fluxes and, hence, excessive soil losses on topographic convexities and at the upper parts of field plots whereas concavities and footslopes are characterised by net deposition of this displaced topsoil (e.g. Revel et al. 1990, Poesen et al. 1997). Tillage erosion is controlled by factors such as slope and curvature of the land, tillage equipment, depth, direction, speed and frequency of tillage, soil type, structure and moisture content of the topsoil at the time of tillage.
In order to reduce the rate of tillage erosion, the following measures should be taken:
1) reduce tillage frequency or introduce no tillage where possible ;
2) reduce depth and speed of tillage (since this reduces the soil fluxes);
3) till on the contour rather than up- and downslope (Poesen et al. 1997);
4) do not till terrain with high profile and plan curvature.

Soil erosion due to land levelling

Given the adverse effects of land levelling (i.e. soil profile truncation and loss of soil productivity) the areal extent and intensity of land levelling should be reduced.

Concluding remarks.

Several soil degradation processes (water erosion, tillage erosion, mass movements, land levelling) which are often human-induced, threaten the Mediterranean region. Therefore, more attention should be given to the conservation of soil resources in this region.

Some soil conservation techniques are good to fight one soil degradation problem, not for reducing the risk of another. A balanced understanding of the various soil degradation processes is of utmost importance in order to select appropriate soil conservation measures. For instance, increasing soil infiltration rates is an efficient technique to reduce water erosion rates, not to reduce the risk for mass movements in particular environments. Some soil conservation techniques reduce the risk of several soil degradation processes at a time: e.g. no tillage is very efficient in reducing both water erosion and tillage erosion rates.

Although many soil conservation techniques exist, their application has been limited.

When introducing soil conservation techniques, these should be acceptable both at the technical and at the socio-economical level. Voluntary actions taken by farmers remain limited except where crop productivity increases directly as a consequence of the application of soil and water conservation techniques (e.g. application of a gravel mulch in Swiss vineyards also improve the quality of the grapes, Nachtergaele et al. 1998). The implementation of a code of good farming practices is an excellent initiative but does not lead to a revolution in the implementation of soil conservation techniques. The application of soil conservation techniques on agricultural land remains the bottleneck of the problem. Experiences gained in North America have learned that farmers are only applying soil conservation practices, if they are forced to do so, e.g. in order to obtain subsidies for their crops. Hence, authorities at all administrative levels should take more actions in this sense.

References.

Agassi, 1996. Soil erosion, Conservation and rehabilitation. Marcel Dekker, New York, 402 pp.

Agassi, M., Benyamini, Y., Morin, J., Marish, S. and Henkin, E. 1986. The Israeli concept for runoff and erosion control in semi-arid and arid zones in Mediterranean basin. Report, Soil Erosion Research Station, Ministry of Agriculture, Israel.

Ambroise, R., Frapa, P. and Giorgis, S. 1989. Paysages de Terrasses. Edisud, La Calade, France, 190 p.

Bochet, E. 1996. Interactions sol-végétation et processus d'érosion hydrique dans le microenvironnement de trois espèces du matorral méditerranéen. Unpubl. PhD. thesis, Department of Geography, K.U.Leuven, Belgium, 264 pp.

Caldas, F.E. and Salguero, T.M.K. 1988. Mulch farming in Canary Islands. In Wichiro, N. (ed.) Agro-geology in Africa. Commonwealth Science Council Technical Publication 226 :242-256.

Chisci, G. 1986. Influence of change in land use and management on the acceleration of land degradation phenomena in Apennines hilly areas. In Chisci, C; and Morgan, R.P.C. (eds.) Soil erosion in the European Community. Impact of Changing Agriculture. Balkema, Rotterdam :3-16.

Dazzi, C. and Monteleone, S. 1999. Consequences of human activities on pedodiversity of soils : a case-study in a vineyard area in south-east Sicily (Italy). Paper presented at the International Conference «Soil Conservation in Large-scale landuse. European Society for Soil Conservation, May 12-15, 1999, Bratislava, Slovak Republic.

Flageollet, J.-C. 1989. Les mouvements de terrain et leur prevention. Masson, Paris, 224 pp.

Joffre, R., Vacher, J., De los Llanos, C. and G. Long 1988. The dehesa : an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain. Agroforestry Systems 6 :71-96.

Lal, R., Follett, R.F., Kimble, J. and Cole, C.V. 1999. Managing U.S. cropland to sequester carbon in soil. J. Soil and Water Conservation 54(1) :374-381.

Lebeau, R. 1972. Les grands types de structures agraires dans le monde. Masson, Paris, 120 pp.

Morgan, R.P.C. 1995. Soil Erosion and Conservation. Longman, Essex, U.K., 198 pp.

Nachtergaele, J., Poesen, J. & van Wesemael, B. 1998. Gravel mulching in vineyards of southern Switzerland. Soil & Tillage Research, 46:51-59.

Oostwoud Wijdenes, D., Poesen, J., Vandekerckhove, L. and de Luna, E. 1997. Chiselling effects on the vertical distribution of rock fragments in the tilled layer of a Mediterranean soil. Soil & Tillage Research, 44:55-66.

Poesen, J. 1989. Conditions for gully formation in the Belgian Loam Belt and some ways to control them. Soil Technology Series 1:39-52.

Poesen, J. 1995. Soil erosion in Mediterranean environments. In R. Fantechi, D. Peter, P. Balabanis and J.L. Rubio. Desertification in a European context: Physical and socio-economic aspects. European Commission, Luxembourg, EUR 15415:123-152

Poesen, J., Boardman, J., Wilcox, B. & Valentin, C. 1996. Water erosion monitoring and experimentation for global change studies. Journal of Soil and Water Conservation 51 (5):386-390.

Poesen, J.W.A. & Hooke, J.M. 1997. Erosion, flooding and channel management in Mediterranean Environments of southern Europe. Progress in Physical Geography 21 (2):157-199.

Poesen, J. and Lavee, H. 1991. Effects of size and incorporation of synthetic mulch on runoff and sediment yield from interrills in a laboratory study with simulated rainfall. Soil & Tillage Research 21:209-223.

Poesen, J., Torri, D. & Bunte, K. 1994. Effects of rock fragments on soil erosion by water at different spatial scales: a review. Catena 23:141-166.

Poesen, J., van Wesemael, B., Govers, G., Martinez-Fernandez, J., Desmet, P., Vandaele, K., Quine, T. & Degraer, G. 1997. Patterns of rock fragment cover generated by tillage erosion. Geomorphology 18(3-4):183-197.

Renard, K.G., Foster, G.R., Weesies, D.K., McCool, D.K. and Yoder, D.C. 1997. Predicting Soil Erosion by Water : a Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). USDA, Agr. handbook No 703, 404 pp.

Revel, J.C., Coste, N., Cavalie, J.L. and Costes, J.-L. 1990. Premiers résultats expérimentaux sur l'entrainement mécanique des terres par le travail du sol dans le Terrefort toulousain (France). Cahiers ORSTOM, Série Pédologie, 25 :111-118.

Torri, D. 1999. Responses of soil and erosion/sedimentation systems. In Proc. Intern. Conf. Synergies in Desertification Processes in the Mediterranean Region. Medesert, Perpignan, France, Medias France.

van Wesemael, B., Poesen, J., Kosmas, C.S., Danalatos, N.G. & Nachtergaele, J. 1996. Evaporation from cultivated soils containing rock fragments. J. of Hydrology 182 (1-4):65-82.

Wallace, A. and Terry, R.E. 1998. Handbook of Soil Conditioners. Marcel Dekker, new York, 596.

Young, A. 1997. Agroforestry for Soil Management. CAB International, Oxon, U.K., 320 pp.

CRITERIA AND INSTRUMENTS TO HALT EROSION

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1. INTRODUCTION

What is soil erosion ?
Which soil erosion processes are important in mediterranean environments ?

2. CRITERIA TO HALT EROSION

on site criteria
off site criteria

3. INSTRUMENTS TO HALT EROSION (SOIL CONSERVATION)

water erosion
tillage erosion
mass movements

4. CONCLUSIONS

June 1, 1999

INTRODUCTION

* What is soil erosion? (Poesen 1995, Pueblo Acantillado)

in a strict sense : detachment and transport of soil particles by a moving fluid (air or water) : water erosion, in a larger sense, it also includes mass movements, tillage erosion, removal of soil by land levelling (Poesen & Hooke 1997).
* Which soil erosion processes are important in mediterranean environments ?
in decreasing order of importance (from spatial point of view) :
Dia : Medalus logo : many examples presented here come from work in Medalus-project
T : soil erosion maps of de Ploey

<u>water erosion :</u>

T : sketch (Farres & Poesen)
- interrill
- rill
- gully erosion : ephemeral gully erosion (critical cross-section) and bank gully erosion
- pipe erosion

<u>tillage erosion and erosion due to land levelling</u>

T : maak schets (shets Govers in Poesen et al. Bevas) : up and downslope tillage or contour tillage, convexity and concavity
Dia tillage erosion Guadalentin : dia caterpillar tractor, stony convexity and filled in concavity
Dia : lower productivity on convexity due to tillage erosion (wheat field, valdinfierno)
dia land levelling (La Librilla)
dia land levelling for establishment of greenhouses (Almeria area)
Erosion due to land levelling : zie tekst Dino Torri (Perpignan) : impact on soil productivity (convexity versus concavity).

<u>Mass movements</u>

- dia Apenijnen
- shallow and deep mass movements

Dia : Agri-basin with landslides

<u>Wind erosion</u>

* Erosiekaart DePloey

relative importance of water erosion, mass movements and wind erosion

CRITERIA TO HALT EROSION

zie Morgan, kursus beros, RUSLE

- on site criteria

Before discussing on site criteria for soil conservation, it is important to look at various soil functions (they determine soil quality)

soil functions :

- bearing function
- plant growth function (production of food and fiber)
- water filter function (surface water, groundwater)
- ecological function : storage of nutrients, genetic pool, shelter for organisms
- function as source of raw material (e.g. bricks)
- archive function, particularly in mediterranean envrinments, soils are key elements for unrevelling (discovering) our past history (archeological artefacts, pollen, soil horizons, …)
- soils are part of our natural heritage ! ! !

- too often, conservation (of nature) is focussing on biotic aspects (e.g. plants, animals) and not at all at abiotic (mineral) parts (e.g. killing bird or cutting tree is considered to be more of a crime than to truncate a soil profile (e.g; in the framework of land levelling programmes), yet a bird or a tree can be replaced in a relativel short time span, whereas a complete soil profile needs hundreds to thousands of year to develop, in some cases it can't develop anymore because of changing climatic conditions).

In order to allow the soil to perfom these on site functions, it needs to be protected or conserved.

T-value for cropland productivity: soil-loss tolerance (T) : = maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically (RUSLE, chapter 1, p. 12).

This T-value only considers soil function 2 :

T-values range between 0 and 13 ton/ha/year (1 mm/year) depending on rate of weathering, depth of present soil. 13 ton/ha/year is for deep soils in temperate climates

For other soil functions it might be necessary to reduce T-value to lower values (e.g. protection of archeological sites).

- off site criteria

- reduce sediment deposition on cropland, infrastructure
- reduce sediment input to water bodies (lakes and streams) : water quality (drinking water and fisheries) and economic considerations (e.g. treatin surface water polluted with very fine clay particles in suspension is quite expensive).

Dia : la Librilla reservoir : flood measure
Dia Puentes reservoir : completely silted up reservoir
Dia : Puentes reservoir : flood control and irrigation water storage : (sustainability of engineering structures : it is better to prevent than to cure)
Dia : bord met kostprijs nieuwe dam (inversion = investering).

Cost of new dam = approximately 4 billion pesetas = 25 000 000 euro ! If no accompanying measures will be taken to reduce sediment input into the reservoir through soil protection measures (soil conservation techniques), the life expectancy of this new strucure will be very short ! ! !
* cost-benefit analysis : need for cheap, simple and efficient techniques to conserve soil (soil protection measures), particularly in the light of Agenda 2000 (reduction of subsidies for crop production, this means that farmers will be less inclined to spend a lot of money to reduce soil erosion. So, there is a need to look out for measures which have other beneficial effects, such as for instance water conservation.

ISTRUMENTS TO HALT EROSION (SOIL CONSERVATION)

NOT SOIL CONVERSATION ! ! !

water erosion
tillage erosion
mass movements

Water erosion
Overall principles for protecting soils against water erosion (Morgan 1997)

1. maximum protection of the soil in space and in time against raindrop impact
2. increasing of infiltration capacity of the soil
3. improving structural stability of the soil (ggregate stability)
4. increasing surface roughness in order to increase detention, surface storage flow energy dissipation on runoff elements (this energy can than not be used anymore to detach and transport soil particles).

Discussion of major techniques with special attention to mediterranean environmental conditions

1. agronomic or biological methods (using vegetation cover to reduce erosion rates) ;

2. soil management (optimalization of soil tillage in order to favour dense vegetation cover, good soil structure, high surface roughness, depression storage) ;

3. mechanical or physical methods : manipulation of topography (e.g. terraces) in order to control overland flow velocity and discharge.

Zie tekst en transparanten college Hellingsgeomorfologie en Bodemconservatie

Tillage erosion
Tillage Erosion = f(depth of tillage, tillage direction, tillage speed, hillslope curvature, …)
In order to reduce tillage erosion rates, several measures can be taken:

1) no tillage = best technique
2) reduction of tillage depth (chissel ploughing instead of moldboard ploughing)
3) tillage direction : on the contour versus up and downslope tillage

T : fig. Poesen et al 1997 (Geomorphology)

4) reduction of tillage speed
5) no cultivation of terrain with high plan and profile curvature

Land levelling
Reduce intensity of land levelling as much as possible to conserve soil

Mass movements
Basic principle is to increase shear strength via drainage (no water tabel build up), root reinforcement (only for shallow landsliding)

CONCLUSIONS

MODELLING EPHEMERAL CHANNEL BEHAVIOUR IN THE CONTEXT OF DESERTIFICATION

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Abstract. Ephemeral channels behave differently from perennial channels and require different modelling approaches to water and sediment routing. Probabilistic routing from random walks to diffusion are discussed together with the kinematic wave strategy and illustrated with reference to the MEDALUS III Project for channel behaviour.

Key words: Ephemeral channel, kinematic wave, Markov chain, diffusion.

Desertification is land degradation due to climatic and human causes in arid, semi-arid and sub-humid regions. It is a complicated process that has often been simply equated with soil erosion. This belies the complex relationship with vegetation cover that is an integral part of the problem. The over-emphasis on soil erosion as the main diagnostic feature coupled, as it is, to loss of agricultural production, has led to a mitigation agenda that concentrates on re-affirming the choice of (re-)afforestation as the panacea to desertification. A recent review of actions taken by Mediterranean governments to combat desertification reveals that they have almost universally sought afforestation as the solution to the problem (Burke and Thornes, 1998). This is encouraging because, only 50 years ago, the great American geomorphologist, Luna B. Leopold, had to urge agronomists and engineers to pay more attention to watershed management and less to structural solutions in flood and erosion problems.

Since then, the wheel has turned almost full circle and there has been a marked neglect of channels in the mitigation arguments. This paper is a call to recognise that ephemeral channels are an integral part of the problem of desertification and hence an integral part of the solution. Floods depend on the speed and volume of water reaching a point in the channel. The volume is intimately related to the soil storage within a catchment and the properties of soils as well as the intensity and spatial distribution of the rainfall, the latter in a manner that is only recently being well understood (Gupta and Waymire, 1998). The translation of water from and through the catchment system is directly a function of channel properties. In this short contribution, the main purpose is to highlight the ways in which the routing of water and sediment through the system can be conceptualised and handled. It has long been standard practice to use in-channel structures to manage water and sediment routing in the form of check dams, stone or concrete walls designed to hold up the downward progress of water and soils from the catchment slopes, to prevent flooding and reservoir siltation. The emphasis here has been on designs and techniques suitable for perennial channels in temperate areas (especially Northern Europe). The second message is that arid and semi-arid channels are special cases of these general principles that have to be recognised before decisions are made on how to mitigate desertification effects. The third signal is that there are unforeseen problems ahead due to the prospects of the impacts of global climate change in the coming decades (Brandt and Thornes, 1996).

Conceptual basis

Three major considerations determine the design of mitigation measures in ephemeral channel systems. The first is the highly sporadic character of rainfalls in arid and semi-arid environments. This means that conventional empirical approaches to flood frequency estimation are largely or totally irrelevant (Woolhiser and Todorovic, 1974) because of the large inter-annual variability in rainfall conditions (Thornes, 1991). Second, unlike perennial channels, ephemeral systems have a high capacity for bed infiltration that reverses the normal logic of downstream behaviour (Thornes, 1994a). Third, because of the large sediment load being transmitted through the system and its special character (as 'slugs' of coarse material in the river beds or as debris flows), the nature of the network control on events is ultra-important. Lekach and Schick (1983) provided empirical evidence of wave movement in ephemeral channels from their study of a small upland stream channel (Thornes, 1977; Thornes, 1994a and b).

Consider first the whole network. Because of the compact form of rain-producing storms (often as little as 10-20 Km across), individual tributaries may provide flow to the main channels as distinctive pulses that can be recognised in sedimentary structures (Reid and Laronne, 1995). These pulses are supplied to the main channel at tributary junctions (here called nodes) for translation through the 'links' between the nodes. Thus it is the characteristics of the link-and-node structure that determine the overall behaviour of the system and how its components interact. This system was described by Thornes (1977) and is schematised in Figure 1. It has also been recognised that each tributary can be thought of as 'gated' or in a state of 'connection' or 'disconnection' with the main channel. This in turn controls the flow in and through the system and needs to be accommodated in models of flow routing. This has been recognised in the engineering practice of building check dams in tributaries just above junctions with the main channel. The system can thus be likened to a national network of major roads or a continental-wide railway system with carriages and passengers joining the trunk routes at key nodes, leading to congestion points at nodes within the system. Different travelling habits and patterns of different nations and cultures thus determine the nature of travel along the main routes, as do different tributaries in river systems. Rice (1999) has demonstrated how this link-and-node structure controls sedimentary features as well as the freshwater ecology of perennial streams and how essential it is to embody these controls in modelling behaviours.

When water and sediment join at a node, they are propagated through the reach immediately downstream of the node, often under braided conditions. The nature of this propagation is again quite different from that in perennial channels, so that the conventional techniques of water and sediment routing are inappropriate or even need completely revising. There are three reasons for this:

a) The wide gravel beds lose water by transmission losses (Butcher and Thornes, 1979) with the discharge per unit width (Q) falling downstream sometimes quite dramatically, so that flow might not reach the next node and becomes 'asynchronous' (Figure 1).
b) The routing is taking place over a complicated (usually braided) channel bed morphology reflecting the history of earlier channel-forming events rather than an over-simplified hydraulic geometry.
c) The transported particles should be thought of ensembles rather than individuals, as

they move through the complex maze of passageways. Just as water moves vertically through soil, through a dense mesh of tortuous pathways, including macro-pores, so water and sediment move through a reach, controlled by the flow characteristics and the topography (with main channels analogous to macropores). So, too, as we treat water in soil by aggregative laws (such as D'Arcy's Law) or by diffusive laws (such as the diffusion equation) we have to accept that there is an acute need to treat the behaviour in a probabilistic rather than deterministic fashion.

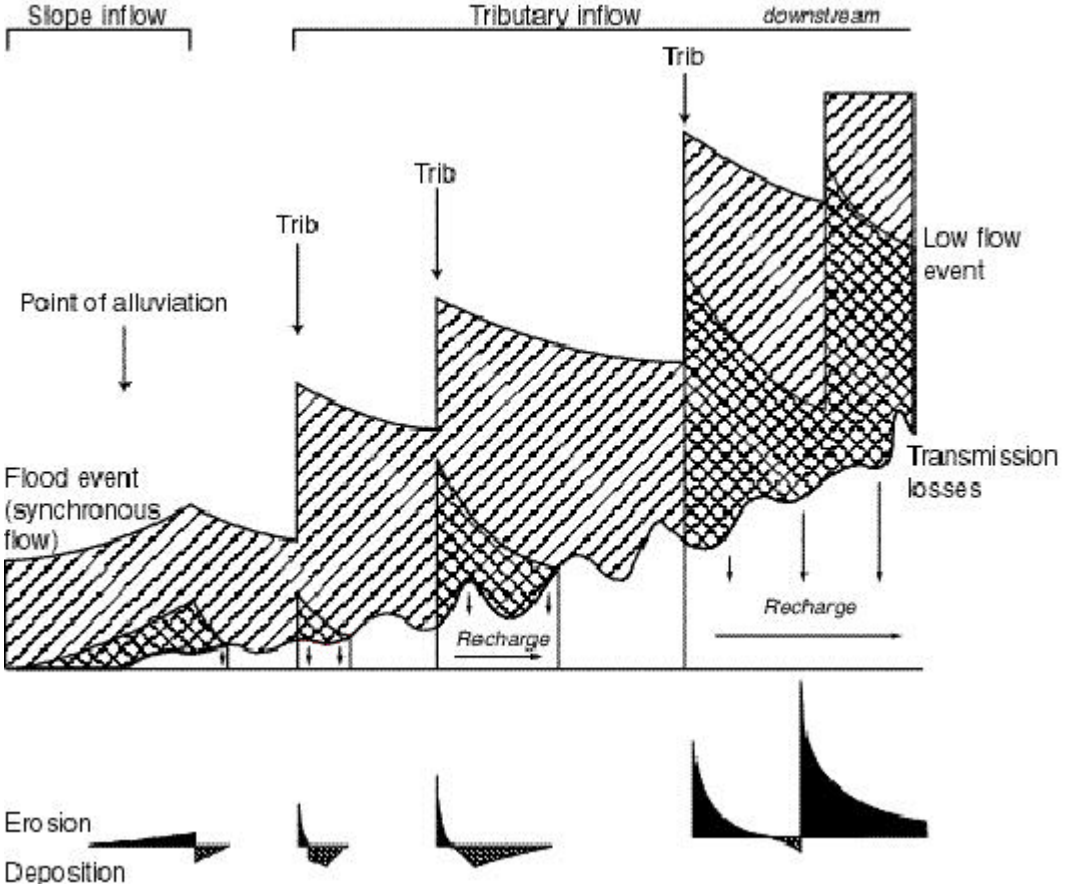


Figure 1: Schematic representation of node-and-link structure in ephemeral channel networks, emphasising sediment wedges (black) and transmission losses (shaded) in the main channel that is increasing in width in an oscillatory fashion (from Thornes, 1977).

Probabilistic routing

The unpredictable nature of the environment and the wide variety of particle attributes (size, shape, density etc) suggest that movement itself will be a probabilistic process (a stochastic process in time at a point), whereby a particle of sediment or a parcel of water changes position in a small amount of time. There is a whole range of models that describe such behaviour (Cox and Miller, 1966; Harr, 1977) ranging from the simplest Brownian Motion, wherein movement is entirely at random (e.g. dust in the atmosphere) and applied to single particles; through discrete Markovian processes where the next state (position) is conditioned only by the state (position) prior to

movement and movement occurs at fixed, regular intervals; to continuous Markovian processes in which the time between state transitions is also a random variable. The end member of this series are diffusion processes, where mass movement of ensembles of particles conforms to variations in particle concentrations (as described below) and as described by empirically-determined parameters.

We would expect routing to be determined strongly by bed topography and that the topography would equilibrate in relation to the movement. This leads to more deterministic modelling strategies. These have a long and distinguished history in hydraulics and their study and methodology is called fluid dynamics and the field of modelling using numerical solutions to differential equations is computational fluid dynamics (CFD), a highly refined set of mathematical procedures. Here two steps are involved in routing: set up the appropriate equations; solve them numerically or simplify them sufficiently so they can be solved analytically. Smith (1972) provided a solution to the routing of a water wave across a dry bed, using numerically solved differential equations that included transmission losses at the wave front.

In the MEDALUS research project, Richardson (1999) used the finite element procedure to determine flow characteristics at a junction of a major tributary and the main channel of the Rambla Nogalte in the province of Almeria, Spain. He also modelled the flow in a sand-bed and in a gauged-reach in the headwater area of the system.

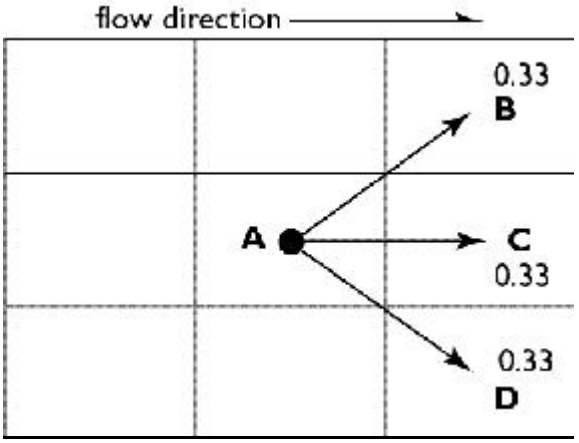


Figure 2: Basic idea of random walk model. Arrows indicate probabilities of movement at next step and. assumes equal probabilities in each direction.

Markov walks

In the same system, Shannon (1999) used the Markov Process in a random walk simulation to track hydrograph and sedigraph movement through a characteristic reach. The approach is very similar to that of Murray and Paola (1994), who allowed the 'parcels of water' to move according to local slopes in the channel bed. In the random walk simulation, Shannon allowed the 'parcels of water' to move in one of three downstream directions, straight ahead, down left or down right (Figure 2), according to equal or assigned probabilities. The particles thus realising a random walk arrive at the end of the channel reach in different numbers and at different times.

Figure 3 illustrates the frequency-time of arrival curve for elements arriving at the end of the reach with two different probability allocations. In Markov random walks, the banks are reflecting states and the end of the reach an absorbing state. Given the probabilities, analytical solutions can be obtained for the mean first passage time to, and the distribution of arrivals in, the absorbing state. The same strategy was used by Thornes and Morley (1972) to 'route' tourists through a road network in which decisions at road junctions were made according to the information provided there or on a purely random basis.

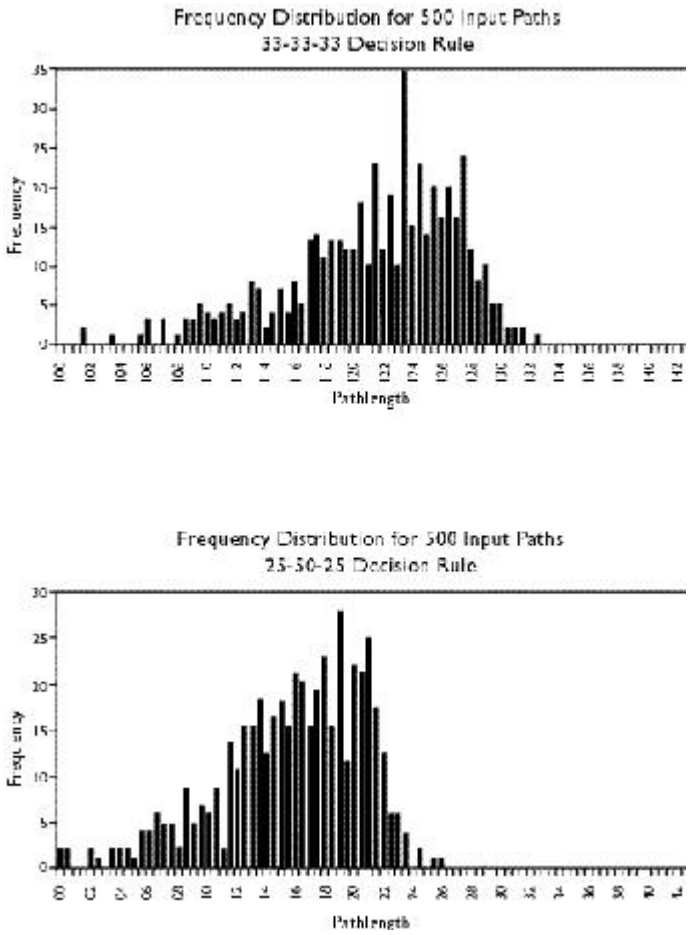


Figure 3: Results of random walks for model of Figure 2. Because each step represents on time period, the path length is also the time taken to pass through the reach, the first arrivals being at the left. Figure 3: Results of random walks for model) of Figure 2.Because each step represents on time period, the path.Simulations by J. Shannon with permission.

Diffusion routing

The logical end-point of the probabilistic scheme is to treat the mass of particles, in which an empirically determined diffusion coefficient fixes the flux rate between two positions in the system otherwise determined by the second difference in their concentrations in space, i.e.

$$\frac{\partial N}{\partial t} = D\frac{\partial^2 N}{\partial x^2} \qquad (1)$$

This is a famous equation that Einstein derived from his assumptions about Brownian particles. The formal connection between the discrete random walk and the continuous-diffusion equation (1) is of great importance. In this regard, Feller (with Beckenbach, 1961) noted that differential equations of the form (1) and derived from probabilistic assumptions represent a rather universal law governing the fluctuations of random variables summed over many independent components (Harr, 1977, p126).
I have used a discretised form of this equation, after Reece (1986) as follows:

$$D\frac{d^2y}{dx^2} = [(\frac{dy}{dx})_{i+1} - (\frac{dy}{dx})_{i-1}] \; / (x_{i+1} - x_{i-1}) \qquad (2)$$

To simulate the behaviour of 'slugs' of particles moving through a set of sections in reaches of the Rambla Nogalte, with the diffusion coefficient assumed to be a function of distance down reach. This assumption is based on the premise that movement is proportional to Q, where Q is the discharge per unit width and is a function of area down the channel, i.e.

$$Q = kA^p \qquad (3)$$

Wave routing and the traffic analogy

Figure 3 illustrates how this equation routes a 'slug' of particles through a reach after they have been dumped from a tributary at the head of the reach. The wave gets longer and flatter as it proceeds downstream under these model rules. Figure 4 shows the same result plotted in three dimensions. The initial condition (i.e. at the start) assumes a number of particles in each section. Otherwise, the differencing rule will produce a negative wave (hollow) that propagates downstream or upstream in a similar fashion.
Figure 5 shows how the wave of Figure 3 passes an observer, standing at section 16 (of 20) in the reach. It is a relatively simple matter to introduce (in the model) numbers of particles at each junction. Of course, in the real channel, the particles that occupy a section raise the bed, so we could use the height of the bed as a measure of the concentration of sedimentary particles. Then the height and the width of the wave depend on the cross-sectional shape of the channel where deposition is taking place. The idea of sediment in channel storage moving downstream has been used by Pickup, Higgins and Grant (1987) to trace the movement of mining waste dumped into the Fly River in Papua-New Guinea. Church (1999) used the concept to emulate the movement of glacial sediments downstream in headwater-glaciated rivers of British Columbia, Canada. In this case, the time that sediments were deposited in the river is well documented so that wave 'speeds' can be estimated. Conversely, if we know the 'speeds', we can trace the waves back upstream to find which tributary produced them, or which storm was responsible for them.

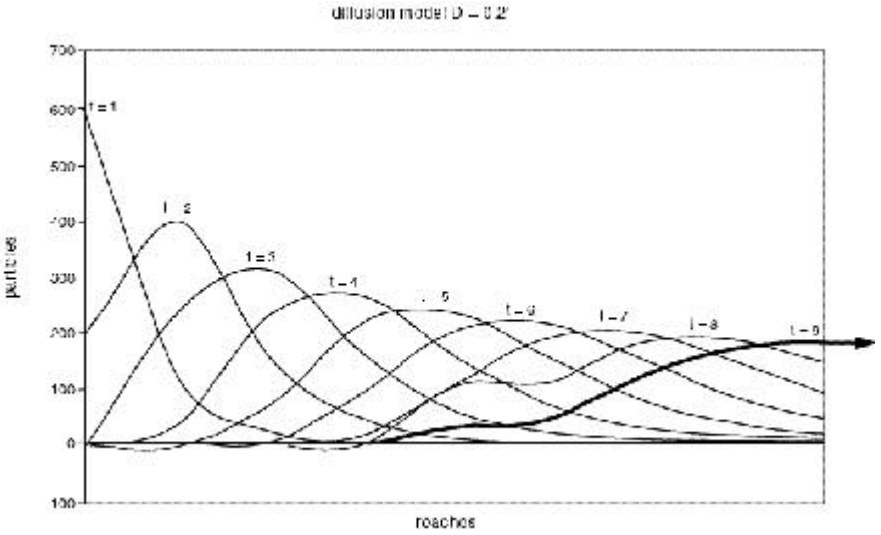


Figure 4: Routing of a "slug"entering the system and leaving at the right. Assuming that the slug is moved in the peak annual flow, the time unit (t) is in years.

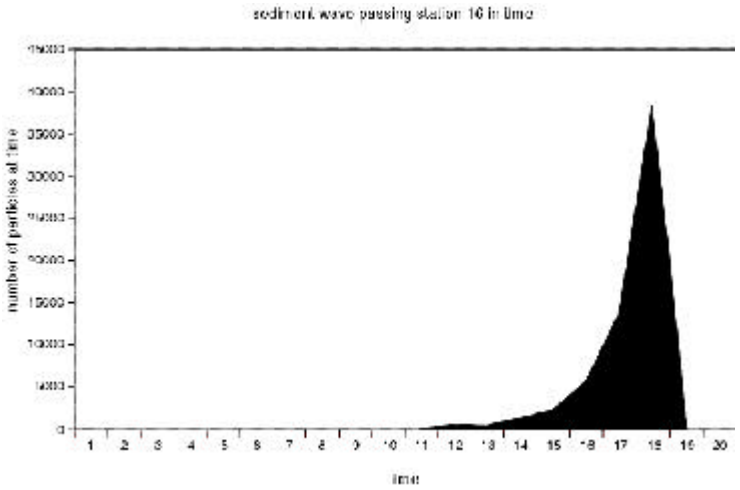


Figure 5: Wave passing section 16 (of 20) in a reach downstream of a tributary junction where it started.

In famous papers, Lighthill and Whitam (1955) and later Wooding (1965) used the traffic analogy to model waves in perennial rivers. The idea is shown in Figure 6. The axes are time and space and the lines on the diagram are therefore space-time trajectories of moving waves. Shallower lines are moving faster and, where two lines intersect, the later wave is superimposed on an earlier one (and so gets bigger). On motorways, traffic 'bunches' into 'waves' that can move up or down the motorway. In rivers, it is assumed that water or sediment waves can only move in the direction of flow (though sand dunes on the bed can and do move both ways). The bunching of vehicles on highways may be associated with local congestion due to accidental slowing of one vehicle (baby screaming in the back seat!) or to incoming traffic at junctions or slowing to observe an accident in the other lane.

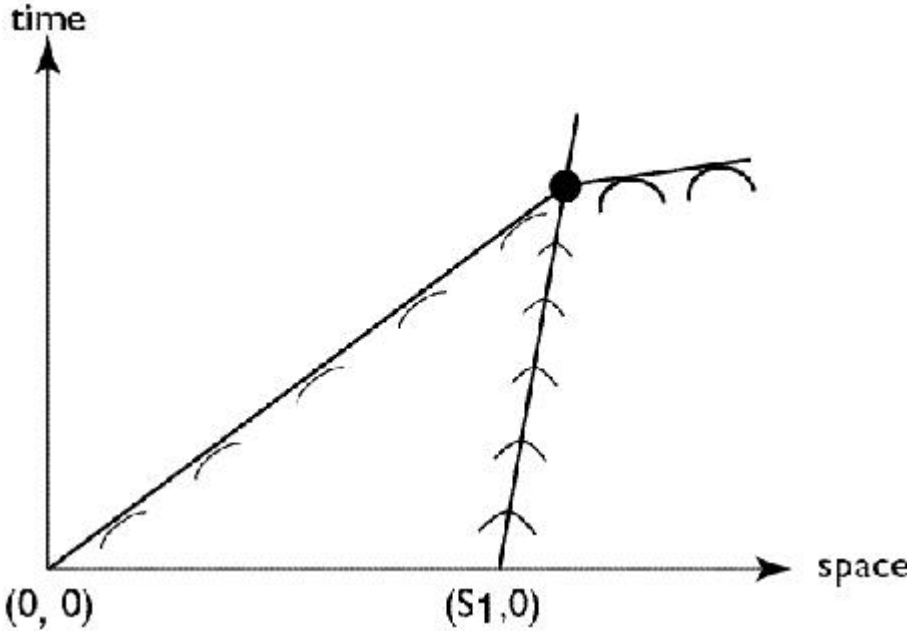


Figure 6: Concept of a wave moving through time (vertical axis) and space (horizontal axis).

Nye (1960) used the same concepts to demonstrate the effects of exceptional inputs of snow at the head of a glacier which subsequently formed a wave that, when propagated down-glacier, caused a surge at the snout of the glacier. The wave is a kinematic wave in physical terms and a simplification of the dynamic wave, described by the Navier Stokes equations and incorporating energy, friction and momentum effects. It is important to accept that the kinematic wave is a moving shape rather than a moving mass. Langbein and Leopold (1968) considered how the kinematic wave simplification could be used to explain the distribution of particles on river bar surfaces. The usual approach (Drew, 1996) is to set up the continuity equations for the mass forming the wave (change in height through time equals difference in space of input and output to the 'store' (a wave)) and to couple this to a process 'law'. In traffic, the process law is that the speed is a function of the density of traffic. Above a critical density, the velocity is the maximum possible velocity (Figure 7). Below this critical speed, the speed is given by:

for $p > p_c \quad u = ë\,(1/p - 1/p_{max})$ (4)

This produces a speed of zero at maximum congestion. These two equations combine to provide a partial differential equation which, when solved for known initial conditions and for given parameter values, yields the position in (future) time and space of the wave of water or 'slug' of sediments. This solution can be numerical or analytical. The analytical solution depends on the method of characteristics (Abbott, 1966) and the trajectories in space-time (Figure 6) are the characteristic trajectories along which the shape remains constant while translated. Luke (1966) used this method to describe the trajectory of a knickpoint, by assuming Scheidegger's 'law' that the

propagation of topography is a function of the local slope and discharge. This suggests that an appropriate model for the 'slugs' of sediment in ephemeral channel streams, arising from deposition at a node, could be that

$$\frac{dx}{dt} = kq^m s^n \tag{5}$$

With the variations in slope (s) being the main driver, with a wave front having a positive slope and the wave rear a negative slope. Some simulations using this model are shown in Figure 8.

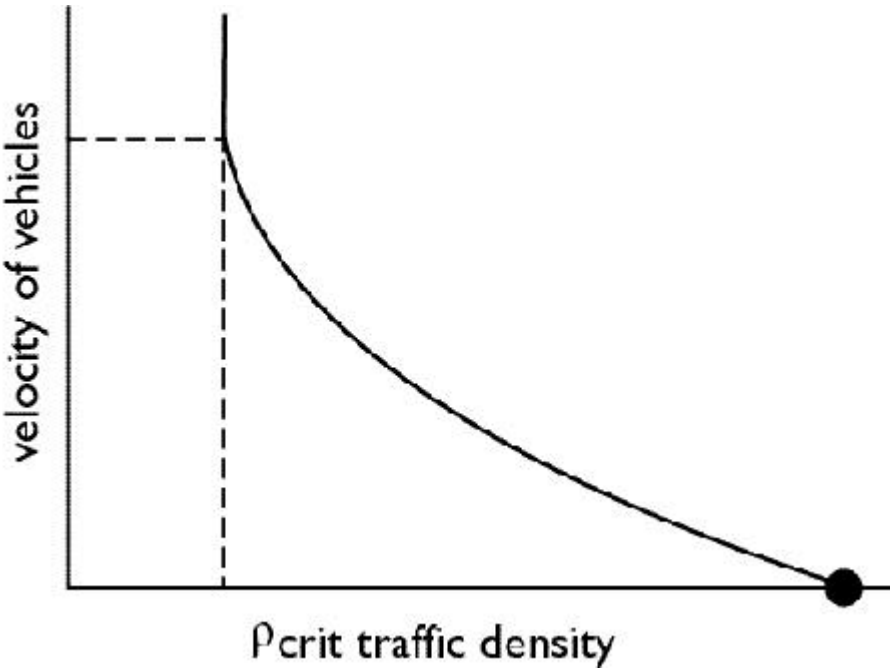


Figure 7: Relationship between velocity (y axis) and traffic density (x axis), illustrating that velocity falls as traffic density increases, until it eventually comes to a complete halt, bumper to bumper.

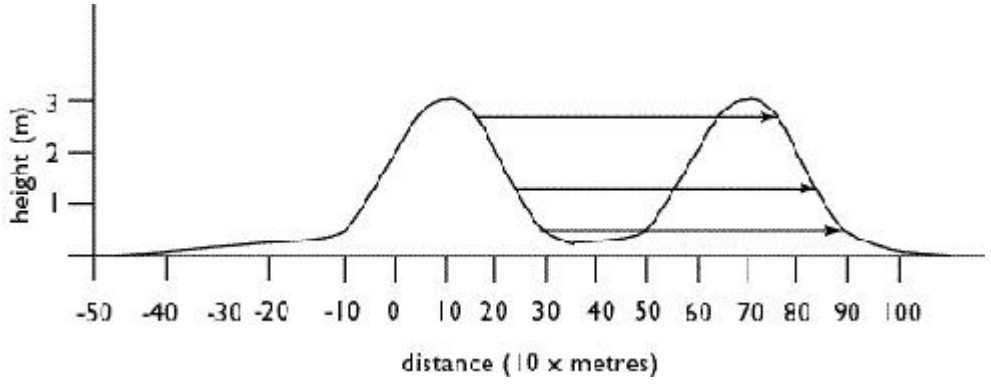


Figure 8: Simulations of a moving wave with u = f(h).

Implications for desertification

As the carbon dioxide, temperature and rainfall change, recharge to the main channels should:
a) reduce the existing sub-surface flow.
b) reduce the base-flow into the streams and recharge from surface transmission losses.
c) reduce the vegetation cover with important consequences or sediment transport and water movement.
Conversely, if the frequency and magnitude of storms increases, then the movements of existing sediments stored in the channels should substantially increase. A suitable test of the first hypothesis could be to examine the evidence from ephemeral channels whose flow has been constrained by headwater dam construction. It is well documented that, in such cases, saltwater incursion in the lowest reaches is an expected and observed outcome. Tests of the second hypothesis are not so easy, though rivers with changed catchment regimes could be examined.

Management implications

It is generally believed that channel management is best achieved through management of runoff and erosion on the hillslopes of the headwaters. Nevertheless, check dams will continue to be used because they are politically more acceptable and have become part of the standard 'lore' of civil engineering practice. In designing the location of such structures, the conservator needs to take account of:
a) *Local channel characteristics*. Are sediment waves 'waiting' to move in to the storage structure, reducing its capacity? If so, under what conditions of rainfall-runoff and how long will they take to propagate to the site?
b) What are the *network implications*? Is the upstream node being supplied by a well-connected tributary? What is happening in its catchment?
c) What are the historical implications? Are there large sediment wedges moving down-channel as a result of historically important floods (such as the great 1973 flood in south-east Spain)? Will works, such as borrow pits, trigger substantial movements of ancient sediments?
d) *Sensitivity implications*. Will small changes of inputs to the system be sufficient to create congestion and changes in sediment movement rates in the channel system? For example, how will the impacts of land use changes be felt in the channel?

Conclusions

Following a relatively long period of neglect of channels, the threat of desertification suggests more attention needs to be paid to the controls on their dynamical behaviour, especially at network and reach scales.

References

Abbott, M.B. 1966. An introduction to the method of characteristics. Thames and Hudson, London.
Bechenbach,E.F.Modern Mathematics for the Engineer, mMcGraw Hill Book Company, New York, 1961

Brandt, C.J. and Thornes, J.B. (Eds) 1996. Mediterranean desertification and land use. Wiley, Chichester. 554 pp.

Burke, S and Thornes, J.B. (1998). Actions taken by national governmental and non-governmental organisations to mitigate desertification in the Mediterranean. Concerted Action Report 1. ENVA líuyh n\ CT95-0183. Eur 18490EN. Commission of the European Union, Brussels.

Butcher, G.C. and Thornes, J.B. 1978. Spatial variability of runoff processes in an ephemeral channel. Zeitsch fur Geomorph. NF Suppl. Bd. 29, 83-92.

Church, 1999. A model for fluvial sediment transfer at geomorphological time scales. Proc. International Conference on Drainage Basin Dynamics and Morphology (Abstracts), Ed. Hassan, M.A., Jerusalem, May 22-29, 1999.

Cox, D.R. and Miller, H.D. 1965. The theory of stochastic processes. Methuen, London, 398pp.

Drew, D.A. 1993. Traffic flow theory. In Braun, M., Coleman, C.S. and Drew, D.A. (Eds). Differential equation models. Modules in applied mathematics, Volume 1, Springer Verlag, New York, 207-215.

Gupta, V.J. and Waymire, E.C. 1998. Spatial variability and scale invariance in hydrologic regeneralisation. In Sposito, G. (Ed) Scale dependence and scale invariance in hydrology. Cambridge University Press, 88-135.

Harr, M.E. 1977. Mechanics of particulate media. 517pp.

Langbein,W.B. and Leopold, L.B. 1968. River channel bars and dunes - the theory of kinematic waves. USGS Prof. Paper, 122L, 11-20.

Le Kach, J. and Schick, A.P. 1983. Evidence for transport of bedload in waves. Analysis of fluvial sediment samples in a small upland stream channel. Catena, 10(3), 267-280.

Lighthill, M.J. and Whitam, G.B. 1955. On kinematic waves. I Flood movement in long rivers. Proc. Roy. Soc. London, Series A, 229, 282-315.

Luke, J.C. 1966. Mathematical models of landform evolution. Jo Geophys. Research, 77(14), 2460-2464.

Murray, A.B. and Paola, C. 1994. A cellular model of braided rivers. Nature, 371, 54-57.

Nye, J.F. 1960. The response of glaciers and ice sheets to seasonal and climatic changes. Proc. Roy. Soc. London. Series A, 256, 559-584.

Pickup, G., Higgins, R.J. and Grant, I. 1983. Modelling sediment transport as a moving wave. The transfer and deposition of mining waste. Jo Hydrology, 60, 282-301.

Reece, G. 1986. Microcomputer modelling by finite differences.

Reid, I and Laronne, J.B. 1995. Bed load sediment transport in an ephemeral stream and a comparison with seasonal and perennial counterparts. Water Resources Research, 31, 773-781.

Rice, S. 1999. The river basin sediment network. Proc. International Conference on Drainage Basin Dynamics and Morphology (Abstracts), Ed. Hassan, M.A., Jerusalem, May 22-29, 1999.

Richardson, R. 1999. Final report of MEDALUS III, Project 4: A framework for understanding and modelling fluvial processes. MEDALUS, Kingís College London.

Shannon, J. 1999. Final report of MEDALUS III, Project 4: A framework for understanding and modelling fluvial processes. MEDALUS, Kingís College London.

Smith, R.E. 1972. Border irrigation advance and ephemeral flood waves. Proc. American Society of Civil Engineers, 98 (IR2) 289-307.

Thornes, J.B. 1977. Channel changes in ephemeral streams:observations, problems and models. In Gregory, K.J. (Ed.) River channel changes, Wiley, Chichester, 317-

Thornes, J.B. 1991. Environmental change and hydrology. In Giraldez, V. (Ed), El agua en Andalucia III, University of Cordoba, Cordoba, 555-570.

Thornes, J.B. 1994(a). Catchment and channel hydrology. In Abrahams, A.D. and Parsons, A.J. (Eds) Geomorphology of desert environments, Chapman and Hall, London, 257-288.

Thornes, J.B. 1994(b). Channel processes and forms. In Abrahams, A.D. and Parsons, A.J. (Eds) Geomorphology of desert environments, Chapman and Hall, London, 288-318.

Thornes, J.B. and Morley, C.D. 1972. A Markov decision model for network flows. Geographical Analysis, 180-191.

Wooding, R.A. 1965. A hydraulic model for the catchment-stream problem. I Kinematic wave theory. Jo of Hydrology, 3, 254-267.

Woolhiser, D.A. and Todorovic, P. 1974. A stochastic model of sediment yield for ephemeral streams. U.S. Dept of Agriculture, Miscellaneous Publications, No. 1275.

ADVANCED TECHNOLOGIES TO SUPPORT MITIGATION ACTION PLANNING
INTEGRATING REMOTE SENSING, FIELD OBSERVATION AND MODELLING

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Abstract. In the context of the paper remote sensing and regional physical modelling are referred to as advanced techniques. At the Mediterranean-wide scale the MEDALUS project has been working to produce a Regional Degradation Index (RDI), from a physically-based model combining climate, soil and erosion processes with actual vegetation cover being derived from remote sensing images. Combining climate scenarios with satellite monitoring of vegetation cover has the potential to give an early warning of change, but the system requires links to be made with ground based observations and high resolution remote sensing data (e.g. Landsat-TM, SPOT, IRS) that have to be improved for the purpose.
Looking at the physical aspects of desertification, we must not lose focus of the fundamental role which land-use, i.e. human activity is playing in the problem. Land degradation is mainly a socially controlled problem because it is considered resulting mainly from land-use. In conclusion the social dimension of the land degradation problem must not be ignored, even though the definition of extent, severity and dynamics of the problem has to be undertaken by natural science.

Key words: Remote sensing, physical modelling, early warning

Introduction

Land degradation processes which imply a reduction of the potential productivity of the land (e.g., soil degradation and accelerated erosion, reduction of the quantity and diversity of natural vegetation) are widely spread in the Mediterranean basin. In continuation of a long history of human pressure upon land resources, the main environmental impact results from interactions between climatic characteristics and ecologically unbalanced human interventions which, in the sense of recent definitions e.g. of UNEP (1991) or of the UN-CCD (1994), are often summarised as 'desertification processes'. An overview of the ecological, physical, social, economic and cultural issues which are collectively contributing to the increasing risk of further degradation of Mediterranean lands has been summarised by Perez-Trejo (1994) and more recently by Brandt & Thornes (1996).
The complexity of the pressures and processes leading to dry land degradation and finally desertification may be highlighted by Figure 1.

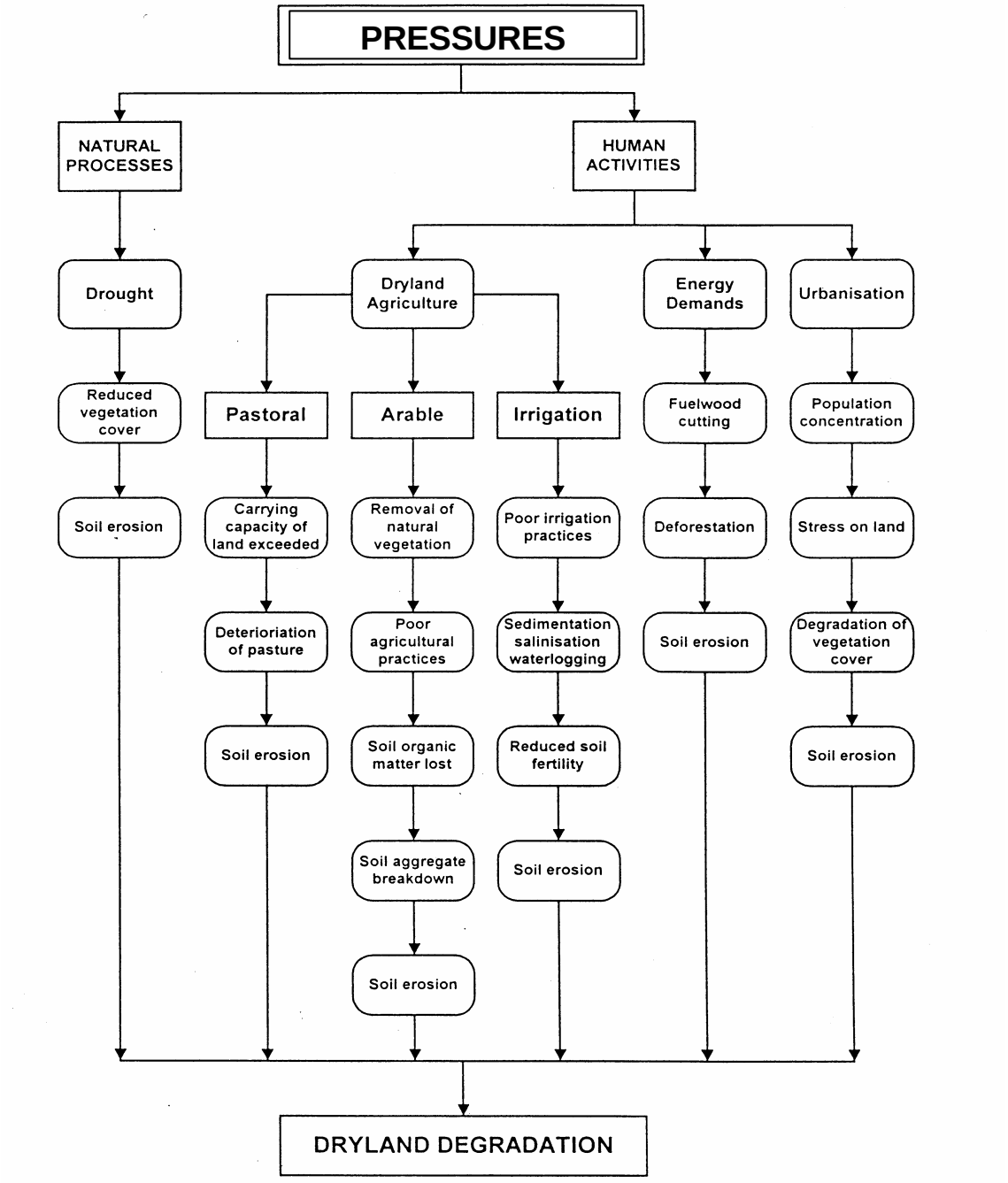


Figure 1: Causes and processes leading to dry land degradation (after Kemp 1990).

From the before mentioned studies and Figure 1 it can be concluded that the most important physical indicators of land degradation in the Mediterranean basin are related to the destruction of vegetation cover and to soil degradation being the final consequence of natural and human impacts.
As land degradation is defined by its consequences we further conclude that it is these consequences that have to be detected and quantified using spatial data. In a regional context levels of land degradation can only be inferred from the remote measurement of

the spatial and temporal dynamics of landscape attributes related to soil and vegetation. A comparison between used and unused landscapes is important. For mitigation action definition and planning however not only realistic assessment of the land degradation status is required, but also a rationally based method for estimating the sensitivity of a landscape to changes in land use or climate and scenarios of possible developments.
Against this background remote sensing and regional modelling have been considered important elements of advanced early warning systems providing information on long term desertification trends and risk scenarios from regional to catchment scale. These systems can be seen as the outermost shell for an explicitly nested approach to determining environmental problems and to define mitigation actions. As the scale changes, the dominant controlling factors also change e.g. from climate, land cover and macro-economic data at continental scales to considerations of local topography, soil conditions and individual agricultural practice. The scientific rationales at these widely different scales should remain compatible. In this way parameters of remote sensing and regional indicator models should be derived from and related to more detailed catchment or plot models in a nested approach.
However remotely sensed information and modelling by themselves are not enough. These dynamic tools have to be integrated with other information of specific relevance, this integration being entirely controlled by the scientific understanding of the relevant landscape processes. Data cannot substitute for understanding in the processes of degradation. Without understanding monitoring will be meaningless, without monitoring understanding will be stunted and land use management will be blind (Graetz, 1996)
Against this background research projects such as MEDALUS III, DEMON or MODEM have been working towards the development of integrated and interdisciplinary concepts for monitoring and early warning tools linking remote sensing, field research and modelling

Integrated methodology concept

The basic idea followed in the above-mentioned EC funded projects is to define and demonstrate a pre-operational desertification monitoring system supporting early warning of desertification risks. The system should account for the regional scale dimension of desertification by a co-ordinated definition, development and implementation of standardised processing chains, data exploitation methods, data management systems and products to be delivered to the end users.
In particular it is proposed to use an integration of regional ecological and physical modelling with information from operational earth observation (Landsat, SPOT) and meteorological satellites (NOAA-AVHRR) to assess and repeatedly monitor regional scale indicators of sensitivity to desertification. In contrast to meteorological approaches which concentrate on the exchange of matter, momentum and radiation between the earth's surface and the atmosphere, we would like to emphasise the importance of thematic interpretation pathways for the characterisation of actual land surface conditions with satellite data.
Consequently the key concept of the proposed remote sensing based methodology is to link from bottom up spectral remote sensing with ground physical and ecological

parameters (e.g. soil organic substance, soil mineralogical components, vegetation cover etc.) in order to obtain spatialised information on land ecological conditions and their behaviour over time as shown in Figure 2.

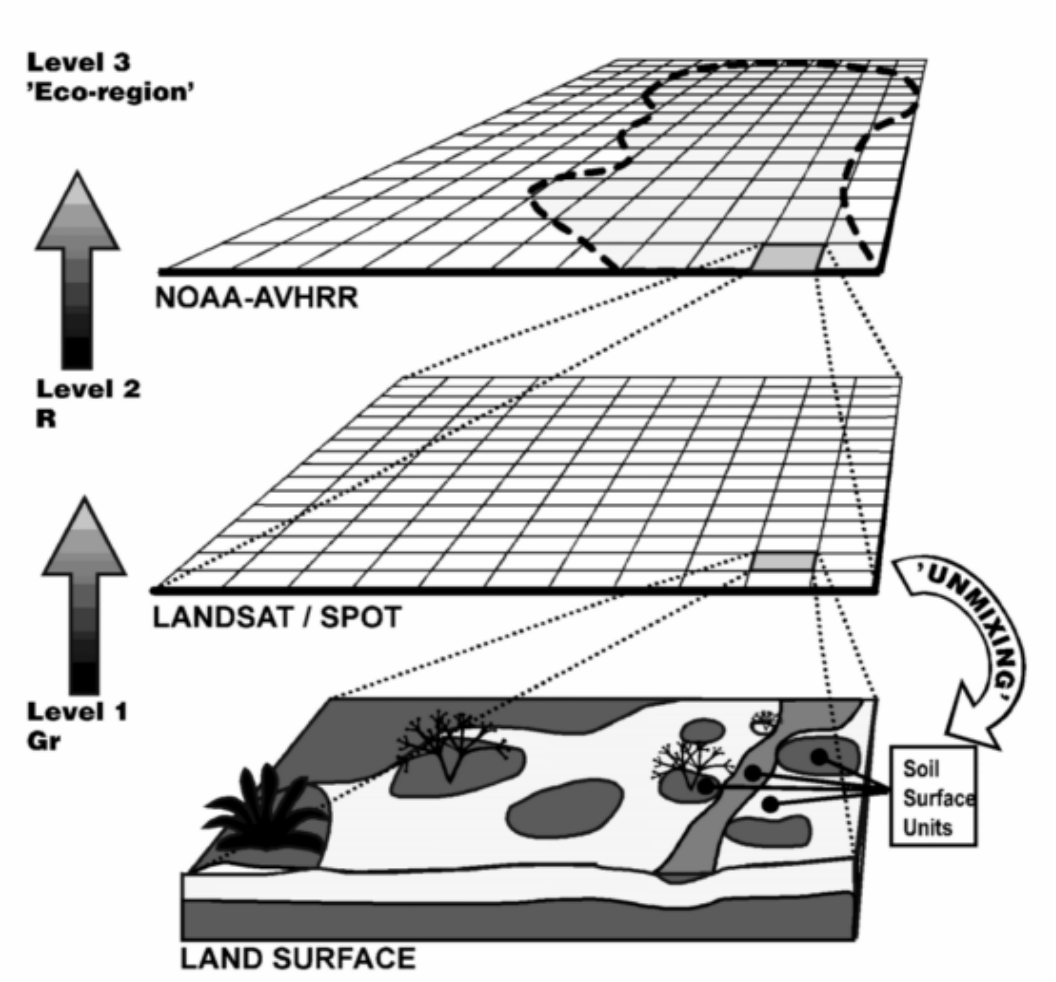


Figure 2: Scheme of the proposed bottom-up approach.

It should be noted that this bottom-up approach has to be seen in the context of algorithm and method development and calibration, whereas the final application is from top-down. Starting from coarse scale monitoring and modelling areas anomaly areas should be identified and then further investigated with higher resolution and intensity.

Within DeMon 1/2 it could already be shown that the degradation of the permanent semi-natural vegetation and the erosional state of soils are tangible items which can be observed with satellite systems (Lacaze et al., 1996). A standardised approach based on spectral mixture analysis (SMA) was developed, suited to be routinely applied to large regions and to identify environmentally sensitive areas. In parallel, it was demonstrated that inputs from remote sensing data can be used to drive and underpin physical models,

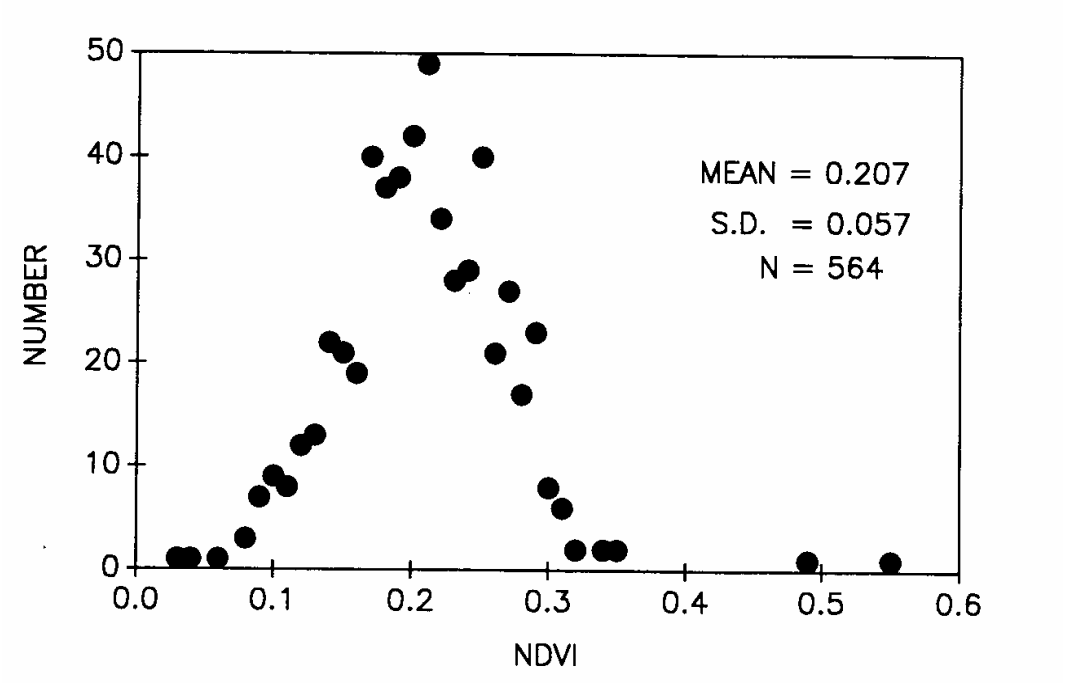
such as we need to evaluate soil erosion risks in environmentally sensitive areas (e.g., Kirkby et al., 1996). Soil erosion, soil water balance and ecological models (vegetation dynamics and productivity) indeed provide the link to the actual processes which might be implicated by the detected land surface changes.

Technical considerations

At the Mediterranean-wide scale the concept is aiming to produce a Regional Degradation Index (RDI, Kirkby et al 1996), from a physically-based model combining climate, soil and erosion processes with actual vegetation cover being derived from AVHRR images. Combining climate scenarios with satellite monitoring of vegetation cover has the potential to give an early warning of change, but the system requires links to be made with ground based observations and high resolution remote sensing data (e.g. Landsat-TM, SPOT, IRS) that have to be improved for the purpose.
Against this background spectral mixture analysis (SMA) techniques are applied to both Landsat-TM and NOAA-AVHRR data in order to derive vegetation abundance as a relatively direct equivalent of vegetation cover density rather than providing land cover classes for indirect cover density estimates. This choice of technique was made because SMA is considered to provide a physically based measure of vegetation cover which is expected to be more directly related to cover density and less influenced by the spectral response of the soil background than conventional broad band vegetation indices (e.g. NDVI). However, the SMA approach being well established for the use with Landsat-TM needs fundamental adaptations for its application to AVHRR data.
In addition SMA opens also possibilities to identify relative levels of soil degradations (Hill et al., 1995)

Rationale for using SMA

The classical approach to assessing vegetation cover with both Landsat-TM and NOAA-AVHRR has been the use of vegetation indices (VIs, mostly the NDVI), which, however, have well known limitations in detecting thin vegetation cover as widely appearing in the Mediterranean Basin. For instance Price (1993) has shown that bare soil spectra alone may occupy already the lower 30% of the usable NDVI value range between 0 and 1 (Figure 3).



(From Price, 1993)

Figure 3: Histogram illustrating the number of soil spectra having given values of NDVI, at intervals of 0.01. The spectral data are from 564 spectra contained in the Purdue University soil spectral data base.

Much concern has also been expressed about the sensitivity of VIS/NIR vegetation indices to the state of the atmosphere, illumination and observation geometry and, in particular, to the background reflectance of soils and rocks (e.g., Huete et al., 1987; Satterwhite and Henley, 1987; Smith et al., 1990). Although some of these disadvantages can be compensated by the use of atmospheric corrections and/or by compositing a number of days of data, several alternative indices have been proposed, which attempt to compensate for most of atmospheric and illumination conditions and soil background reflectance. But also new indices such as the GEMI (Pinty and Verstraete, 1992) or the SAVI (Huete 1988) have not really proven to overcome fundamentally the major variation of band-ratio indices, due to the background reflectance of soil and rock surfaces. In view of these undesired properties it would be preferable to use an approach which subtracts or corrects for the contribution of soil reflected radiation instead of accepting the measurement uncertainty as expressed in Figure 3.

In this context spectral mixture analysis (SMA) has become known as one of the most promising approaches. It has been successfully applied by several research groups (e.g. Smith et al., 1994, Hill et al., 1995, Melia et al., 1997) to reduce the detection limits of sparse vegetation on Landsat TM images in areas with spectrally diverse substrates. The results clearly show that the spectral resolution of TM is setting a kind of minimum limit to identify soil conditions and vegetation density at the local scale and thus a direct application of this promising approach to the 2 reflective channels of AVHRR is not the best choice. Nevertheless, a modified approach adapted to the characteristics of the

AVHRR system has been defined and tested on data covering a number of test sites in the Mediterranean Basin..

The 'mixing paradigm' provides a type of image enhancement which is not only intense but also physically meaningful (Craig, 1994). Its objective is of course to isolate the spectral contributions of important surface materials ("endmember abundance") before these are edited and recombined to produce thematic maps (Adams et al., 1989).

Spectral mixture analysis (SMA) assumes that most of the spectral variation in multi-spectral images is caused by mixtures of a limited number of surface materials, and it attempts to model the multispectral reflectance ρ as a mixture of representative 'prototype' spectra, the so-called 'spectral endmembers' (i.e., vegetation, soil and bedrock components, 'shade' as an illumination component, etc.) which have to be known or to be determined from the image context.. Linear mixing within the footprint of a multi-channel spectrometer or imaging sensor further assumes that the surface components are large and/or opaque enough to allow photons to interact with only one component, i.e. the radiative transfer processes are additive. Spectra can then be 'unmixed' by inverting the linear mixing equation

$$R_i = \sum_{j=1}^{n} F_j \times RE_{ij} + \varepsilon_i \quad and \quad \sum_{j=1}^{n} F_j = 1$$

through a least squares regression, while constraining the sum of fractions (i.e., the proportional weights) to one; R_i denotes the reflectance of the mixed spectrum in band i, RE_{ij} the reflectance of the endmember spectrum j in band i; F_j is the fraction of endmember j, and ε_i the residual error in band i. A unique solution is possible as long as the number of spectral components (endmembers) does not exceed the number of bands plus one.

This forms the arithmetic basis for SMA of both Landsat-TM and AVHRR, although the newly developed AVHRR approach is based on different physical assumptions.

Satellite data pre-processing

Geometric, radiometric and atmospheric corrections of the satellite data constitute a pre-requisite if we intend to apply physically based spectral models and need to compare the behaviour of remotely sensed indicators over time. This pre-processing of satellite data can be considered the most operational step in the remote sensing processing chains. But nevertheless it is time consuming, computationally intense and its quality is decisive for the level of accuracy and transparency of information extraction.

In principle the radiometric pre-processing includes the same procedures for both types of satellite data we used. Engineering data about the detector sensitivity (i.e., calibration coefficients) allow us to reconvert encoded image grey values into measured radiance, and radiative transfer calculations can be used to correct for atmospheric effects, such that the surface-reflected radiance is restored from the satellite-measured signal. Dividing this term by the down-welling solar irradiance provides us with an important primary parameter, which is termed 'bi-directional reflectance' ρ and is a physical property of the observed target.

However, the different specific radiometric and geometric characteristics of Landsat-TM and NOAA-AVHRR imply in practice quite different approaches to the implementation of the corrections and also to the level of accuracy that can be achieved.

High resolution satellite data

Today, we are in the favourable situation that several radiative transfer codes are available which, if constrained with the same atmospheric parameters, provide consistent results (e.g., Conel et al., 1988). Reflectance factor retrievals from the Landsat TM bands have been achieved with an accuracy of ± 0.005 to 0.02 (Moran et al., 1992; Markham et al., 1992), and it is important to note that this level of precision can also be accomplished when the atmospheric parameters are estimated from scene data itself (Hill and Sturm, 1991; Hill and Aifadopoulou, 1990) by relating the measured at sesnor radiance to reference targets of known reflectance. The major problem in retrieving reflectance factors from satellite data lies in the sensitivity to the absolute radiance calibration of the sensors.

In-flight calibrations for Landsat-TM and SPOT data are conducted at various high-reflectance sites which is useful for determining at least an absolute radiometric calibration gain and monitoring the sensor degradation with time (e.g., Slater et al., 1987; Thome et al., 1993).

Although the coefficients are not continuously updated, they are at least valid for specific periods of the sensor's lifetime. This allows to follow simplified pathways which do not require that each individual scene is radiometrically corrected through radiative transfer calculations (see figure below). It is considered sufficient to apply atmospheric corrections only to reference scenes from so-called 'periods of known calibration', and to routinely adjust the radiometry of earlier or later image acquisitions with reference to pseudo-invariant surfaces in the scenes (Hill et. al., 1995).

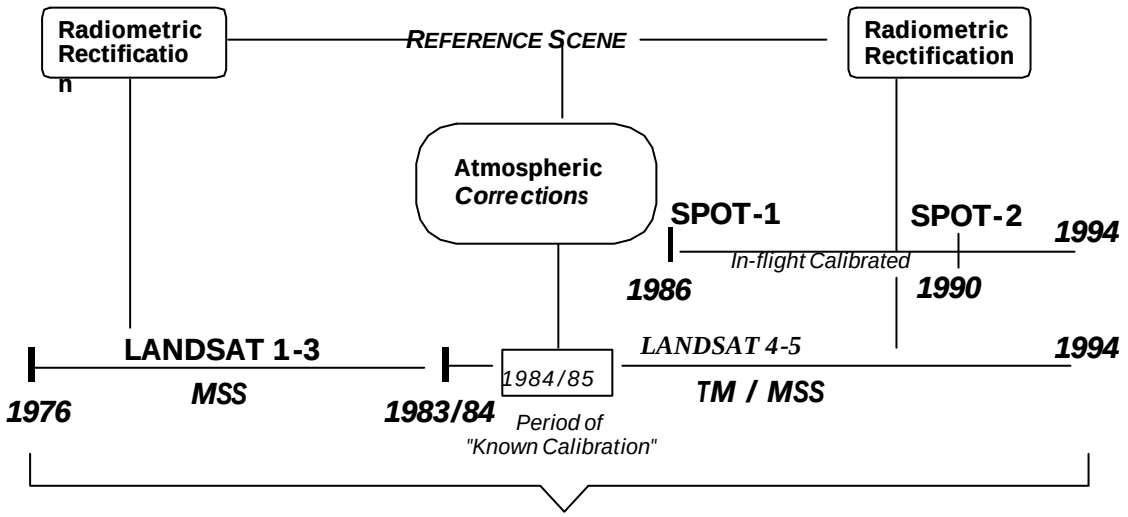


Figure 4: Radiometric rectification pathways for the analysis of Landsat and SPOT time series (Hill et. al., 1995).

Based upon these consideration sets of stable bright and dark targets in the available Landsat-TM scenes can be identified, of which the reflectance can reliably be assessed by comparison and spectral matching with ground radiometric measurements stored in spectral data bases. These targets can be then used as pseudo invariant targets in the before-described sense.

Then the following processing steps are applied:

- Calibration of DNs to at sensor radiance
- Estimation of atmospheric parameters from the scene using a modified "5S" atmospheric model (Tanre et al., 1990) and radiative transfer calculation for retrieval of surface reflectance.
- Geo-referencing to UTM co-ordinates
- For selected areas, where a digital elevation model is available also the topographic illumination effects may be considered in the radiometric transfer calculations.

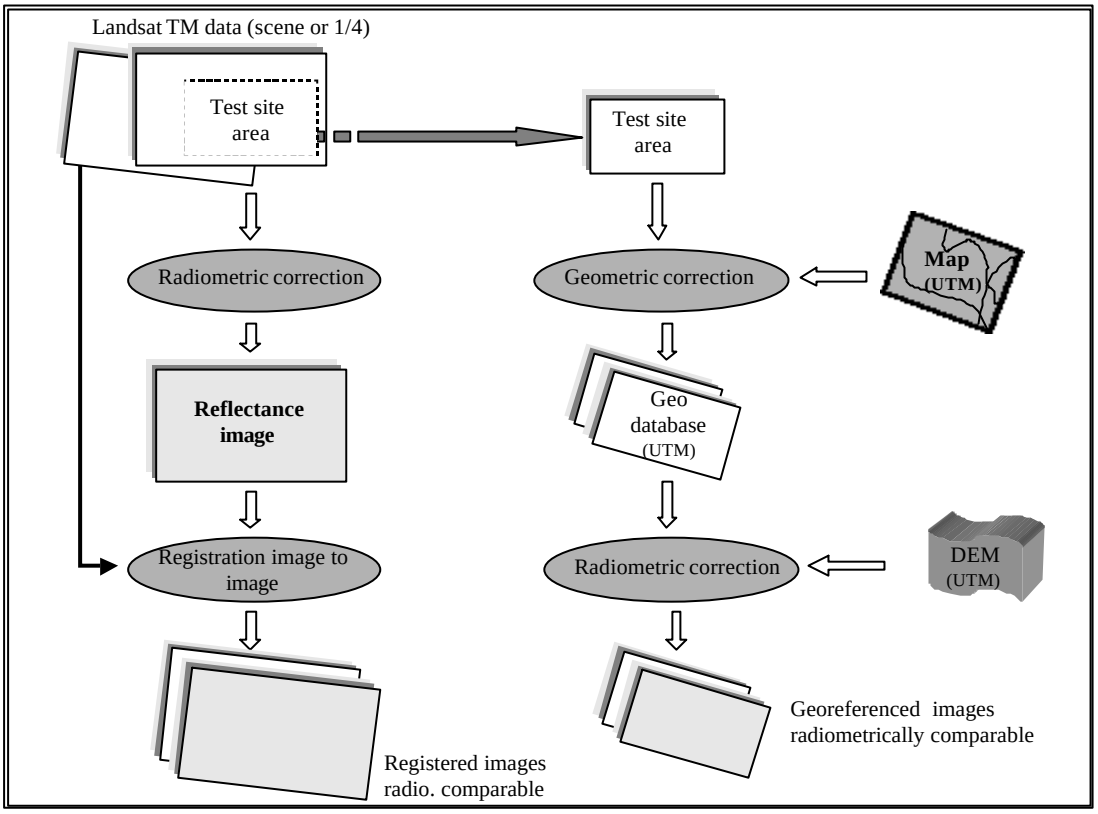


Figure 5: Schematic flow-chart of pre-processing steps applied to Landsat-TM data.

NOAA-AVHRR data

Even after accurate radiometric calibration and geometric correction multiple orbits of AVHRR data must be pre-processed before they can be used for land cover mapping. This is because the surface remotely sensed response is affected by a variety of external factors (e.g. cloud cover, variable sensor response over the wide AVHRR field of view) and intrinsic surface variations. Compositing procedures are commonly used in an attempt to reduce external factors and intrinsic surface variations (Roy 1997).

The utility of AVHRR data is reduced by a variety of non constant factors that include variable sensor response over the wide AVHRR swath (approx. 2500 km) and cloud and atmospheric contamination. This highly variable sensor response is caused by angular sensing and strong illumination variations across the scanned field of view combined with the anisotropy of reflectance from most natural surfaces and the atmosphere. Parametric correction for these effects would require a comprehensive knowledge of the

scene inherent surface and atmosphere bi-directional reflectance properties, which are not usually available. Other than in the case of Landsat-TM, this information cannot be assessed directly from the scene itself due to the difficulty to identify large homogenous reference fields of known surface reflectance (several pixels of 1x1 km size) and the highly variable sensing geometry across the image and between different orbits.
A practical and common approach to reduce these problems and to improve the utility of AVHRR data is to apply a compositing procedure to a time series of co-registered data (Holben, 1986). Compositing criteria have included the maximum NDVI, maximum surface temperature (Ts), minimum scan angle, differences in single channel reflectance and combinations of these.
Given these constraints standard pre-processing may be performed as follows:

- Calibration: Correction for the differences of sensitivity between the NOAA AVHRR sensors and the signal degradation over time.
- Cloud Detection: To identify cloud contamination in the data set.
- Atmospheric Correction: application of average standard atmosphere parameters for molecular scattering and absorption.
- Geometric Registration: To remove geometric distortion resulting from inaccurate sensor orbital information.
- Renavigation: Updating the orbital information and rewriting the corrected geographical data back into the data set.
- Calculation of the daily normalized difference vegetation index (NDVI).
- Calculation of the surface temperature (Ts).
- Generation of the monthly maximum composites for NDVI and Ts

The normalized difference vegetation index is calculated from daily NOAA-AVHRR data (channel 1 - red; channel 2 - near infrared) according to the equation:

$$NDVI = (C2 - C1) / (C2 + C1)$$

C1 = reflectance values of channel 1
C2 = reflectance values of channel 2

To derive the surface temperature data set the “Split Windows” algorithm according to Price (1984) can be applied to the brightness temperature values of channel 4 and channel 5.
This empirical method models the surface temperature (Ts) in a way that

$$Ts = [T4 + 3.33 \times (T4 - T5)] \times [(3.5 + e4) / 4.5] + 0.75 \times T5 \times (e4 - e5)$$

Ts = surface temperature

T4 = brightness temperature of channel 4
T5 = brightness temperature of channel 5
e4 = surface emissivity of channel 4
e5 = surface emissivity of channel 5

where the surface emissivity is set to an estimated average value, respectively differences in surface emissivity are not taken into account.

In a further step the maximum values per month for each pixel are extracted from the daily data in order to derive monthly maximum value composites for NDVI as well as Ts.

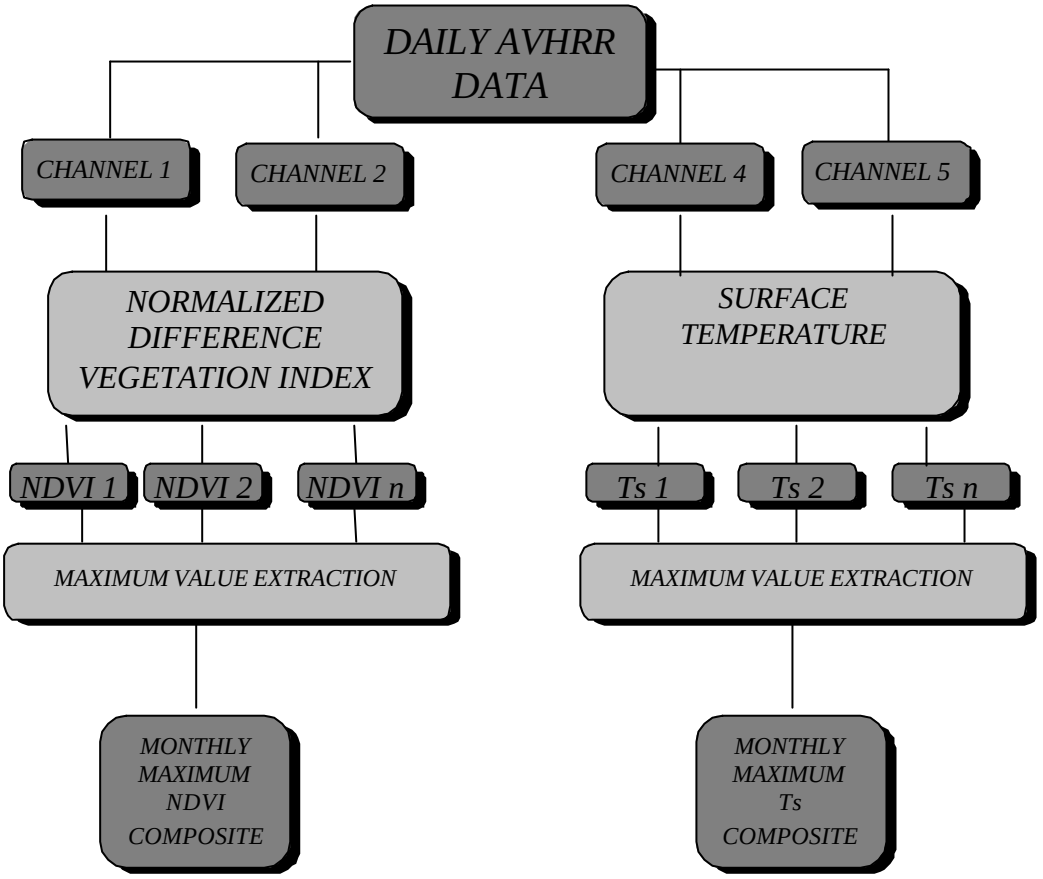


Figure 6: Flow chart for the derivation of NDVI and Ts maximum value composites.

RDI modelling

The modelling comcept is based on the use of a 1-dimensional hydrological model for areas of 1-100 km^2, which provides a dynamic estimate of potential vegetation and organic soil bio-mass based on land use and monthly climate. Vegetation cover is then used as to define erosion thresholds in the context of local climate (mainly the distribution of extreme rainfalls), relief and soils. Susceptibility to salinisation is similarly defined in terms of climate and soils, although with different functional dependence. These simulations are compared with actual land cover from remote sensing to show the extent of current perturbation by human impact. The model

provides a rationally based method for estimating not only current relative levels of desertification but also the sensitivity to changes in land use or climate. Figure 7 shows in schematic the required data sources and outputs.
The approach to RDI's has been applied so far primarily for soil erosion by water, for which the detailed methodology has been most fully developed.
The vegetation cover may be obtained as a potential cover, using a growth model as outlined in Figure 8, based on evapotranspiration and water use efficiency having the advantage of allowing soil organic matter to be estimated at the same time as vegetation bio-mass. However, it is recognised that vegetation is strongly influenced by human activity (e.g. cropland, grazing and fire management etc.) so that the use of remote sensing images may be more valid. Atmospherically corrected mosaics of AVHRR data of 1 km resolution are being used to give periodical values (e.g monthly or 10 days intervals) of NDVI and surface temperature (Ts), which can be used to estimate land cover and/or bio-mass. Future remote sensing systems such as VEGETATION, MERIS and MODIS may help to retrieve also estimates of soil organic matter and other soil properties.

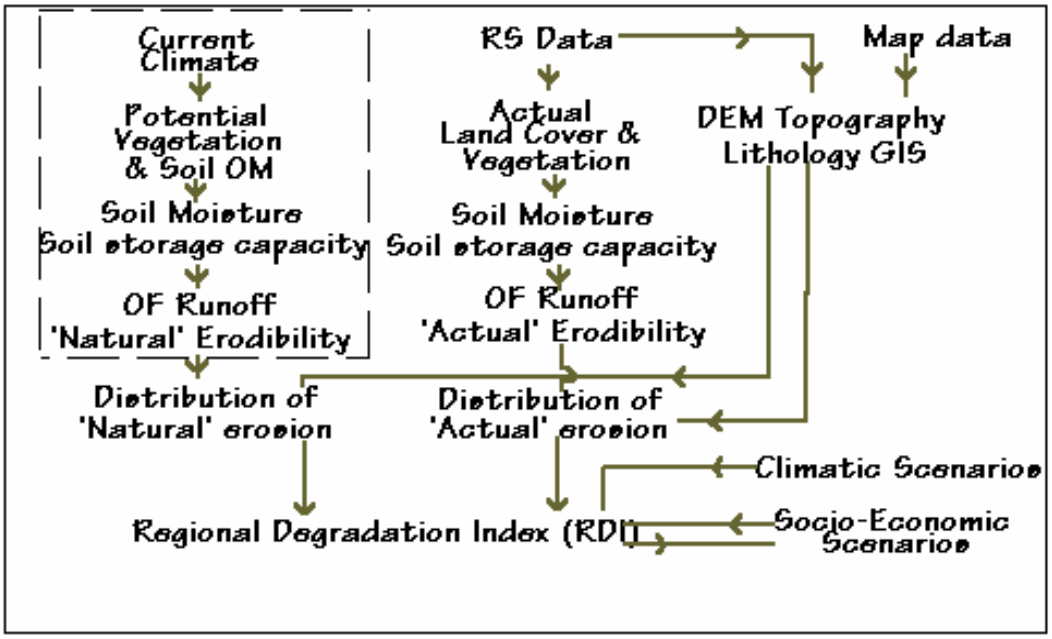


Figure 7: Scheme of the required data sources and outputs fo the RDI model.

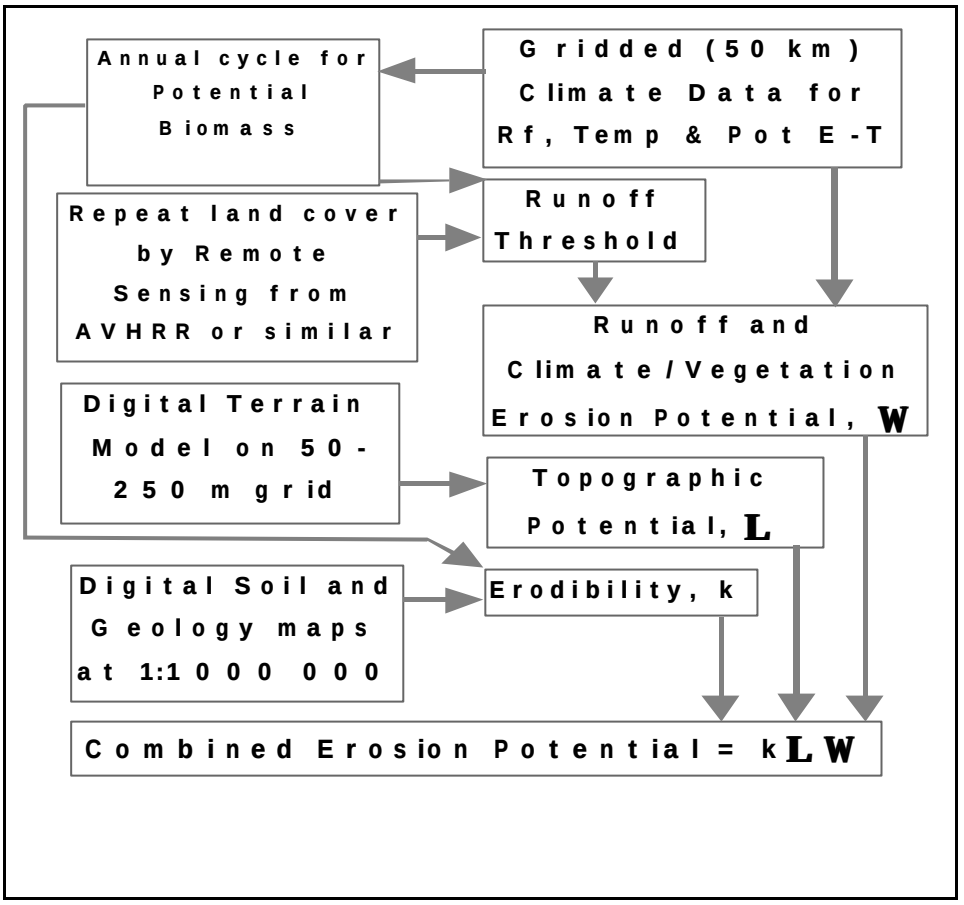


Figure 8: Data for estimating erosion.

Figure 8 outlines the data required for estimating erosion risk in the RDI framework and the outputs produced. The monthly climatic data is used to both generate runoff and grow the bio-mass at each given location. The developing bio-mass produces organic matter, which decomposes and is added to the soil column. The soil moisture storage threshold of this soil column must be exceeded before runoff is generated. The runoff then accumulates linearly down-slope with the assumption of a second power law for sediment transport.

Provisional results and outlook to future developments

Based on the pre-processed time series of satellite data covering test sites throughout the Mediterranean region, trends in site specific long-term (15-20 years) vegetation dynamics can be established by change detection techniques such as regression analysis (see also Roeder et. al., 1999 this report). The same is possible at much higher temporal resolution at coarser scale, however covering the entire Mediterranean Basin. These temporal profiles of vegetation cover changes are a core dynamic input to the RDI model that may be calibrated against this input by hind-casting (i.e. retrospective run of the model with historical climate records). Upon this basis the model may then be used

to produce scenarios of erosion risk change to be used as early warning signal in mitigation planning.

Initial runs of the model forecasting the development from the present time to the year 2090 have been performed within the MEDALUS III project at a resolution of 1 km.

Current erosion levels produce sediment yields, which have been found to be within some of the highest yield categories globally. Erosion levels are forecasted to increase considerably over the next 100 years as a result of climate change. This is particularly true across the Iberian peninsula. It should be borne in mind that the erosion levels forecast are natural levels and so factors which cause further increase, such as anthropogenically induced land use change, will exacerbate an already serious problem.

Parts of the Mediterranean are already suffering from severe degradation. The RDI forecasts suggest a scenario of increasing degradation, which brings not only environmental but also socio-economic costs. The degree of severity is neither temporally nor spatially uniform and therefore regional monitoring and early warning of increasing risks need to be an element of a nested structure of desertification control and mitigation. Policy and management efforts to control degradation need to be carefully targeted and reassessed with the passage of time in a cost and time efficient scheme.

We seek to further develop this RDI system to make use of improving data sources, particularly for remote sensing based land cover, rainfall scenarios and DEM resolution, and to improve methods for calibrating and validating this approach.

The RDI concept may then be applied to a wider number of environmental processes being equally relevant to desertification in the Mediterranean. So far being applied to water erosion adaptations to the development of physically based Indicators for wind erosion and salinisation risks are possible.

Making use of socio-economic and improved climatic scenarios, the RDI's should be applied to the Mediterranean area to make an objective assessment and provide objective advise on areas of potentially increasing risk from water or wind erosion, or salinisation.

This implies the application of the remote sensing approaches to longer time series on a broader range of test sites throughout the Mediterranean and comparisons of observed actual vegetation with modelled potential vegetation at regional scales with the goal to optimise the regional RDI models. Thus this method opens possibilities to real regional, i.e. Mediterranean wide application needed for improvements of test site inter-comparison and of retrospective assessment of degradation processes. In this function the possibility to better combine meteorological and earth observation satellite data for an integrated monitoring and assessment of vegetation dynamics may be an interesting element for an operational Desertification Observatory for the Mediterranean basin. Such an observatory could be seen as an element of a long-term early warning system, being of interest e.g. for the UN-CCD. As such it has to rely both on historical data for identifying the long-term trends and on forecasting tools. Thus it cannot exclusively rely on new global scale satellite systems such as VEGETATION, MERIS, MODIS, Meteosat 2nd generation etc., which however are expected to allow also accurate semi-quantitative methods to derive information not only about vegetation but also about soil properties such as soil colour, mineralogy and organic matter content. The retrieval of these soil parameters would allow considerable improvements and broadening of the RDI concept.

References

Adams, J.B., M.O. Smith and A.R Gillespie, (1989). Simple models for complex natural surfaces: a strategy for the hyperspectral era of remote sensing, Proc. of the IGARSS '89 Symposium, July 10-14, Vancouver, vol. 1, 16-21.

Brandt, C.J. and Thornes J.B. (eds.) (1996). Mediterranean Desertification and Land Use. Wiley, London.

Craig, M.D., 1994, Minimum-volume transforms for remotely sensed data, IEEE Transactions on Geoscience and Remote Sensing, vol. 32, no. 3, 542-552.

Hill, J. and B. Sturm, 1991, Radiometric correction of multitemporal Thematic Mapper data for use in agricultural land cover classification and vegetation monitoring, Int. J. Remote Sensing, 12, 1471-1491.

Hill J., Sommer S., Mehl W. & Mégier J., (1995): Use of Earth Observation Satellite Data for Land Degradation Mapping and Monitoring in Mediterranean Ecosystems: Towards a Satellite Observatory. In: Environmental Monitoring and Assessment 37, pp. 1-16. Kluwer Academic Publishers.

Holben B., (1986): Characteristics of Maximum Value Composite Images from Temporal AVHRR data. International Journal of Remote Sensing, Vol. 7, 1417-1434.

Huete, A.R., R.D. Jackson, and D.F. Post, 1987: Spectral response of a plant canopy with different soil backgrounds, Remote Sensing of Environment, 17, 37-53.

Graetz R.D., 1996: Empirical and Practical Approaches to Land Surface Characterisation and Change Detection. In: J. Hill & D. Peter (Eds. The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin – State of the art and future research. Experts workshop 13 to 15 June 1994, Valencia (Spain). EC Report EUR 16732 EN, pp.9-21.

Kemp, D.D., (1990). Global Environmental Issues. A Climatological Approach. London : Routledge

Kirkby, M.J., A.C. Imeson & G. Bergkamp, (1996). Scaling up processes and models from the field plot to the watershed and regional areas. J. Soil & Water Conservation 51(5), 391-396

Lacaze B., Caselles C., Coll C., Hill J., Hoff S., de Jong S., Mehl W., Negendank J., Riezebos H., Rubio E., Sommer S., Teixeira Filho J. & Valor E., (1996): DeMon Integrated Approaches to Desertification Mapping and Monitoring in the Mediterranean Basin. Ed. J. Hill, Final Report of the DeMon-1 project. EUR 16448 EN, JRC Ispra, 176pp.

Markham, B.L., R.N. Halthore and S.J. Goetz, 1992, Surface reflectance retrieval from satellite and aircraft sensors: results of sensor and algorithm comparisons during FIFE, J. of Geophys. Res., 97, 18,785-18,795.

Moran, M.S., R.D. Jackson, P.N. Slater, and P.M. Teillet, 1992, Evaluation of simplified procedures for retrieval of land surface reflectance factors from satellite sensor output, Remote Sensing of Environment, 41, 169-184.

Perez-Trejo, F., 1994. Desertification and land degradation in the European Mediterranean, EUR 14850 EN, (Office for Official Publications of the European Communities: Luxembourg).

Price, J.C., 1993, Estimating leaf area index from satellite data, IEEE Transactions on Geoscience and Remote Sensing, vol. 31, no. 3, 727-734.

Slater, P.N., S.F. Biggar, R.G. Holm, R.D. Jackson, Y. Mao, M.S. Moran, M. Palmer, and B. Yuan, 1987, Reflectance- and radiance-based methods for the in-flight absolute calibration of multispectral sensors, Remote Sensing of Environment, 22, 11-37.

Smith, M.O., J.B. Adams, and D.E. Sabol, 1994a, Mapping sparse vegetation canopies, in J. Hill and J. Mégier, eds., Imaging spectrometry - a tool for environmental observations, (Kluwer Academic Publishers: Dordrecht ...), 221-235.

UN-CCD, 1994: United Nations, Intergovernmental Negotiating Committee For a Convention to Combat Desertification, Elaboration of an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, U.N. Doc. A/AC.241/27 (1994), 33 I.L.M. 1328

UNEP, 1991, Status of desertification and implementation of the United Nations plan of action to combat desertification, (UNEP: Nairobi).

DEMON-II - SATELLITE MONITORING OF DESERTIFICATION IN THE EUROPEAN MEDITERRANEAN
THE CRETE CASE STUDY

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Abstract. Within the DeMon-I project, carried out under the previous EC Environment and Climate Programme, tools were implemented and refined to derive physical parameters from earth observation data and to relate them to degradation processes. Models on different scales were developed to describe overall soil transport and susceptibility to erosion due to single rainfall events. The DeMon-2 project aims at integrating these tools and models in order to demonstrate their adequacy for operational approaches in monitoring land degradation and desertification over long time periods. Results from the analysis of satellite time series dating back to the mid seventies suggest that even Mediterranean mountainous rangelands under substantial grazing pressure, as to be found in central and southern Crete, have not experienced an overall reduction of semi-natural vegetation cover. To the contrary, the impact of socio-economically-triggered land use changes could only be perceived in limited locations. It is now the subject of more extended studies to document whether this represents a general trend which, if being confirmed would question some concepts of Mediterranean Desertification.

Key words: satellite-based vegetation cover estimation, long-term desertification monitoring

Introduction

The Mediterranean Basin has been under enormous ecological pressure since historical times, from extensive deforestation in ancient history to recent manifestations in agriculture, industry and tourism, many of which are resulting in regressive soil development and degraded vegetation formations (Graetz, 1996). In a response to the progress of desertification the European Parliament calls for strategies to combat this process and asks for "the preparation of a programme for data collection, information and observation on a systematic basis in respect of regions of the Community which are vulnerable to desertification and drought, .." (Official Journal No. C 268/148). Thus the basis for drafting and implementing regional development plans for a sustainable use of Mediterranean land resources lies in the availability of environmental inventories and a continuous surveillance on a regional scale. However, the scientific debate on nature and mechanisms of land degradation processes in the European Mediterranean, and whether these processes can be adequately summarised under the term 'desertification', still continues. In the context of developing policies and management practices responding to 'desertification', special attention has to be paid to a coherent and consis-

tent way of assessing the magnitude, extent and distribution of susceptibility to degradation processes with near-real-time procedures.

Objectives

In a first project phase (DeMon-I) we successfully developed an initial monitoring methodology for selected test sites, resulting in a standardised approach which can routinely be applied to large regions and is able to identify environmentally sensitive areas. We could demonstrate that degradation of the permanent semi-natural vegetation and the erosional state of soils are tangible items which can be observed with earth observation satellites, and that remote sensing derived parameters can be used as input parameters to drive ecological models evaluating soil erosion risks (Lacaze et al., 1995). Based on this expertise, DeMon-II was launched under the Environment and Climate Framework in 1996. Emphasising our opinion that 'desertification' is not primarily a climatological problem but triggered by socio-economic forces the objective was to integrate ecological models and information from operational earth observation and meteorological satellites to assess and repeatedly monitor regional scale indicators of susceptibility to degradation in the Mediterranean. Resulting from these statements the concept for DeMon-II comprises five major objectives:

- The optimisation of conceptual and methodological pathways for deriving coherent indicators of vegetation abundance and the erosional state of soils from remotely sensed imagery in the reflective and thermal domain;
- the definition of the conceptual requirements and the design of an operational *Satellite-Based Desertification Observatory* for the Mediterranean Basin, and the validation of methods and processing modules needed for its implementation in the context of three retrospective case studies.
- the integration of spatialised ecological models on dynamics and productivity of vegetation as well as soil water balance along with remote sensing methods for improving our capabilities to assess the present degree of degradation;
- the development of an approach for modelling degradation processes, particularly with respect to the degradation of vegetation communities and the risk of soil erosion (Desertification Susceptibility Index);
- and finally an integrated and interdisciplinary study on the sustainable management of rangelands in mountainous ecosystems performed in Central Crete.

Task distribution

Beside the geometric and radiometric pre-processing of the satellite data, special emphasis is put on dedicated interpretation techniques such as the derivation of vegetation abundance estimates and the characterisation of soil conditions by Spectral Mixture Analysis supported by GIS-based stratification procedures (University of Trier, CNRS-CEFE). Ground truth is provided by field reference measurements being organised in a spectral database, i.e. MedSpec, which forms a basis for operational image interpretation (JRC/SAI-EMAP).

Additional information on vegetation communities in the Crete test site is provided by the team from NAGREF/University of Iraklion. Another focus is the integration and comparison of these results with parameters derived in the thermal domain of the wavelength spectrum, which requires the definition of an emissivity library from field measurements as a first step (University of Valencia). The performance of these methodologies is validated by applying them to a time series of data from satellites such as Landsat-TM, -MSS and NOAA-AVHRR yielding a 20 to 25 year retrospective analysis of desertification dynamics.
The transfer of results found for specific test sites to other Mediterranean regions is only possible by defining zones of similar conditions in terms of climate, vegetation, lithology, soils etc. This concept of ecozones is developed by the University of Utrecht based on NOAA AVHRR data, DEM derived information and field measurements. Associated with this concept is the calculation of biomass parameters at different scales, from a combination of satellite data and transect measurements. Since it is of great importance to examine the ecological consequences of historic and future climate changes ecosystem modelling on different scales, supplied by the teams from CNRS-CEFE and University of Utrecht, is incorporated to simulate seasonal and multi-annual course of ecosystem functional processes like carbon and water cycling from local to regional level. The results are validated by comparison to extensive ecological field experiments in the Crete test sites executed by NAGREF/University of Iraklion.
Finally, the retrospective analysis is implemented to identify the existence and severity of degradation processes, which in turn forms the basis for developing mitigation strategies based on adequate grazing management scenarios for the island of Crete.

Study sites

The project sites were chosen to represent a variety of typical Mediterranean ecosystems. The Languedoc-region in France is relatively stable, representing a Mediterranean-type ecosystem in the process of successional recovery after centuries of intense grazing and agricultural activities, with only local disturbances through urban and agricultural developments or occasional wildfires. The Valencia Province, Spain, is known to be one of the most hazardous areas in terms of severity and frequency of wildfires, which, during the past years, is additionally affected by a severe drought. It is considered important for studying the resilience of semi-natural vegetation communities.
In this paper, we focus in particular on a case study developed on the island of Crete, Greece, a region that experienced an increasing pressure on natural resources through excessive grazing activities in mountainous ecosystems. This was triggered by an increasing demand for animal products (tourism) and an extension of the network of roads and tracks induced after Greece joined the EU in 1981.

The Crete Case study

The Asterousia and Psiloriti mountains of Crete (figure 1) represent characteristic cases of

degradation caused by intensive grazing and fires set by shepherds. Today, the whole mountain range of Asteroussia, reaching about 1100 m above sea level, is dominated by phrygana communities. Soil erosion is apparent in many locations, and we frequently find areas which appear irreversibly degraded or "desertified". The grazing areas of the Psiloritis Mountains in central Crete extend into higher altitudes (1000-2000 m) where we meet sub-humid climatic conditions. Here, in areas which are mostly covered with matorral or mountainous phrygana we can still find relicts of kermes oak forests (Quercus coccifera).

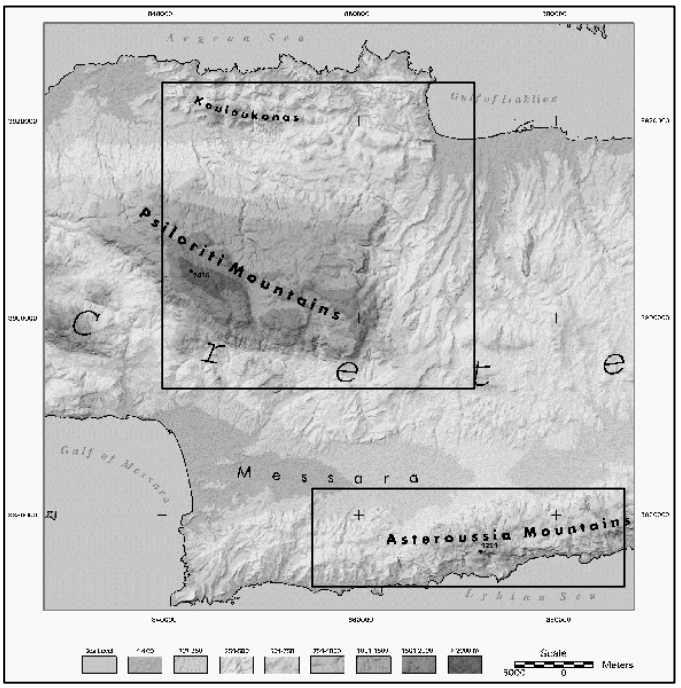


Figure 1: Study Sites on Crete.

Both regions are known for the fact that the grazing pressure has significantly increased during the past decades, in particular since Greece joined the European Communities. Official statistics indicate that the number of sheep in the mountain communities of Psiloritis has grown by more than 65%, the number of goats by more than 68% (Ziogonas et al., 1996). Without overestimating the accuracy of these figures it is evident that grazing pressure has been continuously high during the past decades. We are thus convinced that the mountainous ecosystems of Crete are highly suited for analysing the development of those semi-natural Mediterranean vegetation communities where free grazing of small ruminants is one of the most important socio-economic factors (Dubost, 1996). An additional element of the increasing environmental impact related to grazing results from the construction of new access roads, which is supported through European Communities' Regional Development and Cohesion Funds. Remote areas are now accessible by car; enabling animals and additional food supplies to be transported up into the mountains, resulting in the presence of man and his animals in these ecosystems being more frequent than ever before. It is therefore believed, that a retrospective analysis of vegetation dynamics in the mountainous ecosystems

of Crete provides one of the few test cases to assess the evidence of recent man-induced degradation processes that might eventually drive desertification.

Monitoring Land Degradation with Earth Observation Satellite Systems

Operational earth observation satellites with multispectral sensor systems (e.g., Landsat-MSS and -TM, SPOT-HRV) are characterised by high spatial (30 or 20 m) and intermediate spectral resolution (6 or 3 bandpasses in the reflective part of the solar spectrum), but have rather large standard revisit intervals (16 - 26 days). The optical systems onboard these satellites register that part of the downwelling solar radiation, which has been reflected by the Earth's surface and transmitted through the atmosphere. Although it is agreed that remote sensing provides a convenient source of information, the data collected by these instruments do not directly correspond to the information we need. One of the most important issues is to identify indicators for land degradation processes which have some general applicability to the Mediterranean as a whole, and which can be observed with operational remote sensing satellites (e.g. Hill et al, 1995).

However, drawing concise conclusions will depend on the ability to analyse multi-annual time series in a completely standardised way, and it is for this reason that retrospective studies are so important with respect to developing approaches for analysing and monitoring environmental change (Graetz, 1996). For the study on Crete we have used a long time series of Landsat-TM images which covers the time span between 1984 and 1996, and which was further extended by adding Landsat-MSS data dating back until 1972. All images were acquired between late May and early June, ensuring comparable phenological states of vegetation.

Pre-processing Issues

In the context of this paper we can only provide a short overview on the pre-processing techniques (i.e. geometric and radiometric corrections) which need to be applied for making the satellite images suitable for a precise and standardised assessment of biophysical variables (see also Lacaze et al., 1996). The Landsat-TM time series was geometrically corrected, where the use of digital elevation data derived from panchromatic images of the SPOT-satellite allowed for the correction of terrain-induced distortions with a much higher degree of accuracy than could be achieved by a standard correction. The following radiometric processing of the reflective bands required an initial collection and evaluation of calibration coefficients including the formulation of a time-dependent function to derive these coefficients. A modified 5S radiative transfer code was employed to atmospherically correct the data, including also corrections of topography-induced illumination effects (Tanré et al., 1986, Hill et al., 1995). The latter is of exceptional importance in areas with a strong altitude gradient, as encountered in central Crete. The consistency of the correction over the whole time series was validated by the use of field reference measurements and pseudo-invariant features found within the images (Hill and Sturm 1991, Hostert et al. 1997, Röder et al. 1997).

Incorporating Landsat MSS data

Landsat TM did not operate before 1984, which limits retrospective studies in a temporal context, while different Landsat MSS generations have been in orbit starting in 1972, which makes these data an interesting option.

However, there are limitations as to the data quality compared to TM data. Landsat MSS data exhibit a coarser geometric resolution of 79 * 79 m^2, as well as lower radiometric and a lower spectral resolution with only 4 bands ranging from 0,5528 to 0,9131 µm. The crucial issue in incorporating MSS data into a quantitative interpretation scheme is the radiometric correction of the data. Since the internal calibration device hosted by Landsat MSS never satisfyingly performed, and in the 1970s no focus was laid on in-flight calibration, we do not possess validated calibration data for the different MSS systems, except for the pre-flight calibration values as published by Markham and Barker (1986).

Hence, an alternative methodology is called for to be able to perform a radiometric rectification of the Landsat MSS data. Due to the fact that the Landsat-5 platform hosted both the TM and MSS sensors, we dispose of images taken under identical constellations, where we can use the respective TM scene as a calibrated reference to deduce calibration factors for the MSS scene. The principle of extending our Landsat TM time series further back until 1972 by integrating Landsat MSS data is shown in figure 2:

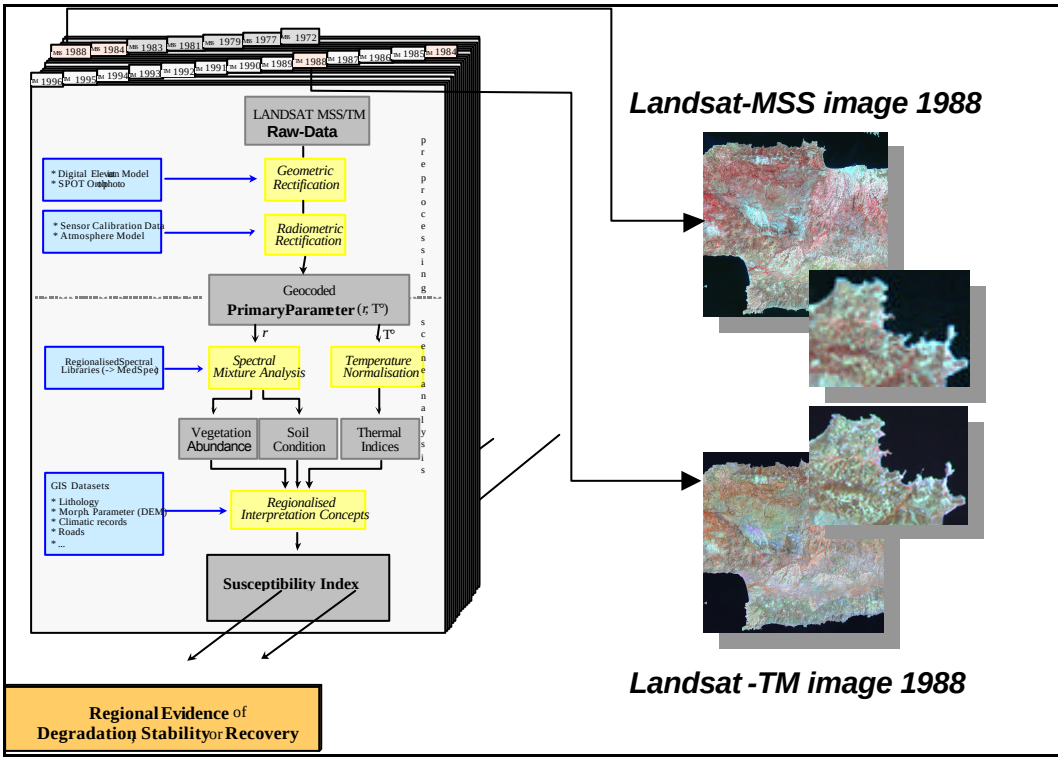


Figure 2: Extension of satellite image timeseries by integrating Landsat TM and MSS.

This can be achieved by simulating the values as expected for different homogeneous areas for the bands of Landsat MSS from the values found for the same areas in calibrated Landsat TM images. Calculating a regression for the different bands eventually yields the calibration factors for Landsat MSS, which are then used to radiometrically correct the MSS image. This reference was then used to subsequently correct the other MSS images. Eventually, this intercalibration between Landsat TM and MSS allows for the quantitative interpretation of Landsat MSS data using the same analysis techniques as for Landsat TM, and produces a timeseries of geoetrically and radiometrically corrected Landsat TM and MSS images ranging from 1996 back to 1972.

Assessing Vegetation Cover based on Spectral Mixture Modelling

It is a well-known paradigm of optical remote sensing that the spectral variation in multispectral images is caused by mixtures of a limited number of surface materials. Modelling the multispectral reflectance of a pixel as a mixture of representative prototype spectra (i.e. Linear Spectral Mixture Analysis) thus allows to derive estimates for proportional vegetative cover with better accuracy than provided by traditional vegetation indices (e.g., Smith et al. 1990; Hill et al., 1995). The reference spectra employed were all recorded in field or in laboratory from samples taken in field, by an ASD-II spectrometer. The continuous spectra, registered between 0 and 2500 nm, were resampled to the spectral bandpaths of Landsat TM and MSS. By using locally adapted endmember sets we were able to estimate vegetation cover comparable to the ground-based mapping of vegetation communities performed by NAGREF/University of Iraklion (Tsiourlis and Kasapidis, 1999). For illustration purposes, maps for the two test sites were produced where the vegetation estimates were classed into four ranges (compare figures 3 and 4)

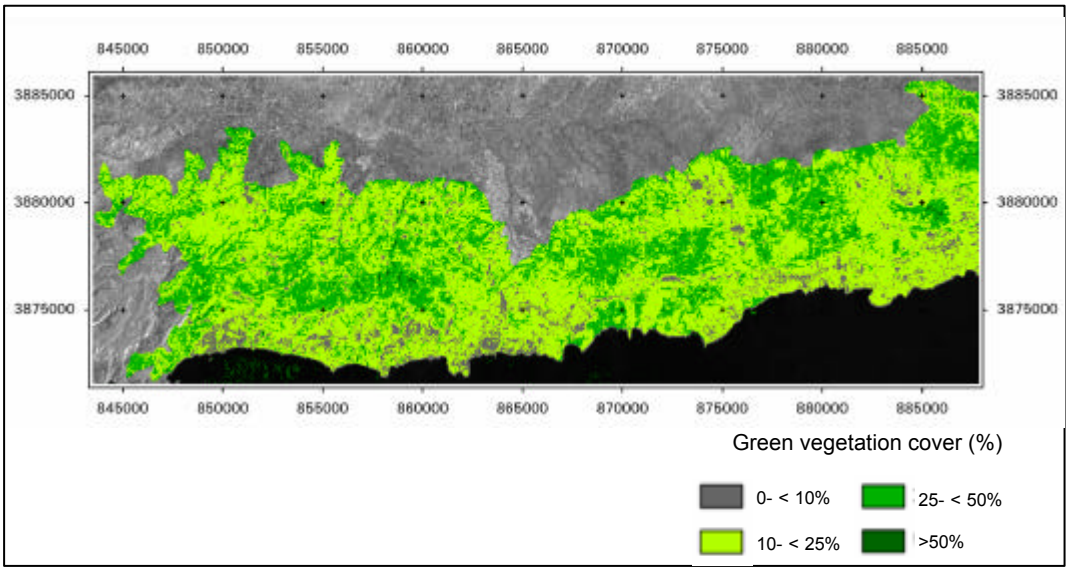


Figure 3: Estimates of vegetation cover as derived from Spectral Mixture Analysis for Asterousia (1996).

Based on extensive field work and the interpretation of aerial photographs and satellite imagery, a digital map of vegetation cover was derived using six classes (0-15%, 15-30%, 30-45%, 45-60%, 60-75%, >75%), and the satellite based vegetation cover estimates were assigned to the same classes.

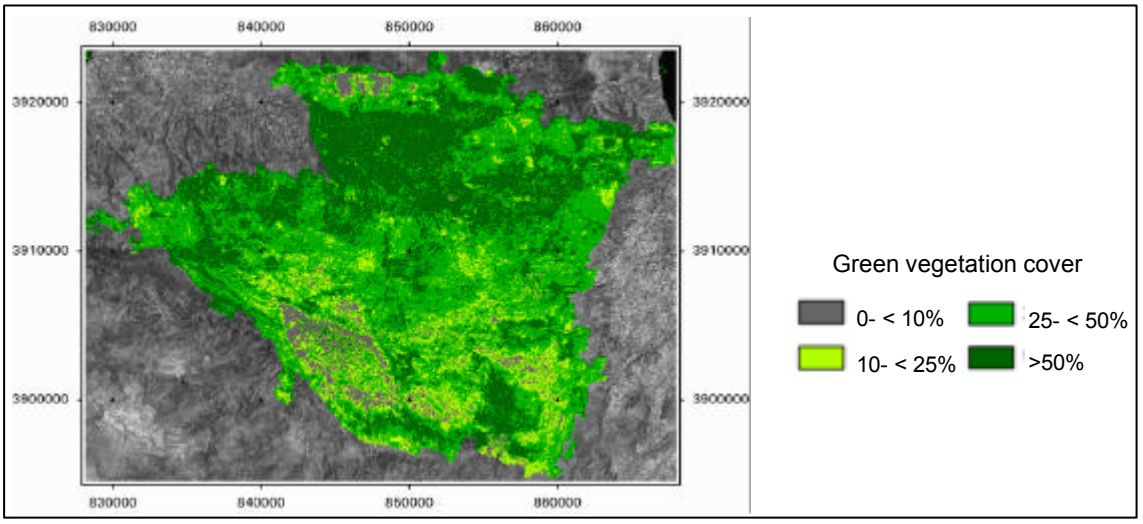
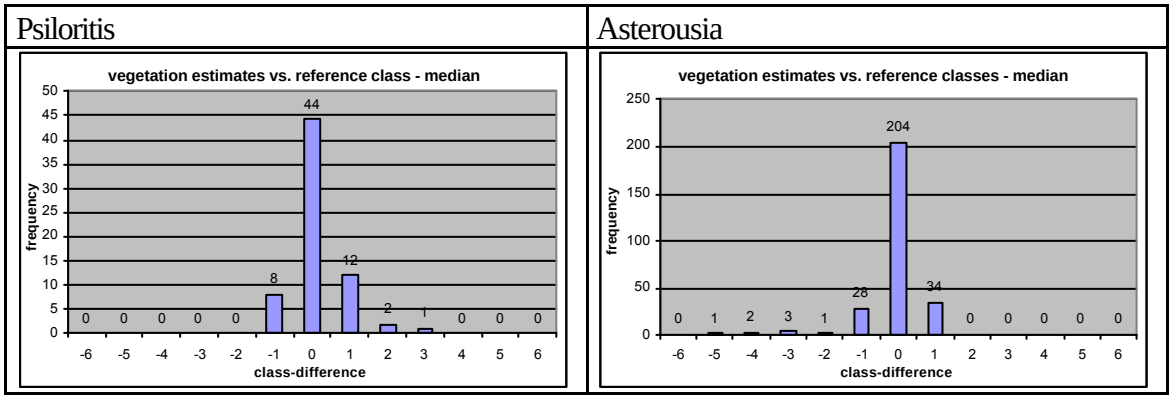


Figure 4: Estimates of vegetation cover as derived from Spectral Mixture Analysis for Psiloritis (1996).

This map was employed as a reference to evaluate the quality of the vegetation cover estimates derived from the most recent Landsat TM image (1996) through Spectral Mixture Analysis. For a set of random points the reference polygons were overlaid the unmixing-based classes, and the mean and medium values were compared by calculating the respective differences. We obtained a high degree of concurrence, as can be inferred from figure 5:



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Figure 5: Evaluation of the accuracy of Spectral Unmixing-based vegetation cover estimates.

(Continuation)

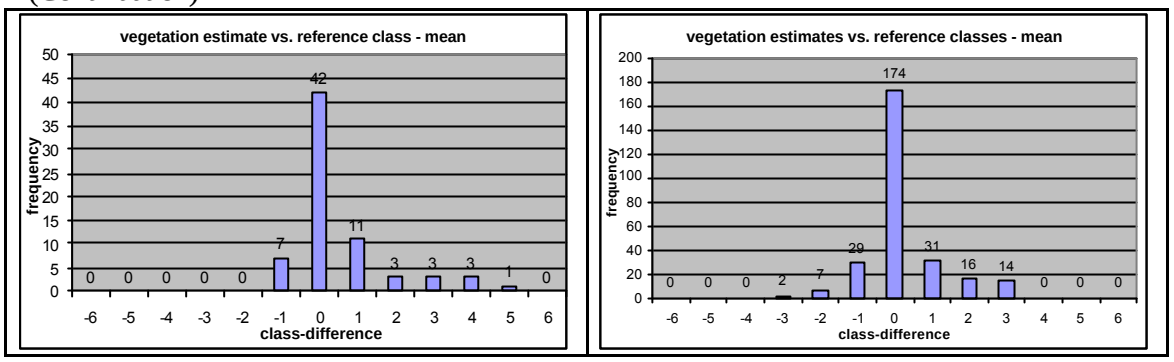


Figure 5: Evaluation of the accuracy of Spectral Unmixing-based vegetation cover estimates.

Monitoring vegetation dynamics from long timeseries

As outlined before, the spectral mixture model tested for the Landsat TM image from 1996 was applied to the full dataset, to yield vegetation cover estimates ranging back until 1972. We observe two different kinds of changes occurring in the study sites, which have to be evaluated separately. The first are increases or decreases in vegetation density that gradually happen over a longer period. These are probably attributable to long-term trigger functions, like i.e. grazing. The second are obvious changes on a much shorter time-scale mainly to be interpreted as consequences of singular events, like wildfires, intentional burning or mechanical clearings.

Singular events

There are two distinct causes for such effects. The first are fires that either happen accidentally or intentionally, associated with a variety of socio-economic factors. Deliberate burning is often aimed at reducing the amount of certain species, such as *Callicotome villosa*, which are impalatable to sheep and goats. These fires often spread under dry and windy conditions to much larger areas. In contrast to fires initiated by shepherds, the retreat of animals may lead to the same effect. A total lack of grazing causes the accumulation of dry biomass, which strongly fuels fires set accidentally or by lightning.

Besides, the introduction of new agricultural plots is preceded by clearing of the actual vegetation, be it through burning or mechanical clearing. This can often be observed in areas dominated by phrygana. Changing initially unproductive lands into cultures (mainly olives) becomes more and more attractive through EU-subsidies, which even make irrigation economical.

Both of these effects are easily detectable from the green vegetation estimates found through spectral unmixing. For a qualitative perspective they can be visualised by rendering movies of the unmixing results of all years. Here, the singular effects manifest as a very sudden change in

colour appearing as a punctual pulse. Figure 6 gives an example for a suite of four years on the Krousounas plateau.

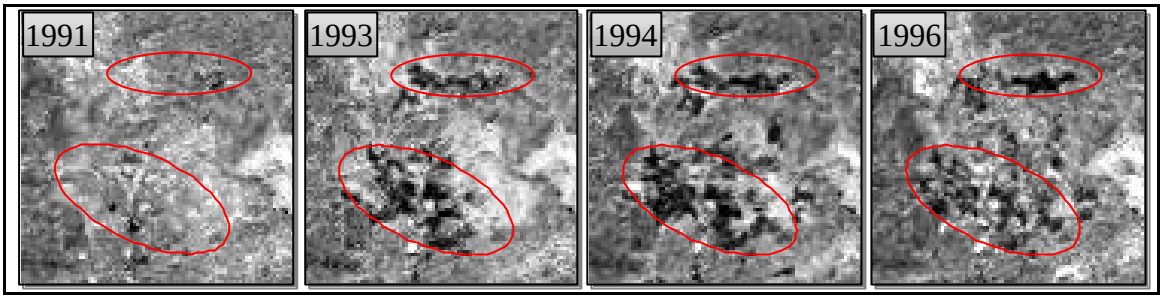


Figure 6: Clearing of phryganic species for horticulture plantation

On a more quantitative level such effects can be investigated by plotting the vegetation estimates over time at a certain point. Distinct vegetation changes due to singular events appear as sharp bends in the profile, where we can also estimate the magnitude of the associated decrease.

The vegetation fraction images of the different years were visualised as movies to detect changes manifesting as pulses as described above. During the field campaigns, these sites were identified in field by using GPS. Our field observations confirmed our results, as all these "hotpoints" were caused by fires or setting up of new plantations. As an example figure 7 shows a photograph and the corresponding graph of vegetation abundances derived from the timeseries.

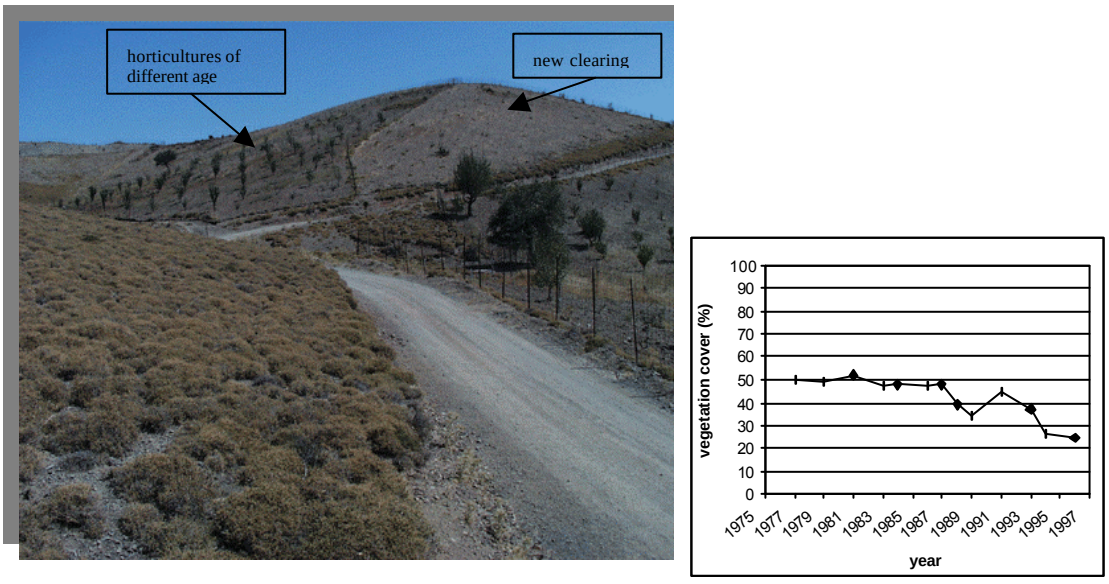


Figure 7: Horticulture on Krousounas plateau (Sept. 1998) and respective vegetation trend.

Summarising, we are able to detect short-term disturbances of the natural vegetation and to estimate the magnitude of these disturbances concerning the decrease of vegetation as well as the spatial extent of such disturbance patterns.

Gradual changes

Gradual changes are not as easily detectable as singular effects. For example, resulting from an increase or decrease in grazing pressure we should be able to observe a spatial pattern of positive and negative changes in vegetation density.

The trend analysis is based on a pixel-by-pixel regression approach. All spectrally unmixed images were assembled on a time axis starting with the first Landsat MSS image from 1972. The subsequent trend analysis yielded a multi-layer file containing the difference between first and last year, regression parameters such as gain, offset, correlation coefficient along with statistical parameters describing the significance, like F-value, RMS, etc. It became evident by cross-checking the results by omitting a single date and re-calculating the time-series that the first MSS-scene recorded in 1972 distinctly reduced the quality of the analysis. This is caused by a different state of phenology due to the late acquisition date (September) compared to the other scenes. Accordingly it was decided not to use this dataset in the trend analysis.

We do find clear spatial patterns that justify a further interpretation of the results (figure 8). However, care has to be taken, as high interannual variations in the vegetation abundances, mainly due to phenology, diminish the statistical significance of the results.

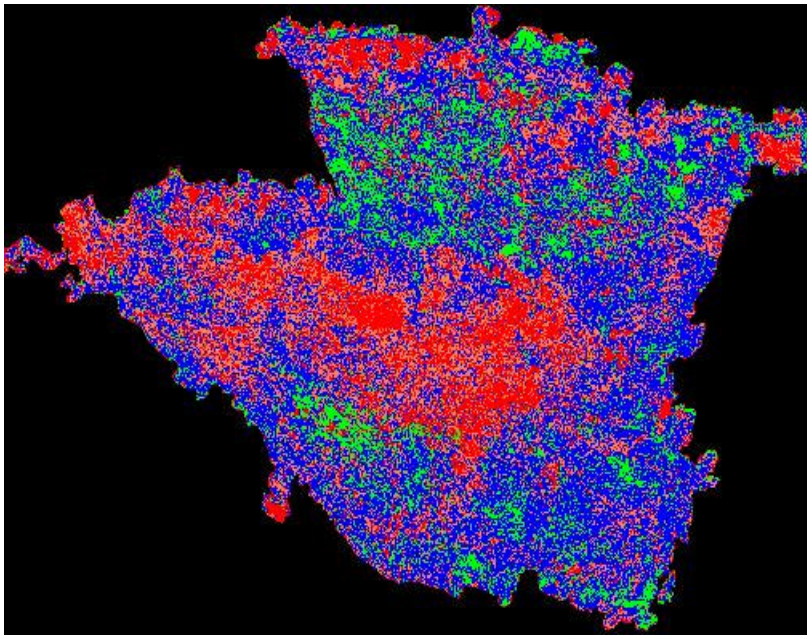


Figure 8: Long-term vegetation trend for the Psiloritis massif
blue: stable conditions, red: moderate decrease,
green: moderate increase

A more detailed analysis was performed by investigating the time profiles of representative areas. We could find a general trend that is documented in figure 9 for the Psiloritis massif. The examined areas are examples for sites, which are permanently exposed to grazing. The area from Anogia up to the plateau of Nida exhibits relatively stable conditions, only interrupted by a singular event, presumably caused by a fire in 1989.

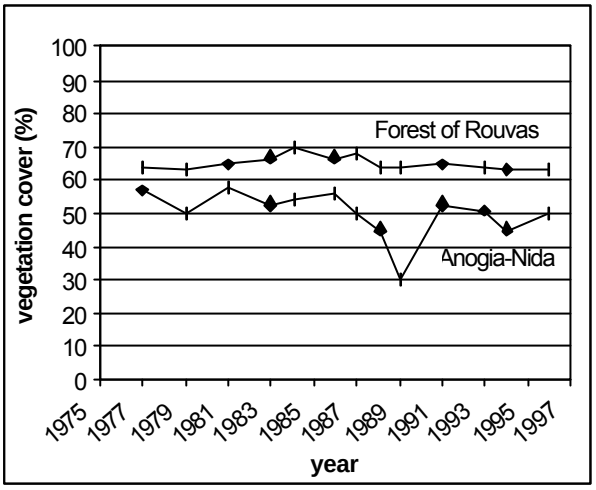


Figure 9: Vegetation trend for the Forest of Rouvas and the transect between Anogia and Nida.

A regression might thus indicate a decreasing trend as an artefact due to a singular disturbance in the time-series. However, no general decrease of vegetation can be noted if the respective year is eliminated from the regression analysis. As a second example, the forest of Rouvas shows an even higher degree of stability with hardly any variations being noticeable (compare figure 9).

In general, a spatial pattern can be observed that follows larger landscape units. We find decreases in vegetation cover mainly in the matorral areas between Anogia and the higher ranges of Psiloritis, an area that is strongly used for grazing. However, this is the same area that shows the highest relative amount of dry vegetation. As no dry vegetation is included in the spectral unmixing employed for this study, we have to note a degree of uncertainty in this region, somewhat questioning the observed negative trend. Stable conditions are encountered on the limestone ridges, which are only very sparsely vegetated and not used for grazing. The same applies for the grazed forests of Rouvas and Krousounas, but obviously grazing occurs only to a degree that does not trigger a significant decrease of vegetation cover. The valley between the massifs of Psiloritis and Kouloukonas shows an increase in many parts, which can be attributed to a strong increase in tree cultures and horticulture.

Overall, we can state that the analysis of a 20-year time-series does not exhibit large-scale negative trends of vegetation development in the Psiloritis mountain range, apart from a few strongly grazed areas, or in the case of singular disturbance events leading to a negative trend.

Notwithstanding we could also detect areas with slight decreases of vegetation cover, but they affect only small areas compared to the rather stable conditions encountered in most of this region. Finally, it has to be noted that stability may be on a high or on a rather low level. Even if a certain vegetation cover can be maintained under the current amount of grazing, it may be possible that a decrease in grazing pressure could even lead to a regeneration and an increase in vegetation cover.

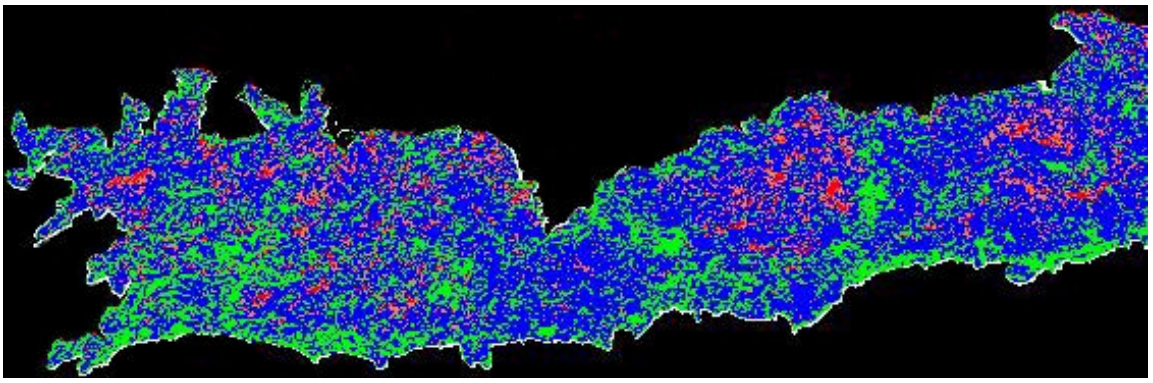


Figure 10: Long-term vegetation trend in the Asterousia mountains.

In the Asterousia mountains these observations are even more evident. The only decreases result from punctual disturbances, which are due to a frequent destruction of Phrygana in favour of olive cultures, or in the areas continuously used for agriculture and horticulture around the villages. Apart from that, we do not find any gradual long-term decreases in vegetation cover (figure 10). The area is characterised by stable conditions on a low level, as supported by the trend delineated in figure 11.

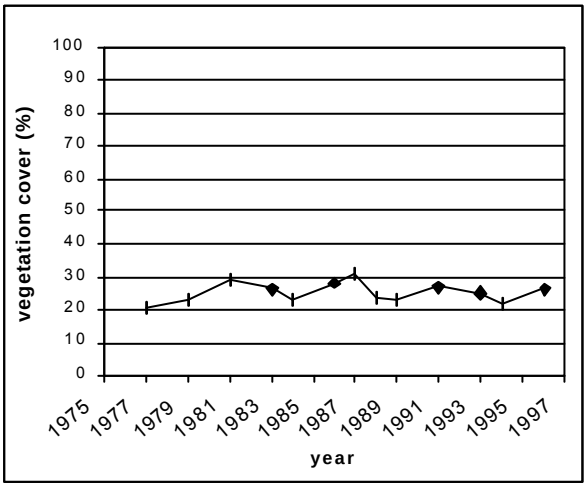
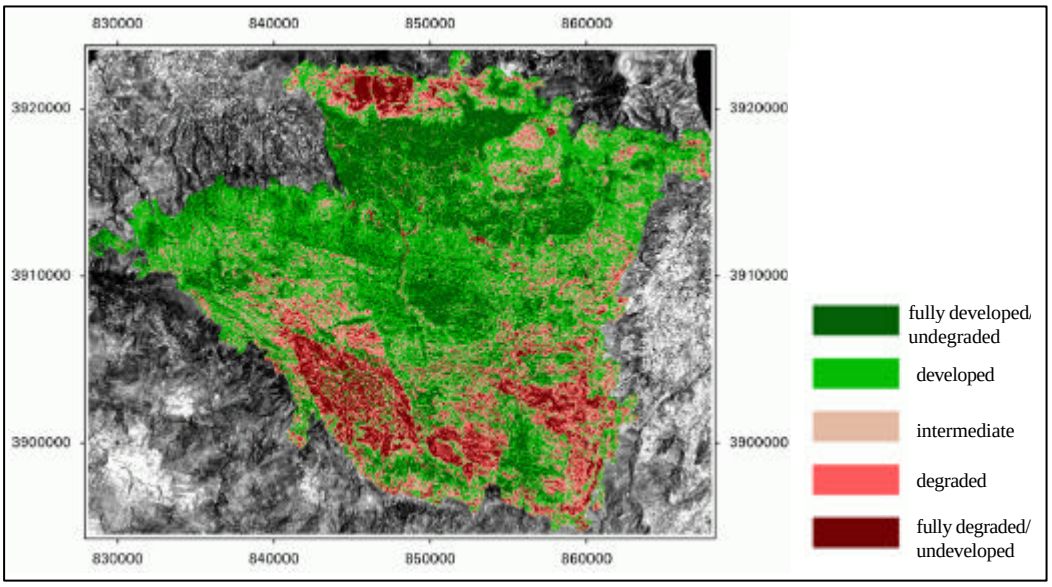


Figure 11: Vegetation trend in the mountain range of Asterousia.

Assessment of soil condition

For the Psiloritis area we have separated developed soils from the lithological background by means of Spectral Mixture Analysis. After applying the mixture model to the whole time-



series of Landsat TM scenes we retrieved a soil condition map from the results. Our approach refers to basic soil development concepts, which consider soil development to be either progressive or regressive with time (Birkeland 1990). Under progressive development, soils become increasingly differentiated by horizons, and horizon contrasts increase. To the contrary, regressive pedogenesis refers to suppression of pedogenesis by surface erosion or the addition of material to the surface at a rate that suppresses soil pedogenesis.

Figure 12: Soil condition Psiloritis (1996) – Derived from SMA and maximum value composite.

We introduced the abundance estimates found for the limestone, which represents the unweathered, underlying bedrock material as a surrogate for the erosional states of soil.
A maximum value composite was computed from the fractions found for different years, yielding a map of maximum rock proportions over the past years, independent of temporal variations, like e.g. changes in agriculture manifesting in field boundaries. The resulting values were assigned five classes of degradation and soil development status, ranging from not developed/denuded to fully developed/undegraded (compare figure 12). Two different effects are included. The first is a degradation of soils caused by external factors such as grazing, fires or clearing of vegetation cover, which decrease the stability of the topsoil, as a result leaving it much more prone to erosion. The same effect may be caused by construction work in areas with a strong relief, where the cutting of slopes creates new local erosion bases and an artificial steeping of the relief. To the contrary, in many places we can not expect soils to develop on account of physiographic factors, the most important of which is the strong relief found on Crete in conjunction with climatic factors. Hence, we consider the soil

condition map to present an inventory of the state of soils rather than an assessment of processes leading to that state.
The resulting map reflects the conditions encountered in field very well. We can note low index values in the fertile areas between Kouloukonas and Psiloritis, where the valleys are completely under use for tree and horticultures. Here, the soils are well sheltered by a dense vegetation canopy against erosional processes. The same applies for the forests of Krousonas and Rouvas, where we find low values, indicating unproblematic soil conditions (compare figure 13).



Figure 13: Protective function of tree cultures for soil.



Figure 14: Poor to undeveloped soils on steep slopes of the Psiloritis massif.

The area between the main massif of Psiloritis and the village of Anogia, which is strongly grazed, exhibits a range from medium low to medium high values, indicating varying erosional states. The high altitudes of Psiloritis and Kouloukonas show very high disturbance levels. In these areas, soils are strongly suscept to erosion, or they are only poorly developed due to the relief, where a development of soils is often denied by constant washoff (compare figure 14).
However, within the Psiloritis massif also values indicating stable conditions occur. They represent singular soil patches that have developed in sheltered depressions. As could be expected, we also observe high index values for the limestone ridges surrounding the forests of Rouvas and Krousonas, where environmental conditions suppress the development of soils beyond initial stages.

Discussion

The last decades are characterised by an unquestionable increase in animal numbers (figure 15), a highly improved accessibility of remote areas and a significant change in shepherding practices, which are highly correlated with subsidies granted by the European Union Regional Development and Cohesion Fund (Grove et al. 1993).

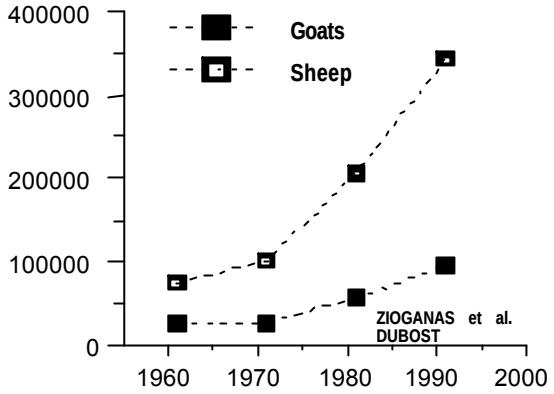


Figure 15: The increase of livestock in Crete (Psiloritis).

With even remote areas being accessible by car a dramatic change of the traditional shepherding methods can be observed. Sheep and goats are grazed in regions that are little suited for pastoralism, with animals and additional food supplies being brought in by car. These aspects result in a far higher grazing pressure on the mountainous ecosystems of Crete than has been there in historical times (Dubost 1998). However, even if the grazing capacity is exceeded we often find an artificial equilibrium between actual animal numbers and carrying capacity, established through these additional food supplies.

In the frame of our case study, we have established a sound processing chain to attain a high level of accuracy within the process of geometrically and radiometrically pre-processing reflective satellite imagery. Auxiliary data required are provided by standard satellite data, such as high geometric resolution orthphotos, or satellite-derived digital elevation models. Parameters needed for the correction are inferred from the images themselves.

The interpretation of the resulting images is based on Spectral Mixture Analysis and has been adapted to specific regional spectral properties, employing a variety of reference data, and has been successfully validated by ground truth data.

Applying the models and methodologies to a timeseries of satellite data we can introduce further interpretation approaches, which allow us to draw conclusions on the development of vegetation cover with time. Calculating trends of vegetation development on a pixel-to-pixel basis, we could demonstrate that, rather than exhibiting widespread strong degradation often expected from the increase in animal numbers and accessibility, the landscape rather shows a complex pattern of stability, moderate degradation and even an increase in vegetation cover in places.

The mountainous vegetation reflects stable conditions in most parts of the study sites, with only small areas showing a distinct decrease in vegetation cover over a period of 20 years. Additionally, aerial photographs reaching back as far as 1945 were integrated in the retrospective study by mapping areas of different vegetation cover and type. The results over the time covered confirmed our findings based on the satellite imagery, since they show no evidence of a general degradation in vegetation cover beside punctual disturbances as was outlined already. However, in many places this is stability on a very low level, which may even turn into severe degradation under increasing stress. Considering the human history on

Crete this is not surprising, since the island has been strongly utilised by man for hundreds of years. This implies that the changes in grazing pressure over the past decades do not cause clearly visible degradation processes further aggravating the historical situation. On the other hand, recovering phryganic communities with a much higher ecological value in places where ruminants are excluded indicate that grazing does indeed prevent a sustainable recovery of the vegetation to higher density and more diversified communities or even back to the forests of ancient times.

Beside these general trends, short-term singular events were identified as major disturbances to vegetation communities, often associated with the planting of new cultures. Given the rather poor soils and relatively little annual precipitation in many of the areas concerned, this appears rather questionable from an ecological and economical point of view and is only worthwhile through strong subsidies.

Based on these findings, a management strategy was proposed, which aims at a reconciliation of economical and conservation matters (Tsiourlis and Kasapidis, 1999). Depending on the carrying capacity, grazing by sheep and goats should be suspended in the respective areas for different duration, to allow for a recovery of the phryganic communities, or even a succession back to the high mattorrals and forests of *Quercus coccifera*. In very sensitive areas, such as on the steep slopes of Psiloritis, seasonal suspension of grazing is proposed in spring and winter to enable the growth of a basic vegetation cover fixing the topsoil.

All in all, a mosaic of vegetation communities is the goal, which supports traditional rotative grazing systems at a level as determined by the carrying capacity of the respective areas, but also provides enough habitats for small animals. Finally, such a mosaic of different vegetation communities significantly adds to the aesthetic value of Mediterranean lands.

Selected References

Adams J.B., M.O. Smith, Gillespie A.R (1989). Simple models for complex natural surfaces: a strategy for the hyperspectral era of remote sensing, Proc. of the IGARSS '89 Symposium, July 10-14, Vancouver, **1:** 16-21.

Birkeland P.W., (1990). Soil-geomorphic research - a selective overview, Geomorphology, 3,

Conese C., Gilabert M.A., Maselli F., Bottai L. (1993). Topographic normalization of TM scenes through the use of an atmospheric correction method and digital terrain models. Photogrammetric Engineering and Remote Sensing, **59 (12)**: 1745-1753.

Dekker A., Donze M. (1994). Imaging spectrometry as a research tool for inland water resources analysis. Hill J., Mégier J. (Eds). Imaging spectrometry - a tool for environmental observations. Dordrecht, 295-317.

Dubost M. (1998): European policies and livestock grazing in Mediterranean ecosystems. Papanastasis V.P., Peter D. (Eds) (1998). Ecological Basis of Livestock Grazing in Mediterranean Ecosystems. Proceedings of the International Workshop held in Thessaloniki, October 23-25, 1998, 298-311

Graetz R.D. (1995). Empirical and practical approaches to land surface characterisation and change detection, in Hill J., Peter D. (Eds). Remote sensing for land degradation and desertification monitoring in the Mediterranean basin, Proc. of a Workshop held in Valencia, Spain, 13-14 June 1994, in preparation.

Hall F.G., Strebel D.E., Nickeson J.E., Goetz S.J. (1991). Radiometric rectification – toward a common radiometric Response among multidate, multisensor images. Remote Sensing of Environment, **35**: 11-27

Hay J.E., McKay D.C., (1985). Estimating solar irradiance on inclined surfaces - a review and assessment of methodologies. International Journal of Solar Energy, **3**: 203-240.

Hill J., Aifadopoulou D., (1990). Comparative analysis of Landsat-5 TM and SPOT HRV-1 data for use in multiple sensor approaches. Remote Sensing of Environment, **34**: 55-70.

Hill J., Sturm B. (1991). Radiometric corrections of multi-temporal Thematic Mapper data for the use in landcover classification and vegetation monitoring. International Journal of Remote Sensing, **12**: 1471-1491.

Hill J. (1990). Radiometric comparison and calibration of remotely sensed data from polar-orbiting earth observation satellites. Proceedings of the 5th Australasian Remote Sensing Conference, 8-12 October, Perth/Australia. 42-53.

Hill J. (1993). High precision land cover mapping and inventory with multi-temporal earth observation satellite data - The Ardèche experiment. Commission of the European Communities, Brussels, Luxembourg.

Hill J., Mehl W., Radeloff V. (1995). Improved forest mapping by combining corrections of atmospheric and topographic effects in Landsat TM imagery. In: Askne J. (Ed). Sensors and environmental applications of remote sensing. Proceedings of the 14th EARSeL Symposium, Basel, 143-151.

Holm R.G. (1987). The absolute radiometric calibration of space based sensors. Ph.D. Thesis. University of Arizona, Tucson.

Hostert P., Udelhoven T., Hill J., Diemer C. (1997). Employing a SPOT-derived Orthophoto and DEM for geometrically correction Landsat Data. Intermediate results of the DEMON-II project. University of Trier, Trier.

Itten K.I., Meyer P., Kellenberger T., Leu R., Sandmeier S., Bitter P. and Seidel K. (1992). Correction of the impact of topography and atmosphere on Landsat-TM forest mapping of Alpine regions. University of Zürich, Department of Geography, Zürich.

Kneizys F.X., Shettle E.P., Gallery W.O., Chetwynd J.H., Abreu L.W., Selby J.E.A., Fenn R.W., Clatchey R.A. (980). Atmospheric transmittance/radiance - Computer Code LOWTRAN 5, Optical Physics Division, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts.

Lacaze B., Caselles V., Coll C., Hill J., Hoff C., De Jong S., Mehl W., Negendank J.F.W., Riezebos H., Rubio E., Sommer S., Teixeira Filho J., Valor E. (1996). Integrated approaches to desertification mapping and monitoring in the Mediterranean Basin - Final Report of the DeMon-1 Project. European Commission, Bruxelles.

Markham B., Barker J., (1986). Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures. EOSAT (editors), 1986: Landsat Technical Notes – New Look-Up Tables. Lanham, MD

Moran M.S., Jackson R.D., Clarke T.R., Qi J., Cabot F., Thome K.J., Markham B.L. (1995). Reflectance factor retrieval from Landsat-TM and SPOT-HRV-data for bright and dark targets. Remote Sensing of Environment, **52:** 218-230.

Perez-Trejo F. (1994). Desertification and land degradation in the European Mediterranean, EUR 14850 EN, (Office for Official Publications of the European Communities: Luxembourg).

Röder A., Hill, J., Hostert P. (1997). A Summary on Calibration Issues for Landsat-EOS Data - Intermediate Results of the DeMon-II Project. University of Trier, Trier.

Royer A., Charbonneau L., Brochu R., Murphy J., Teillet P. (1987). Radiometric comparison of the Landsat-5 TM and MSS sensors. International Journal of Remote Sensing, **8 (4)**: 579-591.

Schott J.R., Salvaggio C., Volchok W.J. (1988). Radiometric scene normalization using pseudoinvariant features. Remote Sensing of Environment, **26**: 1-16.

Slater P.N., Biggar S.F., Holm S.F., Jackson R.D., Mao Y., Moran S., Palmer M., Yuan B. (1986). Absolute radiometric calibration of the Thematic Mapper. SPIE-Proceedings, **660**: pp. 2-8.

Smith M.O., Ustin S.L, Adams J.B., Gillespie A.R., (1990). Vegetation in deserts: I. A regional measure of abundance from multispectral images. Remote Sensing of Environment, **31**: 1-26.

Tabarant F. (1999). Apport de la télédétection et de la modélisation à l'étude de la dynamique de production d'un écosystème méditerranéen de chene vert (Quercus ilex L.) dans le sud de la France. Thèse, Univ. Orsay-Paris Sud, 173pp.

Tanré D., Deroo C., Duhaut P., Herman J.J., Morcette J., Perbos J., Deschamps P.Y. (1990). Description of a computer code to simulate the signal in the solar spectrum - the 5S code. International Journal of Remote Sensing, **11 (4)**: 659-668.

Teillet P.M., Fedosejevs G. (1995). On the dark target approach to atmospheric correction of remotely sensed data. Canadian Journal of Remote Sensing, **21:** 374-387.

Thome K., Markham B., Barker J., Slater P., Biggar S. (1997). Radiometric Calibration of Landsat. Photogrammetric Engineering and Remote Sensing, **63 (7)**: 853-858.

Tsiourlis G.M., Kasapidis P. (1999). Contribution to the study of degradation – desertification processes in central Crete: Structure, dynamics and function of Mediterranean ecosystems in relation to overgrazing in Asterousia and Psiloritis mountains (Greece). University of Crete & National Agricultural Research Foundation. Unpublished report

Vermote E., Tanré D., Deuzé J.L., Herman M. and Morcrette J.J. (1994). Second simulation of the satellite signal in the solar spectrum (6S), Greenbelt, Villeneuve, Berkshire.

Volchok W, Schott J. (1986). Scene to scene radiometric normalization of the reflected bands of the Landsat Thematic Mapper. Earth remote sensing using the Landsat Thematic Mapper and SPOT sensor systems, Slater, P.N. (Ed), SPIE-Proceedings, **660**: 9-17.

Wong F., Orth R., Friedmann D.E. (1981). The use of digital terrain models in the rectification of satellite-born imagery. Proceedings of the 15th International Symposium on Remote Sensing of Environment, Ann Arbor, 653-662.

LAND EVALUATION TO MITIGATE DESERTIFICATION

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Introduction

When we discuss the relationships "man-environment" it is unavoidable to refer to the land degradation and to the desertification. As a matter of fact man is the only animal able to go out of the ecosystem in which he lives and to apply from the outside forms of energy not in equilibrium with the ecosystem (Vink, 1975).
It is obvious that man applies energy to the ecosystem in order to derive benefits.
This can be accepted provided the benefits are durable and stainable.
In the case that the applied energy makes unstable the ecosystem with consequences on the land productivity we indicate such a status as land degradation which is defined as "ant process that results in loss of biological or economic productivity from the soil-vegetation-water system" (Thornes, 1996).
A particular and especially severe form of degradation is desertification that is taken to mean "land degradation in arid, semiardi and dry subhumid areas resulting from various factors including climatic variations and human activity" (Thornes, 1996).
Desertification as well as land degradation are different from but may be related to desertion (the abandonment of the land) and desertization (the creation of deserts). (Thornes and Burke, 1996).

Land and classification

Degradation and desertification occur on the land. This last is defined as "the result of a dynamic integrated system of components, alive and inanimate, and including man and his activities, which influence each other in various ways".
This conceptualization of the term "land" is synonimous with the term "geobiocoenose". The dynamic system which supports the geobiocoenose is the "ecosystem" (Zonneveld, 1979).
This concept is relevant because represents the linkage between land, environment, ecosystems, landscape and the sustainable land use (Fig.1).
Once the land had been classified taking into consideration characteristics, qualities and dynamism, then it is necessary to proceed to the land evaluation in genral terms capability or for specific uses suitability (see chapter 3). EIA procedures are also related to this point (see chapter 4).
[1]The land classification is assessed as a total character of a portion of the terrestrial surface and not in terms of the separate aspects of its component elements which are too

[1] The term "land classification" is intended here as a taxonomic one and not as categorization to be used in view of selected uses. This last possibility is here named "land evaluation"
of the land systems) coincides with that of some discernible geological or geomorphogenetic feature or processes. One must to be aware of the importance of the scale in problems connected with the

variable in their combinations and deter from the real comprehension of the ecosystems. Two are the main reasons for such an approach: from one side the land is a subject holistic in itself, from the other side the remote sensing techniques are suggestive of the global perception of the land. In addition to these reasons we may observe that man in the pre-scientific period created holistic names for personal land appraisal: swamp, bog, tundra, taiga, caatinga, brughiera, chaparral, matorral, macchia ecc.

According to Mabbut (1968) one may uses different approaches in classifying the land:

a) single parameter (e.g. vegetation density

b) group of parameters (e.g. vegetation density and botanical composition)

c) comprehensive land attribute (e.g. soil classification)

d) group of land attributes (e.g. soil classification and vegetation types)

e) unit of land classification as a whole.

a) and b) are parametric approaches, e) is holistic, c) and d) are intermediate,

In practice the parametric and holistic approaches are not so antithetical; as a matter of fact the holistic approach also needs parametrisation but is different the sequence of the chronolical phases.

With a holistic system, the observations would be first verified and then quantified according to a more exact analysis (measurements) of the parameters.

The Australian land classification (see Christian and Stewart, 1964) has been the first to appear, is holistic in character and uses the following categories:

1. "site" This is a part of the land surface, which is, for all practical purposes, uniform throughout its extend in land form, soil, and vegetation.

Variations in soils, vegetation, and landform do not exceed the variation allowed within the classification units of the various land attributes.

Site can be named also "ecotope", or "smallest concrete ecosystem" (Naveh and Lieberman 1984).

2. land unit. Is a group of related sites which have a recurring pattern of topography, soils and vegetation (Basinsky, 1978) which have special significance for some specific use (Hill, 1976). There is no general agreement on the term "land unit" FAO 1973 and DOS 1987 prefer "land facet".
3. land system. Is made up of geomorphologically and geographically associated land units which form recurrent patterns. The boundary of these recurrent patterns (hence

Land evaluation

The original model of land capability (Kleingebiel and Montgomery 1961) has not been substantially changed and it continue to be used as a reference.

Land is estimated through the examen of the intrinsic soil characteristics (depth, texture, workability, pH, stoniness, lime, permeability, etc.) and of the characteristics of the environment where the soil is located (microclimate, slope, drainage, risk of erosion,

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visual perception, as a matter of fact "at a more detailed level of working some land units would be regarded as land systems" (Christian and Stewart op.cit.)

Land and landscape classifications are similar used in other parts of the world are similar to the Australian one (Tab,).

The land or landscape classifications have proved in many cases to be useful (FAO 1992, 1996, Brinkman 1990, Klijn 1994, Purnell 1990, Regione Piemonte 1982, 1998, Smalley 1991, Giordano 1989, Ongaro 1988).

etc.). So soils can be grouped in 8 classes with progressively morelimitations for possible uses from the first to the eighth (cf. Table 2 and Fig. 3).
The basic principles of the land capability are two:
- the range amplitude of the possible uses;
- the sustainability of the uses.
The first four classes allow agricultural, range and forest uses; the following three classes exclude agriculture allowing range and forest uses, the last class should be considered as a natural reserve, where any kind of exploitation has to be avoided.
The land capability classification is categorical. In any case each part of the surface is placed into a class and/or subclass of the system.
This way of evaluating the land is referred to the usual land management based on the local habits and not to possible extraordinary transformations of the environment such as changing soil slope or soil depht. The capability classification may change after major improvements of the land.
Socio-economical factor are considered only as general frame, but they are not a classification criteria. Land capability for land evaluation is shown in Fig.2.

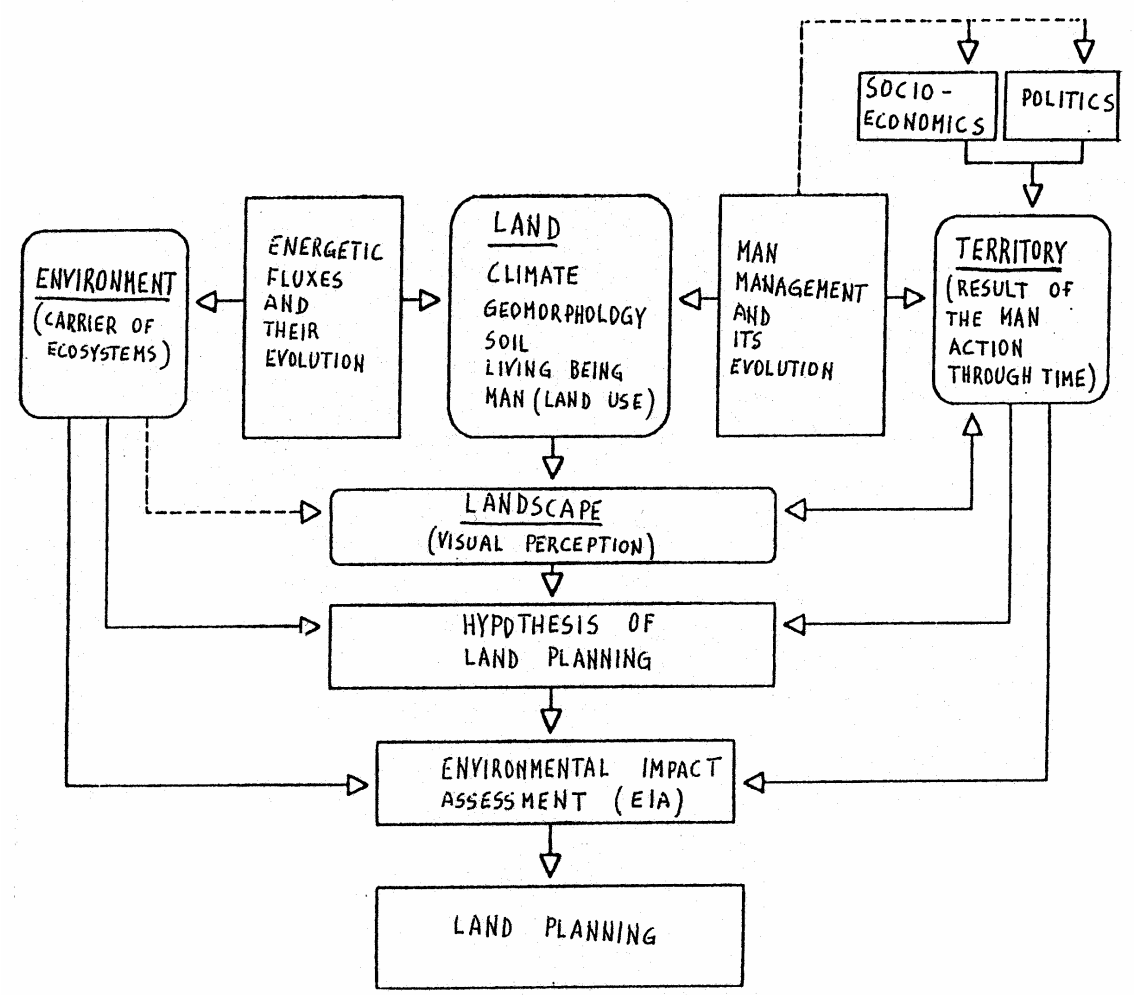


Figure 1: Representation of a site (ecotope) in its dynamic equilibrium between biophysical components and forms of energy (from Giordano 1992).

Scales and main characterizing aspects	Main types of land classification	FAO(1)	AUSTRALIA CSIRO(2)	GRAN BRETAGNA DOS(3)	OLANDA Van Zuldam(4)	OLANDA Zonneveld ITC	URSS SG(5)	CANADA CFS(6)	USA USSF(7)
Reconnaissance ≤ 1:250.000	Physical geography	land province	complex land system	land region	terrain province	main landscape	mestnosti	land district	land sub-region
Semi-detailed ≥ 1:250.000	Geomorphology	land system	land system	land system	land system	land system	Mestnosti and Urochischa	land system	land type association
Detailed ≥ 1:50.000	Geomorphology botany and soils	land facet	land unit	land facet	terrain units	land unit or land facet	Urochischa	land types	land types
Very detailed ≥ 1:1.000	Botany and soils	land element	site	--	terrain element	synonym of site	Facies	--	habitat type

(1) FAO Food and Agriculture Organization. Cfr.Howard 1973
(2) CSIRO Commonwealth Scientific and Industrial Research Organization. Cfr. Christian 1968
(3) DOS Directorate of Overseas Surveys Cfr. DOS 1987
(4) ITC International Institute for Aerial Survey and Earth Sciences. Cfr. Van Zuidam et al. 1979 and Zonneveld 1979
(5) S.G. Soviet Geography. Cfr. Isachenko 1973
(6) CFS Canadian Forestry Service. Cfr. Lacate 1969
(7) USFS United State Forestry Service. Cfr. Smalley 1982 e Steele et al. 1983

Table 1: Various systems of land classification.

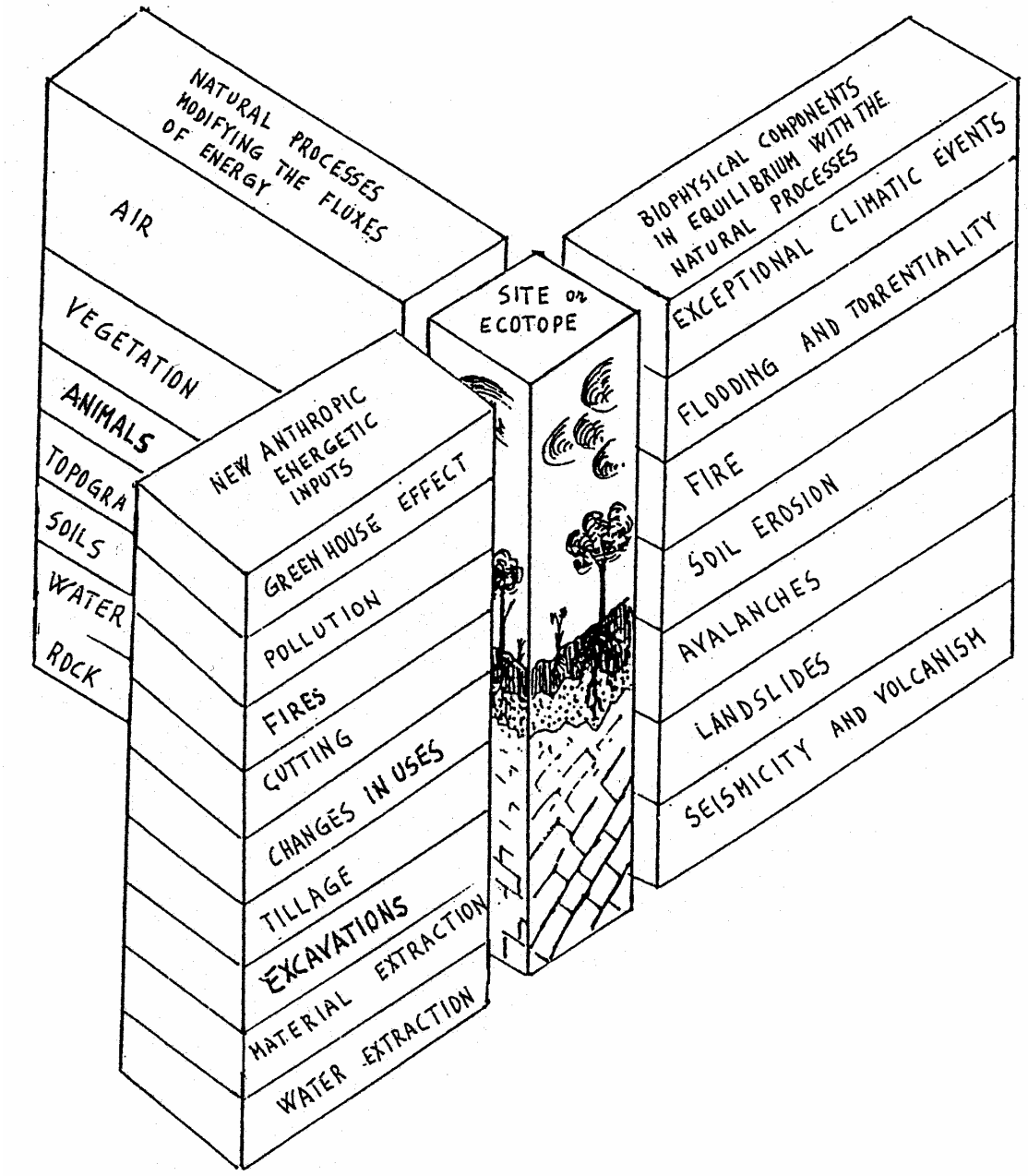


Figure 2: Relationships among land - environment - territory – landscape.

In practice land evaluation logically follows the definition of land units and the large application of remote sensing. Advantages of the land capability classification are (Aru et al., 1982):

- it allos to identify arable soils in plans and projects;
- it identifies soils suitable for reforestation, pasture, etc.;
- it delimits areas requiring drainage or reclamation;
- it delimits areas requiring special soil conservation practices (either at watershed or at farm level);
- it is useful for locating farm or community facilities (roads, etc.);

- it is an essential basis for planning land development (agricultural or not);
- it is a tool for political and economical decisions on the land.

On the other hand a disadvantage is the little specificity of answer which often are too generic.

Class I	Soils in Class I have few limitations that restrict their use
Class II	Soils in Class II have some limitations that reduce the choice of plants or require moderate conservation practices
Class III	Soils in Class III have severe limitations that reduce the choice of plants or require special conservation practices, or both
Class IV	Soils in Class IV have very severe limitations that restrict the choice of plants, require very special management, or both
Class V	Soils in Class V have little or no erosion hazards but have other limitations, impracticable to remove, that limit their use largely to pasture, range, woodland, or wildlife food and cover
Class VI	Soils in Class VI have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, or wildlife food and cover
Class VII	Soils in Class VII have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland or wildlife
Class VIII	Soils and landforms in Class VIII have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, or water supply, or to aesthetic purposes

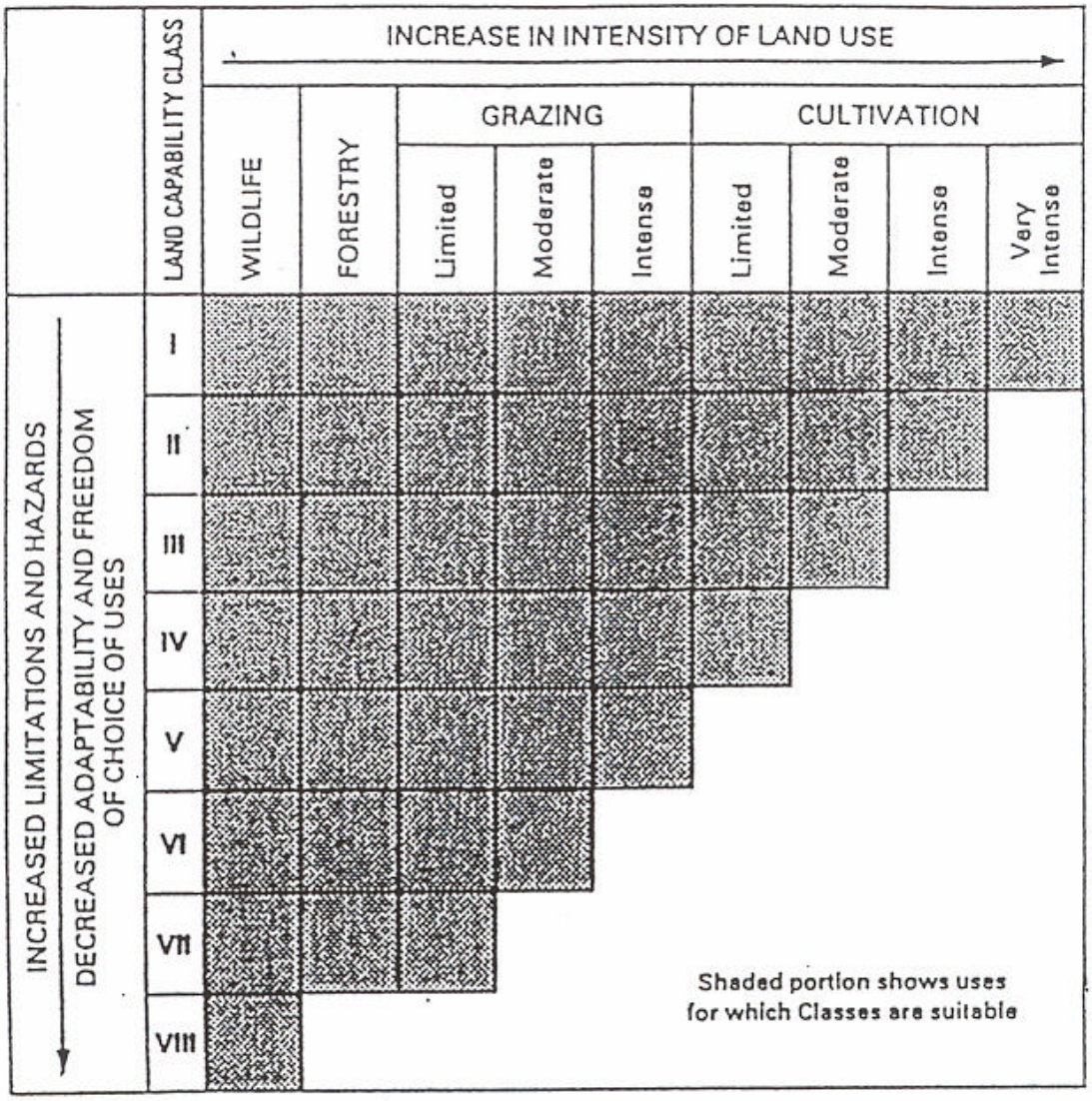
Source: Klingebiel and Montgomery (1961).

Table 2: The definitions of classes in the USDA Land Capability Classification.

Land suitability

The general framework of the land suitability refers to FAO 1976 and Purnell 1983.
It has to be stated that:
- land suitability is referred to a specific use;
- the land must be estimated by comparing outputs and inputs;
- land evaluation must concern geographical, economical and social conditions;
- suitability refers to sustainable land uses;
- several kinds of uses must be compared in the evaluation;
- many sciences are necessary for its approach.

Land suitability for a specific use is estimated by matching requirements for that use with land characteristics and qualities.



Source: Brady (1974) after Hockensmith and Steele (1949).

Figure 3: USDA land capability classification.

References

Christian C.S. and Stewart G.A. 1968 "Methodology of integrate survey" in: Aerial survey and integrated studies. Proceeding of Toulose Conference. UNESCO, Paris

D.O.S. 1967 "Planning the use for land resources, a guide to the work of the land resources" Division of the Directorate of Oversea Surveys. G.B.

Ellemberg H. 1963 "Vegetation Mitteleuropas mit den Alpen" Verlag, Stuttgart

FAO 1976 "A framework for land evaluation" Soil Bulletin n° 32 FAO, Rome

FAO 1996 "Agro-ecological zoning" Soil Bulletin n° 73, FAO, Rome

Giordano A. 1989 "Il telerilevamento nella valutazione delle risorse naturali" Relaz.e Monografie Agrarie Subtropicali e Tropicali. Ist.Agron.Oltremare, Firenze

Giordano A. 1992 "Relazioni tra terre, territorio, ambiente e paesaggio" Monti e Boschi n° 6

Howard J.A. 1973 "Phyto-geomorphic classification of land Units" FAO, Rome

Isachenko A.G. 1973 "On the method of applied landscape research" Investiya Wsesoyuznogo Geograficheskogo Obshchestva

Lacate P. 1969 "Biophysical land classification" Ministery of Forestry and Agriculture, Ottawa, Canada

McDonald R.C., Isbell R.F., Speight J.G, Walker J. and Hopkins M.S. 1984 “Australian soil and land survey” Field Handbook Inkata Press, Melbourne

Smalley G.W. 1982 “Classification and evaluation of forest sites on the Mid Cumberland Plateau” Forest Service USDA, General Tech. Report 90-30. Southern Exp.Station. New Orleans Luisiana, USA

Soil Conservation Service 1994 “Soil Survey Manual” USDA, Washington D.C.25

Steele R., Pfister R.D., Ryker R.A. e Kittams J.A. 1981 “Forest habitat type of central Idaho” Gen.Tech.Rep.Int. 114 Ogden UT USDA Forest Service. Intermountain Forest and Range Exp. Station

Treccani 1979 “Enciclopedia Italiana” Istituto della Enciclopedia Italiana, Roma

Van Zuidam R.A. e Van Zuidam.Cancelado F.I. 1979 “Terrain analysis and classification using aerial photographs (a geomorphological approach)” ITC Textbook of Photointerpretation - Vol.7, Enschede, NL

Zonneveld I.S. 1979 “Land evaluation and land(scape) science” Textbook of Photointerpretation - ITC Vol VII, Enschede (NL).

LAND USE PLANNING FOR MITIGATING DESERTIFICATION IN EUROPE

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What and where is desertification in Europe, and what is LUP for mitigating desertification?

What is desertification?

Desertification is land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities (UNEP, 1992).

What is land and what is land degradation?

Land is soil in a landscape with natural resources of weather, water, flora and fauna.
An equivalent that is often used for the term land is natural resources. Irrigation is not considered a natural water resource. Natural vegetation and wild life are considered natural resources (though often not without human interference). Cattle is not a natural resource. Land degradation is the reduction of productivity caused by: erosion, deterioration of physical, chemical or biological properties of soils, long-term loss of natural biota. If all aspects of land are in balance one considers land: good, fertile, productive, etc. If aspects are out of balance one calls the land sick. If the sickness worsens and the land dies one speaks of desertification (FAO/UNEP, 1996).

Where exist arid, semi-arid and dry subhumid areas in Europe?
In the Mediterranean climatic zone (Wickens, 1998).

Is there land degradation in the Mediterranean zone and if so, what is the main cause?
The above definition of desertification (as a form of land degradation) stresses the dynamic nature of desertification. In other words it is the rate that counts and not the present state of the land. There are numerous areas where land degradation has been severe in the past but has stabilized a long time ago. Although the land may be bare and deserted the rate of degradation is nil and therefore, by definition, there is zero desertification. The question is whether this also holds for the Mediterranean zone where historical degradation is obvious but present estimates of degradation rates seem highly controversial.
From 1991 – 1995 the European Union (EU) funded research linking land use and desertification in the Mediterranean area (MEDALUS I & II). Results are reported by Brandt and Thornes (1996). In a summary of their work no clear evidence of desertification could be given in spite of clear evidence of changes in land use due to land abandonment and the increase of irrigation (Margaris et al., 1996).
For Africa there are numerous studies challenging the desertification narrative (e.g. Swift, 1996). He argues that 'desertification is probably the best example of a set of ideas about the environment that emerge in a situation of scientific uncertainty and then prove persistent in the face of gradually accumulating evidence that they are not well-founded'. There is indeed rapidly mounting scientific evidence that the desertification story was inaccurate, and that the policies it suggested did not deal effectively with dryland degradation. The winners of this situation are national governments, aid burocracies and some scientists. The losers are dryland farmers and herders, whose own control over resources was whittled away by central planning, land tenure reform, ranches and other good ideas from governments, aid agencies and outside consultants.
It is the fate of development narratives to be replaced by counter-narratives. The present one is more attuned to the concerns and strengths of the previous losers, more plausible, using indigenous knowledge and customary institutions, more partipatory, based on better science, and more likely to result in better land management.

What is land use planning (LUP)?
LUP is the systematic assessment of land and water potential alternatives for land use and economic and social conditions in order to select and adopt the best land use options (FAO, 1993). Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances.
LUP is based on sound science on which the sustainable use of land and water resources is based. There are three main aspects of LUP:
1 Physical planning (the allocation of land)
2 Land development (the technology to be used)
3 Land management (the way the land will be managed)

What is land use planning (LUP) for mitigating desertification?

LUP is a tool for conservation policy making, which often is the stimulus for local action. In the end however, it is the local action (by the community of by the individual farmer or landowner) that will yield a degree of land stewardship sufficient to sustain our global farm (ISCO, 1999).

What is conservation policy making?

Planning public intervention to make up for market failures with the aim to get farmers adopt conservation technology. Traditionally the instruments used were: economic incentives and regulations. These instruments have failed. A modern approach will be discussed in Chapter 10.

What says Land Use Planning (LUP) at the European level?

Reasons to carry out LUP at the European level

1 The structural increase in agricultural productivity which means growing surpluses
2 The possibilities for further technical improvements to increase production have by no means been exhausted (WRR, 1992)
3 The growing concern for land degradation
4 The growing social pressure for attention to matters other than productivity (Mansveld and van der Lubbe, 1999)
5 The forecast growth in the budgetary burden on the EC if policy is not amended
6 The decreasing public support for agriculture (low % work force, low % national income and high % subsidies, etc)

In 1992 the Netherlands Scientific Council for Government Policy undertook a study on the perspectives for the rural areas in the European Community (WRR, 1992). There have been four scenario's (see also Chapter 6) used :

A Free market and free trade
B Regional development
C Nature and landscape
D Environmental protection

In the outcome of the study (ibid.) there are differences of a factor 2-7 between: amount of land required, costs, employment and use of fertilizers and pesticides. There are also similarities:

1 Continuing rise of productivity
2 Increasing land surpluses
3 Further loss of jobs in agriculture
4 Good possibilities for more environmentally friendly agricultural practices
5 Sufficient land is available to achieve an ecological main structure as the backbone of nature

In all cases, policy which is not geared to reducing the amount of land under cultivation would appear to be counterproductive. Expansion of the EU with states from central and eastern Europe will enhance this.

In present day economy there is a considerable tension between the vision of the Green Space as a production environment and the vision of the Green Space as a consumption environment. It is expected that this tension will increase with the increase of the network character of our society. With respect to land use there is an obvious shift in

power relations. Through the formation of production chains there is also a change in institutions around the productive function of land. All these changes will determine the behaviour of investors in the Green Space.

More specific: what means LUP for mitigating desertification in Europe?

Private land: full time farmers

New technologies on suitable land according to the produce & protect paradigm

- Crop Residue Management (or Conservation Tillage)
- Precision farming
- Manure management
- Soil organic matter management

Private land: Ecological farming

This is slowly growing type of farming that has its own planning paradigm, i.e. holistic planning (Mansveldt and van der Lubbe, 1999). Some planning principles are:

- Organic farming
- Closed nutrient balances at the farm level

Private land: part-time farmers

People who see their farm as a rent free place to live. They farm for pleasure or additional income. Some do this ecologically friendly. Other this is potentially an environmental hazard. They lack control on fertilizer & biocides control and lack the economy of scale.

Private land: abandoned (marginal) land

Alternative (productive?) land use:

- Forest
- Recreational (hunting, golf, survival, hiking, camping)

Public land

- Recreation
- Infrastructure (roads. Airport, etc)
- Wetlands
- Biodiversity (contineous nature infrastructure)
- River bank development
- Coastal development

What are the strategies for mitigating desertification?

We distinguish between a bio-physic and a socio-economic strategy although they are strongly linked.

Bio-physic strategy

There are two biophysical strategies. The first is aimed at decrease the soil's sensitivity for the eroding agents (erodibility). The main instrument to achieve this is an increase the soil's organic matter (SOM) content. Research has shown that under continuous agriculture the SOM percentage continues to decrease with a decreasing infiltration rate as the result, see Figure 1. About 30% of the world's land degradation is due to agricultural practices lowering SOM (FAO/UNEP, 1996).

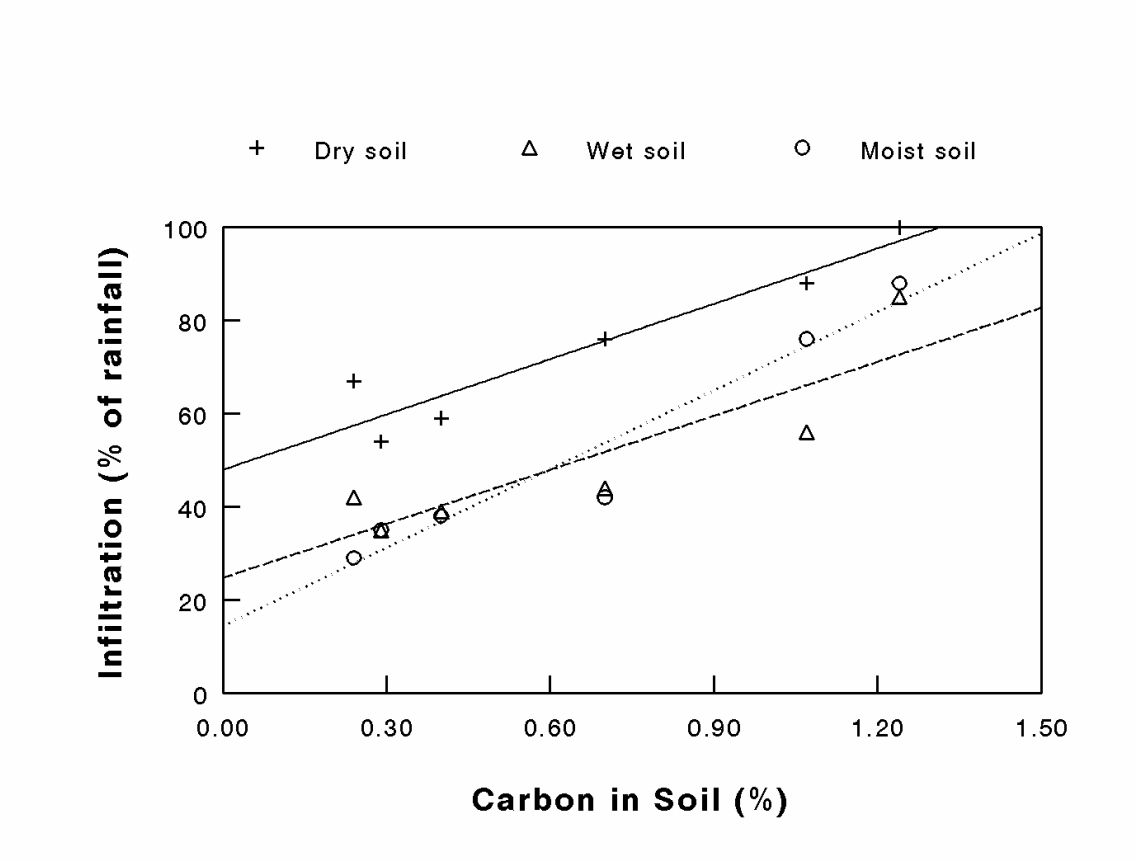


Figure 1: Infiltration as percentage of rainfall for dry, moist and wet soil conditions and various carbon percentages of sandy soils in the Sahel (after: Hoogmoed et al., 1999).

The second biophysical strategy is to decrease the effect of the rainfall erosivity. This can be achieved by an increase in the cover that protects the soil (Giraldez et al., 1989). Stream power can be reduced by increasing infiltration and increasing resistance against overland flow (increase roughness). About 70% of the world's land degradation is due to the removing of protective cover as the result of deforestation and overgrazing (FAO/ENEP, 1996).

A crop management technique that contributes to both strategies is crop residue mulching (CRM) also known as conservation tillage (CT). Rather arbitrary this technique leaves the soil under mulch at a coverage that never comes below 30%. The mulch originates from crop residues from the previous crop. The mulch reduces the

impact of rain, increase the surface roughness, stimulates soil fauna and contributes positively to the organic matter balance of the soil.

Socio-economic strategy
There should be an economic base for the planned intervention aimed at mitigating desertification. The planned intervention should be effective and efficient. Effective means that it reduces erosion till a predetermined rate. Efficient means that the expected benefits are larger than the costs. The latter can hold for private or social benefits and costs.

Who are actors and stakeholders in LUP?

Stakeholders in LUP
A stakeholder in LUP is anyone with an interest (stake) in the use of land for productive or any other kind of use. At least six groups of stakeholders can be distinguished:

- Policy makers
- Agribusiness and financial institutions (regional / multinational)
- Farmers (they want to make a living out of the land)
- Urban population (for leisure)
- Environmental (pressure) groups (for environmental concern)
- Consumers (through the quality of the food produced)

These stakeholder groups have different (often conflicting) goals with private as well as with public land. In a country like the Netherlands land use planning is dominated by the need for urban growth, infrastructure and space for leisure. Land use planning has become a highly complex multi-purpose almost social affair. Urban and other stakeholders dominate over farmers and the rural area is named the 'Green Space'. Environmental issues like manure management and groundwater pollution are more important than land management issues for crop production.

Actors in LUP
An actor is a land user. A land user is one who invests in land (labour, capital) in order to exploits land for consumption purposes. An actor group is a (more or less) homogeneous group of land users. Many different actor groups can be distinguished:

- small and large farmers
- grain, animal, horticulture farmers
- foresters
- mixed farms
- irrigated / rainfed farmers
- farmers with different farm styles

Planners
Usually a combination of stakeholders and actors

Victims of planning
Usually the actors

What are land use scenarios?

Land use scenario: A direction for land use that is envisioned for the time horizon being considered; in other words, an end-vision that could be possible.
Scenario's used by WRR (1992):
A Free market and free trade
B Regional development
C Nature and landscape
D Environmental protection
Scenarios used in Stroosnijder and van Rheenen (2000)
A Agro-technical,
B Socio-economic
C Environmental.
Scenario building is an essential step in land use planning. Scenario building should be done with a multi-disciplinary team of disciplinary experts. Still few people have experience with it. Economist are more able to participate since they are more forward looking. Social scientists are least eager to participate. Their discipline has more experience with backward looking and explanations (anthropology) than with scenario thinking.
For the Mediterranean area scenario's should pay attention to productive as well as consumptive land uses such as forestry, tourism, sports, biotypes, wild environments and part-time farmers. This was recognized already a long time as shown by Landi (1989) in Italy and Rubio et al., 1989 in Spain.

What are suitable spatial and temporal scales for LUP?

Spatial scales
LUP can be performed at several spatial scales. Amongst others:
- World (agro-chains)
- European scale (WRR, 1992)
- National scale
- Regional scale
- Watershed scale (Craswell et al., 1998)
- Village scale (Stroosnijder and van Rheenen, 2000)
- Farm (household) scale (Erenstein, 1999)

Each scale has its own set of stakeholders that should be involved in the planning process. This involvement is not synonym with participation. Usually the need for a participative approach increases with the lowering of the scale. In other words, planning at the European scale is typically top-down while planning at the farm scale is by definition fully partipatory.
An innovative method at the farm scale is proto-typing. This implies the planning (design) as well as the practical testing of the improved system.

Temporal scales
For private assessment or adoption the annual scale is best. For social (public) assessment or adoption the best scale depends on the life time of the interventions. For physical structures this is usually > 10 years.

What is the role of models in LUP?

Planning conservation means planning effective and efficient technology. Planning for effectiveness can only be carried out with a thorough understanding of the erosion process, a quantification of its rate, the standardisation of the conservation target and the foreseen biophysical effect of conservation alternatives. Planning for efficiency implies handling all socio-economic aspects; household resources, preferences, production technology and institutions.
In order to get answers to all these questions numerous type of models exist and are used with some success. There are five categories of models:
1 Models that determine the erosion rate
2 Models that convert erosion into effect on productivity
3 Models that convert conservation technology into effect on productivity
4 Models that convert effect on productivity in socio-economic impact.
5 Integrative models for land use systems
Within each class one further distinguish between: (i) statistical and (ii) (physically-based) simulation models. The statistical models include regression models, multivariate and factor analyses and geostatistical models. The simulation models, being more sophisticated, are also more data demanding. Yet the site-specific data needed to actually calibrate and evaluate model performance may well be limited. What's more, without an experimental base for validation, the value of models is limited and may be dangerously misleading. The more comprehensive methods are probably far too information intensive to be practical.

Models that determine the erosion rate
There is no straightforward cause-effect relationship for soil erosion. The problem is complex, having both bio-physical and socio-economic aspects; both only partly understood and hardly measurable.
Soil erosion has various facets - time, space and location (*i.e.* state of nature). The temporal and spatial dimensions imply the existence of externalities. They also make the problem scale dependent and give rise to often arbitrary decisions regarding boundaries and valuation. The problem is confounded by the locational aspect, whereby both the temporal and spatial dimensions and their valuation are extremely site-specific.
One of the most widely used erosion prediction models is the empirically-based *Universal Soil Loss Equation (USLE).* It is a simple multiplicative model, though USLE is somewhat of a misnomer. First, its 'universality' is limited as the model was calibrated on empirical data (2,300 plot years) from the mid-west USA. It has only been verified in temperate climates and cropping systems, medium textured soils and slope gradients of 3-18%. Second, 'loss' does not refer to the field sediment yield; *i.e.* the soil that actually leaves the field. Instead, it refers to soil movement off a particular slope segment and does not include deposition. The literal interpretation of USLE estimates will therefore systematically overestimate actual soil loss, a problem that is compounded when these

estimates from a small field plot are extrapolated to larger geographic scales. In addition, it should be acknowledged that it estimates long-term average gross soil movement (based on a normal 20-22 year rainfall cycle), using time to cancel out the short-term oscillations.
USLE is a relatively old model and newer models have been developed since then, including the revised USLE (RUSLE) which retains the one-equation format. SLEMSA (Soil Loss Estimator for Southern Africa) suffers from some of the inadequacies of USLE, but is claimed to be less data demanding using 'rational' parameters.
Other models are:
1980 ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulator)
1980 CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems)
1983 GUESS (Griffith University Erosion Sedimentation System)
1994 EUROSEM (European Soil Erosion Model)
1995 WEPP (Water Erosion Prediction Project
The WEPP model provides a more sophisticated, process-based model. Whatever the model, its use should be subject to prior validation - which is typically compounded by the lack of data.

Models that convert erosion into effect on productivity
Soil loss itself still says little about the economic costs of soil erosion - either on-site or off-site. The main on-site cost is the erosion-induced productivity loss - irrespective whether this loss is realized, offset or prevented. However, this entity is even more imperceptible than soil loss. There is no clear-cut relationship between soil loss and productivity loss, whereas productivity is influenced by numerous factors. The productivity loss has both ephemeral and cumulative elements and is highly site-specific. Technical change further masks the costs of the erosion-induced productivity loss - leading to a false sense of complacency.
Erosion-induced productivity loss is highly probable in most soils - though the extent and severity are unknown. Yet, it is the latter indicators of magnitude that are of interest from an economic point of view. The difficulty of establishing the physical relationships in combination with data limitations have favoured the use of uniform empirical equations, frequently ignoring the underlying complexities and site-specificity. Excessive extrapolations over time and space ensure that the reliability of available data is highly uneven. One specific example is the productivity index model, a regression-type parametric model. The *simulation models* simulate the underlying biophysical relationships over time, for different crops and management practices - the most renowned being EPIC (Erosion Productivity Impact Calculator).

Models that convert conservation technology into effect on productivity
The main effects of soil conservation are on soil depth, on available nutrients and water for crop growth. In Europe lack of nutrients is easily compensated by the application of chemical fertilisers. This is in contrast with the situation in developing countries. Here we will leave out a discussion on the conservation of nutrients and concentrate on the role of water conservation.
Deterministic crop growth models have been developed with the aim to explain and understand crop growth as it can be observed at different scales of observation. When

looking for an appropriate model one may choose an existing model or develop a new one. Since many models exist already, it must be possible to find a suitable existing model and adapt it to the specific user's and environment's needs. In choosing such an existing model there are a few essential choices to be made: (1) the complexity of the model, (2) time step of modelling and (3) time horizon of the effect.
The complexity of a model depends among others on whether one can assume one or more growth variables irrelevant. So-called potential growth models assume both water and nutrients ample available. This makes these factors irrelevant and water and nutrient submodels often do not even exist in these level-1 models. Level-2 models assume either water or nutrients ample available while the other factor is then part of the dynamic model.
Each process, being part of the deterministic modelling of crop growth, has its optimal time step. In level-2 models processes of the water balance have a much smaller optimum time step than crop growth processes. In such case, parametric modelling is used to match water balance processes with crop growth processes so that calculation time steps of one day can be used. However, it must always be checked whether crucial process information is not lost in this upscaling of the time frame.

Models that convert effect on productivity in socio-economic impact.
The bio-physic variability is compounded by socio-economic differences. Valuation of on-site effects is highly site-specific indeed, being dependent on local preferences, resource endowments, technology and institutions. Socio-economic variables - like input and output prices - can also influence soil erosion rates directly by inducing land management adaptations (*e.g.* in terms of intensification; extensification; or change in land use). Alternatively, soil erosion itself can induce land management changes. Indeed, farm management decisions and soil erosion are not independent.
The off-site costs of soil erosion revolve around the generally adverse effects imposed by the reappearance elsewhere of the eroded sediment and chemical pollutants. These costs can be important, but present various measurability problems and again tend to be highly site-specific. High off-site costs do not necessarily coincide with either high soil erosion rates or high on-site costs.
A major controversy revolves around when and whether the erosion-induced damage is irreversible. The soil resource presents a mixture of both renewable and non-renewable characteristics. In addition, opinions vary on the possibilities to substitute for the eroded soil resource. Some of the erosion-inflicted damage is only temporary and can easily be substituted. Other damages are more permanent. A confounding factor is that the line between the temporary and the permanent damage is dependent on the available technology and resources. The issue is compounded by the existence of thresholds and non-linearity's in responses. Irreversible damages increase the cost of soil erosion and thereby has profound implications for soil management and the urgency of intervention.
The assessment of soil conservation indeed poses considerable analytical challenges that have been tackled in varying ways. The different analytical approaches can be broadly grouped under two main schools of economic analysis: (i) the evaluation school and (ii) the adoption school. The *evaluation school* basically tries to quantify the economic impact of different soil conservation scenarios. The *adoption school* tries to explain and predict the divergences in soil conservation behaviour between economic agents. Each school therefore focuses on different aspects of soil conservation and is to a certain degree complementary to the other.

The *evaluation school* basically tries to quantify the economic impact of different soil conservation scenarios. However, such attempts are seriously curtailed by severe data limitations. A first analytic choice relates to the mode of costing erosion; a second choice to the mode of economic analysis.
Alternative approaches for costing erosion include the dose-response approach, replacement cost, mitigation behaviour, opportunity cost approach and demand curve approaches (*e.g.* contingent valuation and hedonic pricing).
The most frequently used modes of analysis include cost-benefit analysis (CBA) and optimisation models, with substantial differences between the two. CBA is a discrete approach and mainly revolves around the efficiency interpretation of soil conservation.
Optimisation models provide a continuous approach more in line with the optimal interpretation of conservation. The choice is influenced by the data limitations and the nature of analysis. Although models provide a powerful analytical tool, their strength in the end hinges on the underlying assumptions. The economic evaluation of soil conservation thereby eloquently highlights the analytical dilemma of opting for a 'messy' empirical or 'clean' theoretical approach.
The *adoption school* tries to explain and predict the divergences in soil conservation behaviour between economic agents. However, the extreme socio-economic site-specificity of soil conservation both warrants and entangles this line of research. The numerous factors that potentially influence the adoption decision of the farm household include resources, preferences, technology, and institutions.
The availability of land, labour and capital resources constrains the farm household's feasible set of activities. Implementing soil conservation may thereby imply substantial opportunity costs. The household's objectives and attitudes determine whether these costs are compatible with utility maximisation. Compatibility is more likely when implementing conservation implies short-term returns and reduces risk.

Integrative models for land use systems
An appropriate tool to investigate options for land use systems is the MGLP (Multiple Goal Linear Programming; Stomph and de Ridder, 2000) technique which can take into consideration several objective functions. This technique has been widely used in explorative land use studies at farm, regional, national and supra-national level. An MGLP model is developed from three blocks of information: objective functions, a matrix of input-output coefficients and constraints, demands and balances (figure 2).
An example of such a model is that which describes village land use in the Sahel. This model is known as SHARES (SHAred REources in the Sahel; Stroosnijder and van Rheenen, 2000)
An ***objective function*** is the mathematical description of an objective. An ***objective*** is a wish or aspiration of a decision-maker. A ***decision-maker*** is a stakeholder in a position to undertake an action and to select among alternative options. An actor is an example of a decision-maker. Any decision-maker has many objectives, each related to another ***attribute***, eg. labour use, risk avoidance, and production. An objective does not include the ***time horizon*** in which a decision-maker assumes to satisfy the aspiration nor the degree in which this aspiration is satisfied. An objective function describes the direction of improvement of an attribute. When a decision-maker is able to quantify the degree to which the objective has to be reached, e.g. minimal production level or maximum labour use the term ***goal*** is used. The combination of an objective funcion for an attribute with a target is a goal. The ***target*** is the quantified level of achievement for an

attribute. In general, goals take the form f (x) > or < t or f (x) = t, where t is the aspiration level or target value. So, a goal is a quantification (in terms of degree of satisfaction and in terms of time) of an objective.

Input-output coefficients quantify the relation between inputs used in a production technology and outputs obtained. The coefficients are always specific to land units or production situations. In semi-arid climates this also implies different outputs for years that differ in rainfall amount and pattern. To obtain these coefficients the production situations or land units are characterized using a qualitative and quantitative land evaluation. The qualitative land evaluation answers the question which land unit is suitable for what. In the quantitative land evaluation all relevant inputs and outputs are quantified for each feasible combination of production technology and production situation. The relevancy of inputs and outputs is determined in relation to the objective functions.

The biophysical and socio-economic environment the actor groups have to cope with is formalized. This is done by translating the biophysical and socio-economic environment into ***constraints*** (e.g. the available area of each land unit and the labour availability), ***demands*** (e.g. the production of cereals or milk needed for self-sufficiency) and ***balances*** (e.g. not more manure can be used than is actually produced). Thus, a constraint is a limiting resource, which obstructs the achievement of a given goal under given conditions. An important consideration in this respect is the access to land. ***Access to land*** is the extent in which a land user has the right of the usufruct of a certain piece of land. A demand is an upper or a lower limit that is placed on an objective function. And, a balance has the primary purpose to ascertain that the supply of an input or product is at least as great as its demand in the model.

Present and future land use options can be explored by optimising while changing upper and lower target values for objective functions. A ***land use option*** is a way of using land that is possible with the presently available technologies and a ***future land use option*** is a land use option that uses technologies which are expected to become available considering the defined time horizon. Land use options are selected for exploration based on assumptions on development, i.e. land use scenario's. A ***land use scenario*** is a direction for land use that is envisioned for the time horizon being considered; in other words, an end-vision that could be possible. Three broad categories of scenarios are in general distinguished: agro-technical (eg reaching certain production levels of milk and cereals), socio-economic (eg. maximizing or minimizing labour use, reaching minimal income levels in poor years) and environmental (eg. limiting erosion losses to certain levels, minimal acreage for undisturbed vegetation and wild life).

The general methodology of explorative land use studies is shown in Figure 2. The output of the model will be optimal values for objective functions as well as an indication of the amount of resources required to achieve these values. The goals of actors for instance, will determine which part of the output is sold and thus becomes a marketable surplus. But also, these goals will tell whether grazing of animals on stubble after cropping is due to social linkages with owners of the cropped fields. Such economic and social information helps to analyse whether the system is economically and socially sustainable given both the economic and the social environment.

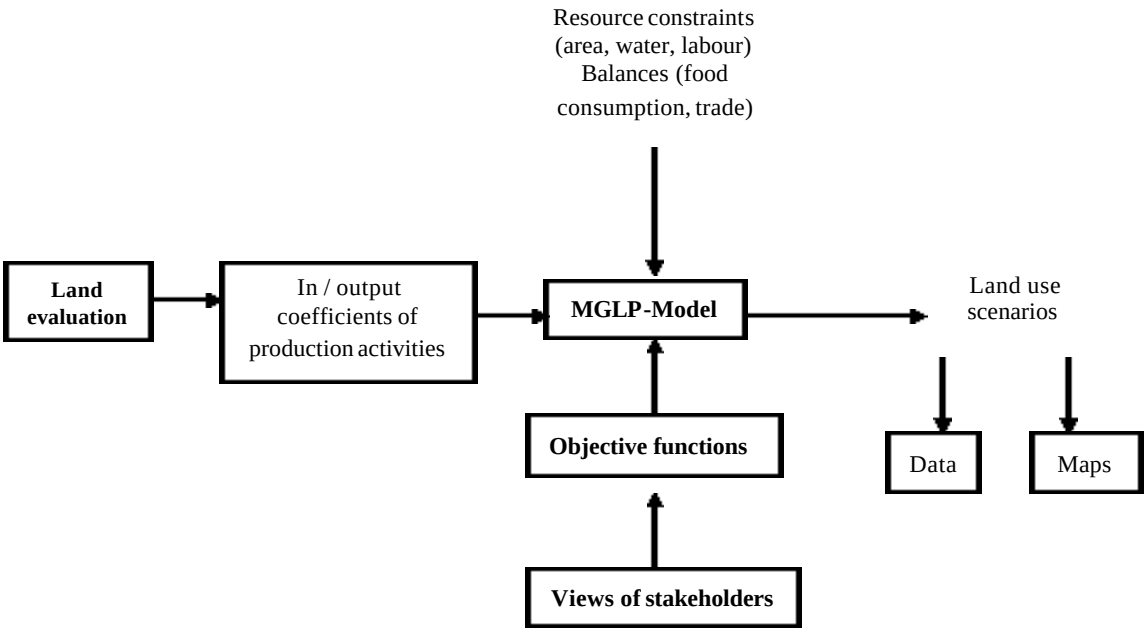


Figure 2: The general methodology of explorative land use studies.

How to find hot spots for LUP?

Why should one try to find hot spots?

Hot spots are areas with rapid change and risk of land degradation. With limited public funds for conservation and research due to a decreasing public support for agriculture and the rural areas in general, it is a matter of using these funds most efficient. That means where the ratio of conservation benefits over costs is greatest.

Recently, Koning (1999), proposed a method to analyse land use dynamics in space and time and which can be used as a contribution to LUP. The method especially provide insight in the relation between land use and the natural resources. The method consist of three steps:

- Analysis of actual land use at different scales. This provide insight in the biophysical and socio-economic drivers in actual land use.
- Modeling of (near) future land use. In this modeling use is made of the insight of drivers gained in step 1.
- Quantification of the effect of (near) future land use on the natural resources.

Ad 1. Multiple regression analysis of land use (derived from census data over a grid covering the area under investigation) versus a large number of land use drivers or their proxies. Land use in cells is aggregated into different spatial scales. The regression is carried out independently for these different scales. Results from a case study in Equador showed considerable differences in drivers for the distinguished scales.

Ad 2. The models contains two modules: a demand and an allocation module. Changes in demand are estimated on the basis of scenarios taking into account population growth, consumption patterns and export developments. The allocation (of land) module takes into account the non-linear complexities of land use. The module takes into account typical scale aspects obtained in step 1. These are competition between land use

types, interconnectivity of landscape elements, proximity of infrastructure, influence of urban centers and migration.
Ad 3. As an example of the effect on land use the nutrient balance can be used as an indicator for the sustainability of land use.
This approach is able to identify 'hot spots', i.e. areas with rapid land use changes in the near future. Timely planning of these changes may be wanted. The method stresses the value of good agricultural census data.

What is a modern planning approach?

Planning theories
There exist many classical planning theories and systems to categorize them. One division is:

- Synoptic planning (based on the system approach)
- Incremental planning (tries to arrive at consensus)
- Transactive planning (humans are central)
- Advocacy (orientated to deprived groups)
- Radical planning (ideal society)

Planning may proceed in many ways. Clear goals may be set or a process may simply proceed without goals. There are advantages and disadvantages to each method. The choice of a planning process is often highly context dependent. It is increasingly clear, however, that unilateral planning processes that seek to exclude the public will fail. The rapid rise of public interest in, and knowledge about, environmental issues has created a climate in which public participation is expected and, indeed, required in almost every planing situation.
Planning is not a linear process. An innovative planning principle is called mixed scanning. It is a method where one jumps from a more abstract high scale level to the more concrete regional – local scale level. FAO/UNEP (1996) provides a blueprint for a modern LUP approach.

Participative approach / platforms
Main cause of poor conservation adoption by farmers is attributed to the top down approach in the past. The technology was good only the farmers were to make to adopt it. Nowadays one realises that farmers are the decision makers and are bound to resource constraints, production technology, preferences and institutions. Institutions is an umbrella term that includes formal and informal rules of conduct at all levels encompassing both market and non-market exchange. Institutions are not organisations though organisations are defined by institutions.
Participation is not without problems. Care is needed to recognize inclusive and exclusive processes in a gender sensitive way (Koppen, 1999). The following steps can be identified:

- Identification of stakeholders
- Education and information of all stakeholders
- Creation of forums for negotiations
- Agreement on the rules
- Empowerment of the people

Hoek (1992) distinguishes three phases:
Trial phase (Land use is matched with potential interventions). Methodologies include (components of):

- Farming Systems Analysis (Stroosnijder et al., 1994)
- Land Evaluation
- Agro-Ecosystems Analysis
- Rapid Rural Appraisal
- Gender Analysis
- Landscape Planning

Development phase: (Organizations are adjusted to prospected Land Use). Methodologies include (components of):

- Extension
- Management

Expansion phase: (Organizations support improved Land Use)

Integrated development (SWC often hidden)

The credo now is production and protection, i.e. make sure that new technology is used that provide higher returns to farmers (production) and are good for conservation at the same time. This approach is also known as the integrated (rural development) approach. A special case of this is integrated watershed management (Heathcote, 1998). Since the adoption of conservation practices by farmers depend on their resources, preferences, markets and institutions it may well be that a change in one of these may affect adoption more than ever could have been foreseen,

Efficient technology

In the past there have been a bias on mechanical (line) measures. Recent studies (Erenstein, 1999) show that areal soil management measures that enhance both production and conservation are more efficient. In general new technology should be developed that:

- increase benefits for the farmer and forward these benefits in time
- reduce costs and backward these as much in time

The following checklist on the benefit side applies (Erenstein, 1999):

- Short term benefits (one year)
- Enhancement of household utility maximisation
- B/C ratio > 1.5-2.0
- Competitive with alternative investments
- Institutional feasonable
- Predictable (risk-averse)

The following checklist on the costs side applies (Erenstein, 1999):

- Cheap (low resource requirements)
- Simple (low learning costs)
- Divisible
- Easy to maintain
- Compatable with the farm system
- Institutional feasonable

- Flexible

Based in indigenous knowledge

In the past too much emphasis on newly introduced technology. This creates high learning costs and often does not match with local institutions, preferences, etc. Research has shown that adhering technology development to existing technology (often called indigenous technology) is a more viable development way. What is true for technology holds for knowledge in general.

Interdisciplinary (b-g integration)

Major constraint not technical but socio-economic. Land use planning of often a sectorial affair. The larger its scale the more sectors of the economy take part in the planning process. At all scales it is important to include several disciplines in the process, i.e. LUP is an interdisciplinary challenge and should be performed with a multi-disciplinary team of experts(beta – gamma integration).

Support from all levels

Although actor participation is crucial for success, support form the highest level is also needed. In fact all levels between the highest and the lowest should be aware of the objectives and support the steps to be taken. However, there is often a lack of political will, a burocratic government and lack of proper legislation.

Careful public intervention (incentives)

Intervention should be carefully targetted. Since the aim of present-day conservation is production and conservation the set of incentives should address both:

Incentives for production are (FAO/UNEP, 1996):

- Right to land
- Economic incentives
- Access to information, inputs and services
- Improvement of the infrastructure

Incentives for conservation are (FAO/UNEP, 1996):

- Security of tenure
- Productive land conservation techniques
- People's participation
- Charges and sanctions

Work at the watershed scale

Planning of soil conservation is seriously hampered by the difficulty in quantification erosion and in valuating its impact. This is true for on-site effects but even worse for off-site effects. Claimed downstream benefits have often appeared illusory. This implies that soil conservation interventions are justified primarily on on-site grounds.

The *downstream effects* of land degradation consist of both gradual changes (in sedimentation and streamflow) that go often unnoticed to the general public, and irregular abrupt effects after special events, such as peak storms (leading to flooding) and severe droughts. These latter effects are unpredictable and difficult to quantify, but clearly visible and able to mobilise people and funds.

The technology of Geographical Information Systems (GIS) is especially helpful in working at this scale (Turner, 1998). The value of GIS contrasts with the disappointing value of remote sensing in monitoring land use (changes), Webster, 1998.

How profitable is mitigation desertification?

Our present understanding of land degradation and erosion in falls short. There is a general lack of cause-effect relations. In addition, qualification of the effects of erosion and conservation is difficult both on-site and off-site. Also the valuation of the effects, if any, is questionable. This makes the assessment of conservation a difficult affair.
For the appraisal of SWC projects much attention needs to be paid to the identification of all actor groups involved and to an assessment of all major on-site and downstream effects of the measures. This requires both socio-economic research and hydrological and erosion research, and a thorough integration of biophysical and economic aspects. Impact assessment is the second of three main phases in project appraisal: decision-making framework, impact assessment and evaluation, see Table 1.
In the impact assessment use can be made of water and nutrient balances and yield response functions, which can be incorporated in spreadsheet models. In the subsequent economic appraisal use can then be made of both cost-benefit analysis (CBA) and multi-criteria analysis (MCA). The efficiency of the projects can be conveniently assessed with CBA, when the effects can be quantified and valued. Whereas MCA can be used to assess scores on non-monetary attributes of the various evaluation criteria, and can also show how conflicting objectives of different actors affect these scores.
On-site effects of erosion are often ignored by land users themselves, since they appear slowly and are masked by annual yield fluctuations, increased fertiliser use and other factors. Even when land users are aware of the erosion problem, there may be a variety of reasons why they do not call for action. The determination of the on-site benefits is often difficult. Since benefits usually do not consist of yield increases but of 'a prevented decline' of yields, much attention needs to be paid to the definition of project options and in particular to that of the 'without-project' situation.
The *downstream effects* of land degradation consist of both gradual changes (in sedimentation and streamflow) that go often unnoticed to the general public, and irregular abrupt effects after special events, such as peak storms (leading to flooding) and severe droughts. These latter effects are unpredictable and difficult to quantify, but clearly visible and able to mobilise people and funds.

How can mitigation adoption be planned?

LUP always implies the planning of public intervention (incentives). While there is a general feeling that the use of incentives should be minimised, it is also realised that there exist cases, in particular in the field of natural resource management that incentives can be justified, also from an economic viewpoint (Graaff, 1999). This is in particular the case when market failures (in their broadest sense) occur, and the incentives should therefore fit well in the overall policy framework.
Many arguments to justify government intervention play a role in the provision of incentives for SWC measures. The public goods nature of land and water resources can be

a strong argument and the externality argument is important as well, since many of the effects of SWC-activities do not only accrue to the land user concerned, but also to their neighbours, downstream people and future generations. This is one of the reasons why a watershed approach is advocated in the planning and implementation of SWC activities.
The book 'Incentives in soil conservation; from theory to practice' (Sanders et al., 1999) gives an excellent general overview of the use of incentives for soil conservation activities in various countries in Africa and Asia. It also brings forward several dilemma's in using incentives,
To remove the major constraints towards adoption of conservation measures various types of incentives can be used. To be economically and socially acceptable, these incentives should be effective (results in line with their purposes), efficient (costs not exceeding social gains), equitable (all actors agreeing on fair compensation), and also 'practically feasible'.
Incentives for SWC measures are meant to change the behavior of land users towards conserving instead of depleting their soil and water resources. At the same time the incentives should form a compensation to the land users for that part of their (investment) costs for which they do not receive the benefits themselves. Incentives form part of government policies that are aimed at objectives that the free market can not achieve on its own: the so-called market failures.
These incentives constitute government interventions that benefit certain target groups.
In order to determine the effectiveness of incentives for SWC, answers to the following questions should be obtained:

- Which market failures can be identified in relation to SWC and how could their effects be quantified?
- How can this serve as a guideline for the extent of incentives for SWC activities and programs?
- What are the physical and subsequent socio-economic effects brought about by SWC activities?
- What are the main barriers and thresholds for the adoption of SWC measures among farmers in different situations;
- And what is the influence of various incentive systems on these barriers and thresholds?

The research aimed at these questions combines physical research methods for analysing the bio-physical effects of SWC measures and agro-economic methods to analyse economic policies and to understand farmer's adoption behaviour. Research is required at various levels for which Figure 3 gives a framework.
At the **national and regional** level research should focus on the policy environment within which incentives for SWC measures are provided. An analysis must be made of past and present national conservation strategies, economic policies, extension approaches and specific incentives in the field of soil and water conservation, and of the market and government failures encountered in SWC.
At **watershed level** a participatory monitoring program (PMP) must be undertaken in selected sub-watersheds. This should combine on-farm erosion and SWC research with careful monitoring of on- and off-site bio-physical and socio-economic effects of the dominant SWC measures and the incentive system used for its promotion. It should be linked to a farm survey (see hereunder).
At the **farm level** the emphasis will be on the adoption process of SWC measures and the influence of incentives on that.

	Project Preparation		Project Appraisal
1	*Preparatory phase*	**2**	*Decision making framework*
1.1	Ecological setting	2.1	Alternatives or options
1.2	Socio-econ. Situation	2.2	Role of actors
1.3	Project objectives	2.3	Evaluation criteria
1.4	Potential components		
1.5	Project organisation	**3**	*Impact assessment*
		3.1	Inputs by actors
		3.2	On-site impacts
		3.3	Downstream impacts
		3.4	Other impacts
		3.5	Overall impacts
		4.	*Evaluation*
		4.1	Financial analysis
		4.2	Efficiency assessment
		4.3	Equity considerations
		4.4	Sustainability
		4.5	Trade-off analysis

Table 1 Framework for the preparation and appraisal of SWC activities

This will start with a general historical review of (non-) acceptance or adaptation by farmers of selected SWC measures, within the framework of past policies, extension approaches and incentive systems. Subsequently an analytical framework for the adoption process of SWC measures should be drawn up. To fully understand farmers' rationale in adopting measures for natural resource conservation, a detailed household modelling will be undertaken. A working group of agricultural economists from the Free University in Amsterdam and from Wageningen Agricultural University has just scrutinised existing models in this field, including both mathematical models and artificial intelligence. The best suited farm survey should focus on labour utilisation, income and expenditure data and attitudes of households. For the farm household analysis a farm market approach (FMA) will be followed. In this approach the market is internalised within the farm household system, not only with respect to farm inputs and outputs but also with regard to trade and other job opportunities (Stroosnijder, 1997).

The olive case (adapted from Graaff and Eppink, 1999)

Abstract

The EU spent about two billion ECU per year on subsidies for the olive oil sector. The European Commission (EC) has formulated two options to change the subsidy system, but these do not take the production systems and environmental aspects into account. Many olive plantations are affected by soil erosion. This paper analyses olive tree production systems in southern Spain, the subsidy systems, the soil erosion problems and conservation options. It then raises the question whether the subsidies could not be

provided in a different way, in order to make olive tree cultivation more sustainable by reducing on-site soil erosion and off-site flood hazard.

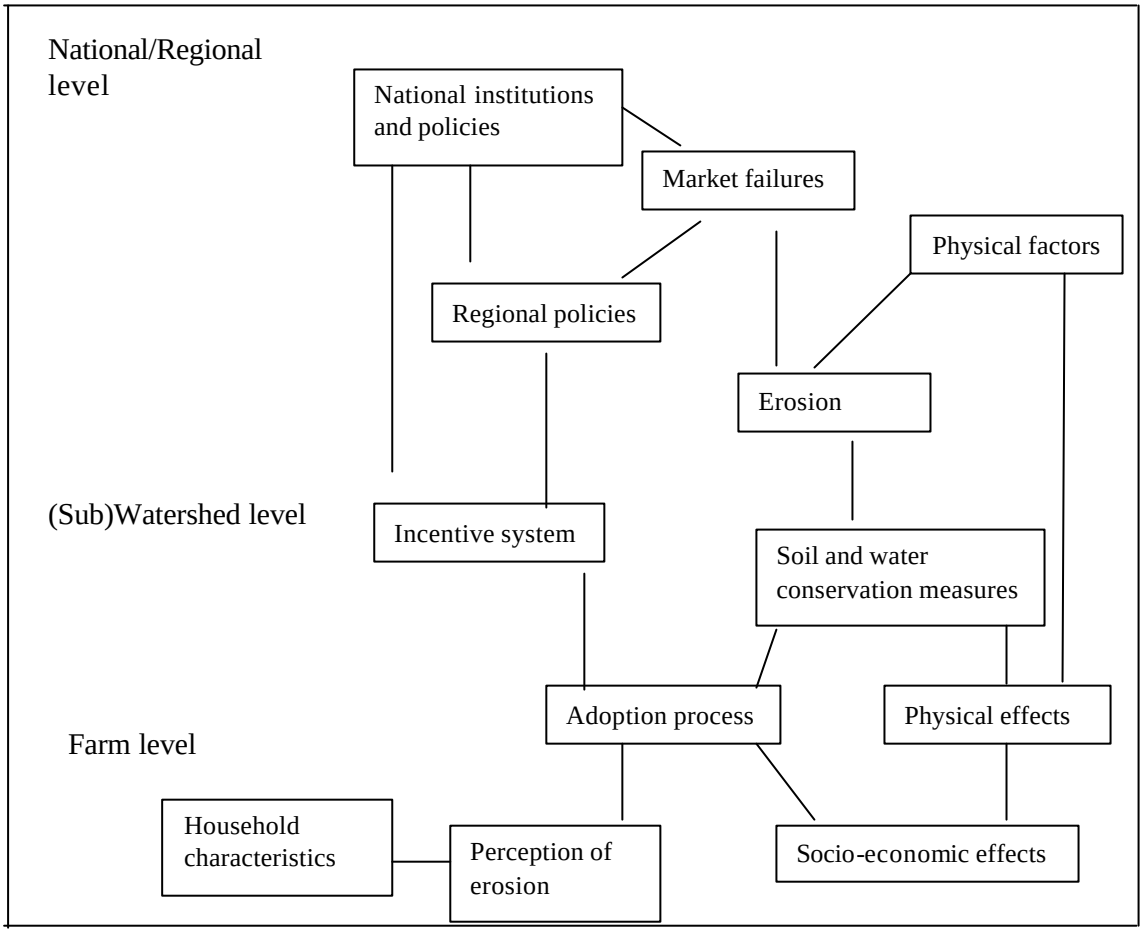


Figure 3: Framework for analyzing effectiveness of incentives for soil and water conservation.

Introduction

Within the European Union (EU) special attention is given to the development of economically deprived regions. Most of these regions are located in the Mediterranean zone, and include the whole of Greece and Portugal, two-third of Spain and half of Italy. It is interesting to note that the boundaries of these zones to a large extent coincide with the most northern limit of olive tree cultivation. Aid to the olive oil sector thus benefits much of these economically deprived rural areas.

Production systems

A distinction is made between three broad categories of olive tree plantations, whereby both the more or less typical ecological and the dominant production characteristics are presented (Table 2). The categories do, of course, not represent homogenous groups of farms, and boundaries are not sharp. A well-managed, relatively young traditional rainfed plantation may have in fact similar features and yields as a rather old, not well-

maintained semi-intensive plantation. However the three patterns can be clearly observed in the field and do serve analytical purposes.

Plantation type Characteristics	Traditional Rainfed	Semi-intensive Rainfed	Intensive (Supplem.) Irrigated
Ecological			
Soil erosion	Usually low	Often high	Medium
Bio-diversity	High	Low	Very low
Environmental effects	Fire prevention	Pesticide pollution	Pesticide pollution
Production			
Tree type, variety	Large, old	Smaller	Dwarf varieties
Tree density per ha	Up to 100 (10 x 10m)	100-200 (8m x 8m)	Over 200 (7m x 7m)
Chemical inputs	Very low	High	High
Weed control	Occasional harrowing	Regular harrowing	Herbicide use
Terracing	Common	Occasional	Rare
Grazing undergrowth	Rare	Rare	None
Average yield	1,000 kg/ha	2,100 kg/ha	4,000 kg/ha
Consistency of yield	Very low	Low	High
Estim. share area	*50 %*	*40 %*	*10 %*
Estim. share product.	*29 %*	*48 %*	*23 %*

Table 2: Ecological and production characteristics of three olive plantation systems in Spain.

Subsidies to olive farmers

The key elements of the current production support system are:

- a minimum price for producers, maintained by a combination of import restrictions and intervention buying;
- an actual production subsidy per kilo of oil produced;
- a special support system for small producers (producing less than 500 kg olive oil per year);

The EC wants to change the subsidy system because of their budget restrictions, the new world trade rules and alleged fraud. Two new options were formulated in 1997: the first is a uniform system on the basis of oil production and the second based on the number of olive trees. Both options were met with much resistance among farmers and their organisations, in particular in Spain.

The effects of the proposed subsidy systems.

The first EU option for revising the subsidy scheme, envisages to abolish the special arrangement for small producers, will lead to a more drastic conversion towards intensive plantations, and a large-scale abandonment of traditional plantations. Farmers will focus exclusively on increasing oil production, and erosive practices such as clean weeding may become the general rule. Large producers with intensive production systems will benefit most, and the nature conservation function of small traditional plantations will not be taken into account.

The second EU revision proposal, to provide a payment per tree, will lead to a further expansion of olive tree plantations to more marginally suitable zones, and to an excessive number of olive trees per ha. While the latter could possibly have some positive effect on controlling soil erosion, the former tendency will certainly contribute to further land degradation and eventually to lower production levels. Since the subsidy does not provide any direct incentive to produce oil, small producers may in fact decide to reduce labour inputs and even to refrain from harvesting the trees. Good for nature conservation, but not for production and income.

Soil erosion problems in olive orchards

The Mediterranean region is one of the areas hardest hit by water erosion in the world. With the practise of clean weeding under olive trees and the replacement of manure by fertilisers, soil organic matter content and water holding capacity are reduced and hence infiltration capacity. This reduces production and increases rates of runoff, which after high intensity rainfall causes much rill and gully erosion and extensive flooding downstream.

Since traditional rainfed olive plantations are often situated on soils less suitable for cropping and on the steeper slopes, erosion levels are very high. Soil erosion by water amounts in Andalusia annually to about 80 t/ha or approximately 7 mm. As a result of the water, soil and nutrient losses associated with this erosion, traditional olive plantations on the hills are badly affected.

Soil and water conservation options in olive orchards

It is accepted that conventional (clean) tillage increases erosion on most soils and that soil losses are cut when tillage is reduced. In Andalusia about 10 tractor hours per ha are spent on tillage, mostly using tine cultivators. Disc harrowing would be more effective in reducing weed growth, but this can cause severe damage of the small feeder roots, which are crucial for tapping the superficial soil moisture after minor rainfall.

The introduction of herbicides in the 1960s has stimulated non-tillage practices. This treatment led to a 20 % increase of the olive production and a saving in machine costs of 5,000 Ptas/ha. Moreover the costs of harvesting was also reduced.

Apart from tillage, attention is also paid to the use of live plants under olives. However, olive still being mainly a rainfed crop, one has to look carefully at the water balance effects of such cover crops. In spring olives have high moisture requirements, since maximum vegetative growth occurs and flowering and fruit set take place. In Cordoba Province experiments in the 1960s, investigations the effects of subterranean clover (*Trifolium subterraneum*) showed that runoff and soil erosion were greatly reduced thereby increasing water availability. Recently attention is paid to some other crops to control erosion under olive trees. Thus far the best results have been obtained with barley (*Hordeum vulgare*) and with vetch (*Vicia sativa*, L.). In the very dry year 1995 vetch and barley cover resulted in a 11 % respectively 6 % higher soil moisture content than under minimum tillage. Vetch has the advantage over barley of fixing a large amount of nitrogen in the soil (about 100 kg/ha), but it consumes more water and its seeds are more expensive Besides, its residues are mineralised within 1-2 months after killing.

Many old olive orchards in the uplands were terraced. These terraces were well adapted to the local situation, but proved not suitable for mechanisation. Many of these terraces are now deteriorating or being removed. In stead of these rather expensive mechanical

conservation measures, vegetative strips along the contour lines could be considered on steep land.
Mountain and hill tops above the olive plantations should preferably be reforested. The regional government of Andalucia provides special subsidies for that purpose. Unfortunately the reforestation efforts by the Government have in the past only barely compensated the loss of forests by fire.

An alternative subsidy system, focussing on both production and conservation

Before a new policy can be introduced, the register of olive cultivation, already embarked upon in 1989, has to be completed in each of the five EU producer states: Spain, Italy, Greece, Portugal and France. Besides a computerised integrated control system on the basis of a Geographical Information System (GIS) has to be introduced.
Considering that neither of the two proposed options provides an optimal solution in line with the objectives set by the EU, and that neither of these take soil and water conservation into account, an alternative subsidy system for producers is hereby proposed. This system provides first of all a fixed income for 'olive tree plantation holders' to enable them to maintain their plantations, and subsequently adds to that incentives to improve the productivity of the plantation and/or to improve soil and water conservation, wherever this is needed.
The system could for example consist of a basic subsidy of 2 ECU per olive tree. For the basic subsidies an upper limit of the number of trees per ha need to be applied, which will vary by ecological zone and between rainfed respectively irrigated systems: e.g. 150 for rainfed and 250 for irrigated systems in areas with less than 500 mm of rainfall per year.
The base system should be complemented with two different bonuses: one for production and one for soil and water conservation. Farmers could qualify for the production bonus, when their records (at the oil-mill) show that they have obtained a production of more than e.g. 3 kg olive oil per (registered) tree. This bonus could increase with the production above this minimum. In order to qualify for such a bonus, farmers should better not use the multiple stem system or otherwise try to increase the number of trees.
For the conservation bonus, the GIS should produce a simple land evaluation system, whereby for example four land capability classes are distinguished: 1. flat or gently sloping land (5 % slope or less): no bonus; 2. sloping land (slopes above 5 %) with soils unsuitable for olive trees (e.g. marls): no bonus; 3. moderately sloping land (5 – 15 % slope) with suitable soils: bonus, when use is made of a cover crop and/or no-tillage; 4. steep sloping land (15 % - 30 %) and suitable soils: bonus when a combination of cover crops, no-tillage and barriers along the contour lines is applied.
This alternative system would cost at least 520 million ECU (base subsidy), and at most 921 million ECU. In the latter situation all traditional and semi-intensive plantations on sloping land would apply soil conservation measures and all intensive plantations and 50 % of the semi-intensive plantations would qualify for a production bonus of 0.8 ECU per kg of olive oil. In this extreme case farmers in all three categories can receive more subsidies than in the for them least interesting of the two actual EU options .
For the reduction of fraud the producer-register and the GIS should be established and verified by an EU commissioned organisation. By linking the number of trees with the area cultivated and by providing a production bonus on the basis of oil production per tree, there is no incentive to plant too many trees per ha or to use multiple stems.

The precise measures that would qualify for the conservation bonus should be very well defined, and clearly visible on the satellite images. These images should have a high resolution and be of high quality, but that will also be required for the counting of tree numbers. To modify the already proposed GIS system to cater for this bonus system, the EU commissioned organisation could undertake or establish a research project of about three years that should cover all five producer countries.

The CRM case (adapted from Erenstein, 1999)

CRM stand for Crop Residue Mulching. Crop residues are left on the soil surface till the next crop in such a way that always a minimum cover percentage of 30% is achieved. This management technique is also known as Conservation Tillage.
Example of adoption of CRM-based cereal production in Guaymango, El. Salvador. This area is located in western El Salvador and comprises sub-humid lowland hills (<250 m, 1,900 mm unimodal precipitation). Agriculture is semi-commercial with predominantly small scale farms. The area is included here as it is frequently mentioned as the regional showcase in terms of CRM-based cereal production. The present section draws on existing literature and a short visit to the area.

Physical implications of CRM-adoption for the crop system
The typical cropping pattern comprises a maize - sorghum relay system. Maize is sown in May and harvested in November. Sorghum is relayed into the maize in June and harvested in December. CRM-based cereal production requires a compatible residue balance so as to retain sufficient residues to surpass the 30%-cover threshold at the time of crop emergence (*i.e.* a mulch of >2 t crop residue per ha). Maize-sorghum relay-cropping, implies two annual cereal crops, with a correspondingly high residue production: an estimated 9.7 ton of residues per ha per year. Weathering levels have traditionally been potentially CRM compatible, and the same applies to tillage practices. Farmers traditionally use zero till practices, in part conditioned by the location of the fields on hillsides with steep slopes (40-90%), thereby eliminating the possibility of mechanical tillage.
Traditionally the stubble was grazed communally and the remaining residues were burned prior to planting the subsequent maize crop. Consequently, the quantities of residues left as mulch were minimal. The necessary changes for CRM in the local context therefore originally related to abandoning pre-plant burning, and (possibly) limiting residue extraction. Farmers have typically abandoned pre-plant burning in the 1970's, but communal grazing remained widespread. Cattle typically graze the stubble during the dry season (January-April). However, extraction levels appear compatible with CRM. It was estimated that about 4 tons of residue per ha remain at the time of land preparation. Adoption of CRM based cereal production is reportedly widespread in the area since the early 1980's. The traditional manual sowing operation was compatible with CRM, but other cultural practices such as weed and nutrient management needed adapting.
These complementary practices for CRM were included in an overall technological package that included herbicide, fertiliser, high yielding varieties and increased density. The overall package thereby substantially increased capital use, but also provided a substantial yield boost: average yields trebled over the decade following 1974 (*e.g.*

maize from 1.0 to 3.2 t/ha; sorghum from 0.7 to 2.0 t/ha). Farmers generally adopted the package as a whole and the data do not allow for a complete breakdown of the individual contributions. However, the short term yield boost can largely be attributed to the productivity enhancing components of the package, and not to the CRM component as such. Compared to the traditional slash and burn land preparation, the short term contribution of CRM primarily revolved around the substitution of capital for labour. The yield boost also implied a substantial increase in residue production, thereby easing an eventual conflict between residue extraction and residue retention as mulch.

	Crop Residue Management		
Practice	Past	Current	CRM-based
Pre-plant burning	Yes	No	No
Tillage	No	No	No
Residue extraction	Yes (communal grazing)	Yes (restricted communal grazing)	Restricted
Mulch	No	Yes	Yes

Table 3: Overview of past, current and CRM-based residue management practices in the Guaymango study area (Erenstein, 1999).

Resource implications for the farm household

CRM based cereal production was largely compatible with the local farm household system. CRM did not conflict with other established farm household activities. Livestock production is a common household activity, but internal livestock pressure on crop residues tends to be compatible with CRM in view of substantial residue production. CRM also did not require major investments. The overall technological package did increase external input use, and thereby competed with other household activities for cash and other liquid assets.

Institutional setting

The institutional environment played a rather influential role in the adoption of CRM based cereal production in the area. Two particular issues merit highlighting: (i) residue rights and markets; and (ii) institutional packaging.

There is a nascent residue market in the area, but communal grazing still prevails. Most fields are unfenced, and the farm household thereby has limited possibilities to regulate extraction levels. Instead, the local communal grazing rights stipulate that about 50% of crop residues must remain at the end of the grazing period. This threshold compares with 20-30% in two other areas in El Salvador. Compared to these areas, the Guaymango area indeed has substantially lower stover depletion rates (*i.e.* extraction plus weathering) over the dry season. The local institution thereby helps ensure sufficient residues are retained as mulch and eliminated the need to actually enclose the fields.

CRM was successfully packaged in an integrated productivity/conservation recommendation. A critical issue appeared the use of conditional credit as incentive. Credit was only provided to farmer groups who as a group had adopted the technical package, including CRM practices. The coveted component generated effective peer monitoring that ensured compliance. This institutional glue prevented the disarticulation

of the productivity and conservation components, and thereby successfully enforced the adoption of CRM practices. Conservation contests and a multimedia extension drive provided further back up. About half the farmers now cite soil conservation as the reason for not burning the residues.

Private and social assessment

The package as a whole provides immediate private returns, with an attractive benefit-cost ratio of 249%. However, the package thereby masks the negative returns of implementing the CRM component. Indeed, without the CRM component, the returns to the package are even more attractive with a benefit-cost ratio of 283%. It is therefore likely that, given the choice, farm households would have opted for only the productivity enhancing components. However, such disarticulation was prevented by the applied institutional glue.

The traditional cereal production practices implied a substantial soil erosion hazard at the onset of the cropping season. CRM addresses this externality, but was not in the private interest - so intervention may have been warranted. The data do not allow for an elaborate social assessment, but do suggest intervention was effective and opportune. Guaymango indeed highlights a case of successful packaging of an integrated productivity/conservation recommendation. The success in terms of CRM adoption is such that Guaymango is now a national and even regional showcase. However, it has been difficult to replicate this success elsewhere.

What are Wageningen-URC research priorities?

Wageningen University and Research Center wishes to develop and disseminate scientific knowledge needed to sustainably supply society's demand for sufficient, healthy food and a good environment for humans, animals and plants.

A recent investigation in Wageningen on innovative research issues on the Sustainable Land and Water Use in the Tropics yielded the following spearheads (in priority order).

Priority	**SPEARHEADS SLWU**
1	Methods for better participation of targer groups and strengthening β-γ research.
2	Development of standardized terminology, of indicators and of measurement and monitoring techniques for sustainability.
3	Strengthening of conflict management with respect to soil and water issues.
4	Spatial interactions in the use of soil and water.
5	Creation of win-win situations at the border between sustainbale land and wateruse and nature conservation.
6	Design of sustainable systems for land and water use.
7	Enhancing the confidence in modelling.
8	The role of policy and economy in sustainable use of land and water .
9	L&W gebruik in en rond de stad
10	Preservation and sustainable use of biodiversity

Table 4: Innovative research spearheads in Sustainable Land and Water Use in the Tropics.

References

Brandt, C.J. and J.B. Thornes (eds.), 1996. Mediterranean desertification and land use. Wiley, 554 p.

Craswell, E.T., C. Niamskul and F.W.T. Penning de Vries, 1998. Catchment approach to combating soil erosion in Asia: the managing soil erosion consortium. P. 161-174 in: Penning de Vries, F.W.T., F. Agus and J. Kerr (eds.). Soil erosion at multiple scales: principles and methods for assessing causes and impacts. CABI/IBSRAM, 390 p.

Enters, T., 1998. A framework for the economic assessment of soil erosion and soil conservation. P. 1-20 in: Penning de Vries, F.W.T., F. Agus and J. Kerr (eds.). Soil erosion at multiple scales: principles and methods for assessing causes and impacts. CABI/IBSRAM, 390 p.

Erenstein, O., 1999. The Economics of Soil Conservation in Developing Countries: the case of crop residue mulching. PhD-thesis Wageningen Agricultural University, The Netherlands (forthcoming).

Fantechi, R., D. Peter, P. Balabanis and J.L. Rubio (eds.), 1995. Desertification in a European context: physical and socio-economic aspects. EUR 15415 EN, 635 p.

FAO, 1993. Guidelines for land use planning. E.A.O. Development Series 1., Rome, 96 p.

FAO/UNEP, 1996. Our land our future: a new approach to land use planning and management, 48 p.

Fresco, L.O., L. Stroosnijder, J. Bouma and H. van Keulen (Eds), 1994. The Future of the Land; Mobilizing and integrating knowledge for land use options. John Wiley Ltd, 409 p.

Giraldez, J.V., A. Laguna and P. Gonzalez, 1989. Soil conservation under minimum tillage technques in Mediterranean dry farming. P. 139 – 147 in: Schwertmann, U., R.J. Rickson and K. Auerswald (Eds.). Soil erosion protection measures in Europe. Soil Technology Series 1, EU, 216 p.

Graaff, J. de, 1996. The price of soil erosion; an economic evaluation of soil conservation and watershed development. Mansholt Studies 3, Backhuys Publishers, Leiden.

Graaff, J. de, 1999. The economic appraisal of soil and water conservation measures. Second International Conference on Land Degradation, Khon Kaen, Thailand.

Graaff, J. de, 1999. Evaluating incentive systems for soil and water conservation. In: Sanders, D, Huscar, P.C., Sombatpanit, S. and Enters, T., 1999. Incentives in soil conservation: from theory to practice.

Graaff, J. de, and J.W. Nibbering, 1998. Difficulties in the monitoring and evaluation of watershed development. In: Blume, H.P., Eger, H. Fleischhauer, E., Hebel, A., Reij, C. and Steiner, K.G. (editors). Towards sustainable land use; furthering cooperation between people and institutions. Advances in Geo-ecology No. 31. Catena Verlag GMBU, Reiskirchen, pp. 45-52 (Proceedings ISCO-Conference in 1996).

Graaff, J. de, and L.A.A.J. Eppink, 1999. Olive oil production and soil and water conservation in southern Spain. Land Use Policy (forthcoming).

Greenland, D.J., P.J. Gregory and P.H. Nye (eds.), 1998. Land resources: on the edge of the Malthusian precipice? CAB International, 180 p.

Heathcote, I.W., 1998. Integrated watershed management: principles and practice. Wiley, 414 p.

Hoek, A. van den, 1992. Planning as a learning process. PhD-thesis Wageningen Agricultural University, The Netherlands, 232 p.

Hoogmoed, W.B., L. Stroosnijder, H. Posthumus and B. Tammes, 1999. Effect decreasing soil organic matter on physical properties of sandy Sahelian soils. (Intern. Conf. China, Sept. 1997)

Hillel, D., 1998. Environmental soil physics. Academic Press, 771 p.

Hudson, N.W., 1991. A study of the reasons for success and failure of soil conservation projects. FAO Soils Bulletin 64. FAO, Rome. ISNAR, 1996. International symposium on policy research for sustainable land use and food security. The Hague.

Hudson, N., 1992. Land husbandry. Batsford Limited, London, UK, 192 p.

ISCO, 1999. Sustaining the Global Farm: local action for land stewardship. 10th International Soil Conservation Organization Conference, Lafayette, Indiana, USA.

Kerr, J., 1998. The economics of soil degradation: from national policy to farmer's field. P. 21-38 in: Penning de Vries, F.W.T., F. Agus and J. Kerr (eds.). Soil erosion at multiple scales: principles and methods for assessing causes and impacts. CABI/IBSRAM, 390 p.

Koppen, B. van, 1999. Strategy, gender, poverty and water. International Water Management Institute, Colombo, Sri Lanka, 6 p.

Koning, F. de, 1999. Spatially explicit analysis of land use changes: a case study for Ecuador. PhD-thesis Wageningen University, 173 p.

Lal, R., W.H. Blum, C. Valentine and B. A. Stewart (eds.), 1998. Methods for assessment of soil degradation. Advances in Soil Science, CRC Press, 558 p.
Landi, R., 1989. Revision of land management systems in Italian hilly areas. P. 175-188 in: Schwertmann, U., R.J. Rickson and K. Auerswald (Eds.). Soil erosion protection measures in Europe. Soil Technology Series 1, EU, 216 p.
Mainguet, M., 1999. Aridity: droughts and human development. Springer, 302 p.
Mansveldt, J.D. van and M.J. van der Lubbe, 1999. Checklist for sustainable landscape management. Elsevier, 181 p.
Margaris, N.S., E. Koutsidou and Ch. Giourga, 1996. Changes in traditional Mediterranean land use systems. Pg. 29-42 in: Brandt, C.J. and J.B. Thornes (eds.). Mediterranean desertification and land use. Wiley, 554 p.
Penning de Vries, F.W.T., F. Agus and J. Kerr (eds.), 1998. Soil erosion at multiple scales: principles and methods for assessing causes and impacts. CABI/IBSRAM, 390 p.
Rietkerk, M., P. Ketner, L. Stroosnijder and H.T. Prins, 1996. Sahelian Rangeland Development; a Catastrophe? J. Range Manage. 49:512-519
Rickson, R.J. (ed.), 1994. Conserving soil resources: European perspectives. CAB International, 425 p.
Röling, N., 1994. Platforms for decision-making about ecosystems. In: Fresco, L.O., L. Stroosnijder, J. Bouma and H. van Keulen, (eds.), The future of the land: mobilizing and integrating knowledge for land use options. John Wiley & Sons Ltd.
Rubio, J.L., M.J. Molina and J. Sanchez, 1989. Land use recommendations for soil conservation planning in Mediterranean envirinments. P. 207-216 in: Schwertmann, U., R.J. Rickson and K. Auerswald (Eds.). Soil erosion protection measures in Europe. Soil Technology Series 1, EU, 216 p.
Sanders D.W., Huscar, P.C., Sombatpanit, S. and Enters, T. (editors), 1999. Incentives in soil conservation; from theory to practice. Science Publishers, Enfield, USA.
Schwertmann, U., R.J. Rickson and K. Auerswald (Eds.), 1989. Soil erosion protection measures in Europe. Soil Technology Series 1, EU, 216 p.
Shaxson, T.F., Hudson, N.W., Sanders, D.W., Roose, E. and Moldenhauer, W.C., 1989. Land husbandry; a framework for soil andw ater conservation. Soil and water conservation society, Ankeny, Iowa.
SSSA, 1994. Defining soil quality for a sustainable environment. SSSA Special Publication Number 35, 244 p.
Stomph, T.J. and N. de Ridder, 2000. Sahelian village land use in a systems perspective. In: Stroosnijder, L. and T. van Rheenen (eds.). Agro-silvo-pastoral land use in Sahelian villages.
Stroosnijder, L., 1996. Modeling the effect of grazing on infiltration, runoff and primary production in the Sahel. Ecological Modelling 92:79-88
Stroosnijder, L., 1997. Andean erosion control: a science perspective. International Potato Center (CIP), Lima and Wageningen.
Stroosnijder, L., 1998. Quantification of nutrient erosion. Geoökodynamik 19(3/4):215-229.
Stroosnijder, L., S. Efdé, T. van Rheenen and L. Agustina, 1994. QFSA: A new method for farm level planning. p 299-331 in Fresco, L.O., L. Stroosnijder, J. Bouma and H. van Keulen (Eds), 1994. The Future of the Land; Mobilising and integrating knowledge for land use options. John Wiley Ltd, 409 p.
Stroosnijder, L. and P. Kiepe, 1997. Systems approach in the design of soil and water conservation measures. P. 399-411 in: M.J. Kropff et al. (eds.). Applications of Systems Approaches at the Field Level. Kluwer Academic Publisher.
Stroosnijder, L. and P. Kiepe, 1998. Simulation of Maize Growth under Conservation Farming in Tropical Environments. Tropical Resource Management Papers no. 19, 90 p. Wageningen University, ISBN 90 6754 550 3.
Stroosnijder, L., E. van Loon, N.A. Chappell and W. Tych, 1999. Tools for sustainable watershed management in the tropics: dynamic time-series and topographic modelling of land use impacts on water flow and erosion.
Stroosnijder, L. and T. van Rheenen (eds.), 1999. Agro-silvo-pastoral land use in Sahelian villages.
Swift, J., 1996. Desertification. P. 73-90 in: M. Leach and R. Mearn (eds.), The lie of the land: challenging received wishdom on the African environment. African Issues. The International African Institute, 240 p.
Turner, T., 1998. Landscape planning and environmental impact design. UCL Press, London, 2nd Edition, 425 p.
Young, A., 1998. Land resources: now and for the future. Cambridge University Press, 319 p.

Webster, R., 1998. Soil resources and their assessment. Pg. 103-114 in: Greenland, D.J., P.J. Gregory and P.H. Nye (eds.). Land resources: on the edge of the Malthusian precipice? CAB International, 180 p.
Wickens, G.E., 1998. Ecophysiology of economic plants in arid and semi-arid lands. Adaptations of Desert Aoganism series, Spinger, 343 p.
WRR, 1992. Ground for choices: four perspectives for the rural areas in the European Community. Netherlands Scientific Council for Government Policy, Reports to the Government no. 42, 144 p.

LAND DEGRADATION CAUSED BY OVERGRAZING AND WILDFIRES AND MANAGEMENT STRATEGIES TO PREVENT AND MITIGATE THEIR EFFECTS

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Abstract. In the Mediterranean environment, land degradation is mainly caused by human activities and rangelands rank first in the proportion of their area being moderately or severely desertified. Improper grazing management may lead to rangeland degradation with overgrazing being the most important single factor causing elimination of plant cover and soil erosion. The effects of overgrazing may be further aggravated by the pastoral wildfires set by the shepherds in order to control the unpalatable woody vegetation. These two factors were found to have a destructive effect on Psilorites mountain in Crete, where an increased number of sheep and goats together with pastoral burning resulted in the restriction of forest cover and dominance of phryganic vegetation which is unpalatable to animals and adapted to frequent fires. Nevertheless, both animal grazing and fire are important ecological factors for the Mediterranean ecosystems and management strategies are suggested for their proper use so that conservation and sustained yield of rangelands and silvopastoral systems are ensured.

Key words: Land degradation, overgrazing, wildfires, Psilorites mountain, management strategies

Introduction

There are several definitions of desertification. The most widely accepted is the one proposed by the Convention to Combat Desertification (European Commission, 1997) which defines it as: land degradation in arid, semi-arid and dry sub-humid areas resulting from climatic variations and human activities. It is clear from this definition that anthropogenic factors combined with harsh climatic events are the main causes of land degradation.

Among the major land uses of the world, rangelands rank first in the proportion of their area being moderately or severely desertified (Mabutt, 1984). The main reason for their desertification is overgrazing which means that too many animals are trying to be fed on a limited supply of forage (Dregne, 1978).

In the Mediterranean region, in particular, there are about 270 million sheep-equivalents which include horses, mules, donkeys, cattle, camels, pigs, sheep and goats (Le Houerou, 1981). The latter two kinds of animals are the dominant group making 75% of the entire population. All these animals graze in about 830,000 km^2 of rangelands or 52% of the whole Mediterranean area thus corresponding to a stocking rate of about 2.2 sheep-equivalents per hectare (Le Houerou, 1981). If we consider that the grazing

capacity of Mediterranean rangelands is no more than 1 sheep/ha/year on the average, we may conclude that these rangelands are seriously overgrazed.
Silvopastoral systems are complex ecosystems because they include pastures, trees and animals. If they also include crops, then they become even more complex and called agro-silvopastoral systems. Depending on the crown density, they may be classified as rangelands if this density is up to 40%, or as Mediterranean forests if their crown density is higher than 40% (Papanastasis, 1996). In any case, silvopastoral systems are important sources of feed to domestic animals and the main components of the Mediterranean livestock production systems (Etienne, 1996).
There is a lot of literature blaming livestock for degradation of silvopastoral systems. For example, Thirgood (1981), considers grazing by domestic animals among the major causes of forest degradation with goats being singled out as the most dangerous ones due to their predilection of woody forage. Similar ideas are expressed by Tsoumis (1985). In addition, overgrazing combined with wildfires has been stressed as the main agent of desertification in Greece (Margaris and Koutsidou, 1998) and in Sardinia (Aru, 1986).
In this paper the role of overgrazing and wildfires in silvopastoral systems is analyzed and methods of preventing and mitigating their impacts are presented.

Role of overgrazing

Overgrazing is the use of a particular rangeland or silvopastoral system by more animals than its grazing capacity. As grazing capacity is defined: the maximum number of animals that can graze in a particular rangeland without damage to its productivity (Heady, 1975).
Desertification of rangelands, however, is not caused only by overgrazing. It may be also caused by the use of inappropriate kind of animals, e.g. sheep instead of goats or vice versa, or the inappropriate system of grazing, namely grazing at the wrong season or for too long or too short of a period. In other words, the whole grazing management may be responsible for land degradation. Nevertheless, overgrazing should be considered as the most important single factor causing desertification in rangelands.
The impacts of overgrazing in rangelands are gradual and complex. In the beginning, species composition is altered and ends up in the restriction or complete elimination of the palatable species. Later, the less palatable species are eliminated and the rangeland may get full of unpalatable species which are weeds (e.g. asphodel deserts). If overgrazing continues, weeds will also disappear and the soil will become bare and compacted by trampling. This will lead to accelerated erosion and eventually to the exposure of the parent rock.
Similar will be the impacts of overgrazing and to the other components of the ecosystem and especially to the fauna. Important wildlife habitats will be destroyed and animal species may disappear.

Role of wildfires

Wildfires are a common phenomenon in the Mediterranean region. Their number and the area burned per fire have significantly increased in the last few decades due to rural

emigration from the mountainous areas and to the change of the socio-economic conditions. As a result, fires have become more frequent, they burn larger areas and they are hotter and, therefore, more destructive to the ecosystems than in the past.
The first impact of wildfires is the destruction of the aboveground vegetation. Although Mediterranean vegetation in adapted to wildfires and it comes back by auto-succession due to its adaptive mechanisms, such as seed germination and stump sprouting, the recovering process is slow. As a result, the soil surface remains bare for quite a long time after the fire, during which erosion may occur. The greatest danger exists with the first autumn rains, particularly if they are storms, but erosion may be continued through the winter months as well.
The majority of wildfires in rangelands and silvopastoral systems is set by the shepherds themselves, in order to control the unpalatable woody vegetation and favor the establishment of palatable herbaceous species, especially legumes. This practice is traditional in the Mediterranean region and is still applied in several parts of Greece, in Corsica and Sardinia (Papanastasis et al., 1990; Le Houerou, 1981).
Very often, however, the problem is not the wildfires per se but the grazing management applied right after them. Such a management includes overgrazing of the recently burned rangelands in order to exploit the palatable herbs and young shoots of shrubs. As a result, the soil surface is maintained without vegetative cover for a longer time, while trampling aggravates the problem of soil erosion (Arianoutsou – Faraggitaki, 1985; Margaris and Koutsidou, 1998; Papanastasis and Noitsakis, 1992).

The case of Psilorites mountain

We studied the problem of overgrazing and wildfires in the Psilorites mountain of Crete, one of the most desertified mountains of the Mediterranean region. The question we tried to answer in our studies was whether grazing intensity is a reliable index of degradation.

Study area

Psilorites or Idi has an altitude of 2456 m a.s.l. It is located at the middle of Crete and has an area of about 558 km^2, mostly lying above 600 m a.s.l. (Fig. 1). It is permanently inhabited by about 18,000 people living in 19 village communities and 1 municipality.
The dominant bedrock is undivided limestone of the "platy series" of the Jurassic-Eocene period. Soils are mostly red. The climate is sub-humid Mediterranean with wet winters which becomes cold in high altitudes.
Vegetation is very diverse. It includes mostly evergreen but also a few deciduous woody species, trees and shrubs, as well as phryganic species. The latter are dwarf shrubs with seasonal dimorphism, widely distributed in the eastern Mediterranean; they form open plant communities interspersed by a high variety of herbaceous species
Land tenure is very complex. Agricultural lands are privately owned. Wildlands on the contrary, where forests and rangelands belong, are state owned but the right to use them belongs to the local village communities which lease it to their inhabitants.

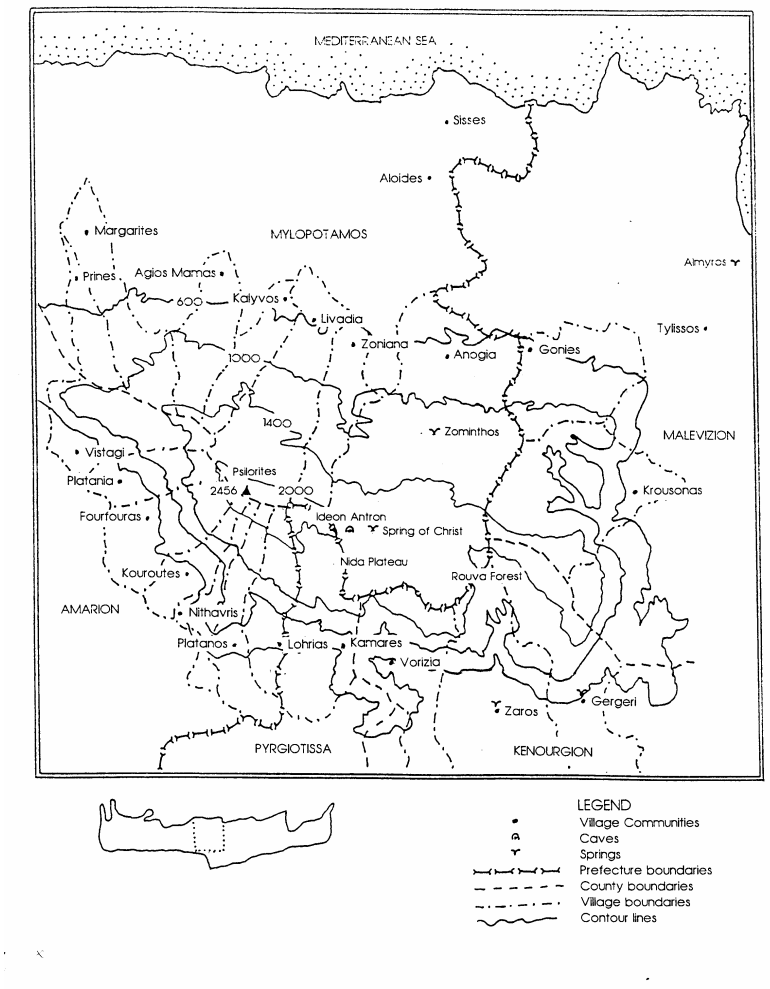


Figure 1: Topographic map of Psilorites mountain indicating the administrative boundaries of the 20 village communities (Lyrintzis and Papanastasis, 1995).

Methods

For obtaining ecological information, vegetation was studied and a land cover/use map was prepared. The latter was based on visual interpretation of 30 pairs of air photos taken in 1989 with a scale 1:30,000. Land cover categorisation was based on the classification developed by the Corine Land Use Project (1992) after adapting it to the local conditions (Karteris and Vila, 1994).

A detailed study of soils was carried out by digging two soil pits in representative locations and describing and sampling the soil profiles (Pentarakis, 1994).

Surveys of avifauna and mammals were done across walking routes all over the study are (Papageorgiou et al., 1994).

The grazing practices were analysed by surveying the number of livestock, the pastoral and fodder systems, the feeding calendar and the pastoral wildfires by means of a questionnaire filled out in each village community (Menjli, 1994). Grazing intensity in each village community was expressed as stocking density, namely in animals (sheep and goats or only goats) per hectare and per year. The land cover types were expressed as percentages of the total area of each village community and correlated with stocking

density by means of a regression analysis, and several linear and non-linear equations were developed.
We further evaluated the impact of overgrazing and wildfires by selecting 30 representative sites all over the mountain and measuring in each one of them the biomass production at the end of the season for four consecutive years(1995-98) (Papanastasis, 1999). The biomass was hand separated into herbaceous and phryganic components and each of them into live and old parts.

Results

There were identified 12 land cover/use types on Psilorites mountain which are shown on table 1. Of those, one was representing artificial surfaces (residential areas), 3 agro--ecosystems (arable areas), 7 semi-natural ecosystems (grasslands, shrublands and forests) and one bare rocks while non-identified areas due to several technical problems (e.g. cloudiness) were put into a separate category. Forests were covering only 9% of the whole area and they were dominated by open or medium crown density stands of *Quercus coccifera, Acer sempervirens* and *Pinus brutia;* dense forests were negligible. On the contrary, medium and high density shrublands were dominating the mountain and covered 63% of its whole area. They were mainly distributed on relatively gentle slopes from low to medium elevations, while open shrublands were covering only 5% of the mountain and tended to be associated with steeper slopes and higher elevations (Villa, 1995). Shrublands were composed of the shrubby trees *Q. coccifera, A. sempervirens* and of the shrubs *Rhamnus oleoides, Salvia officinalis* and *Berberis cretica* while their understory was composed of various phryganic species, mainly *Sarcopoterium spinosum, Euphorbia acanthothamnos, Corydothymus capitatus* and *Phlomis spp.* Grasslands were limited in dolines (0.5%) and bare rocks occupied 0.5% of the area, mainly on high elevation and sheep slopes. All these data clearly show that Psilorites is a truly deforested and degraded mountain.

Class	Hectares	% cover
No data	324.66	0.58
Artificial surfaces	248.66	0.45
Arable lands	29.92	0.05
Fruit trees	3804.42	6.82
Annual & permanent crops	7722.45	13.85
Open forests (10-40% crown cover)	3216.70	5.77
Medium forests (41-70% crown cover)	1834.84	3.29
Dense forests (71-100% crown cover)	47.68	0.09
Open shrubs (10-40% crown cover)	2914.44	5.23
Medium shrubs (41-70% crown cover)	16966.60	30.42
Dense shrubs (71-100% crown cover)	18140.76	32.53
Grasslands	272.98	0.49
Bare rock	247.89	0.44
TOTAL	55771.97	100.00

Table 1: Land cover/use classes in Psilorites (Vila, 1995).

The dominant soil units existing in the study area were: (a) chromic luvisols characterised by a strong brown to red argilic B horizon, mainly occurring on dissected

plateaux with steep slopes on the south and west part of Psilorites, and (b) calcaric lithosols characterised by shallow soils developed on calcareous parent material.
They were found 45 species of birds in Psilorites belonging to different families (Fig. 2) and 6 species of mammals. Among the birds, an important proportion (26%) was birds of prey including *Gypaetus barbatus, Buteo rufinus, Gyps fulvus* and *Aquila chrysaetos,* all of them classified as endangered and vulnerable species under the Directive 79/409 of the European Union. This variety of birds of prey indicate that Psilorites is an ecosystem of significant importance because it functions as a breeding and feeding ground for rare and endangered species. Among the mammals, hares were the most important species while rodents were also present.

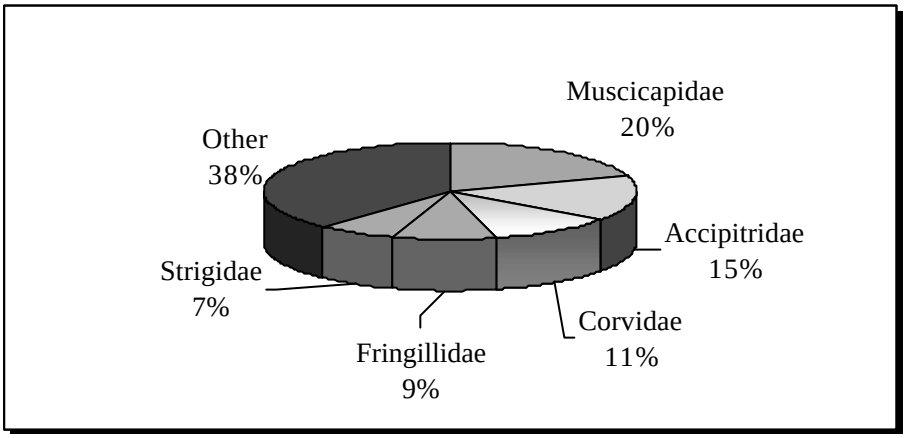


Figure 2: Distribution of avifauna families in Psilorites (Papageorgiou et al., 1994).

Livestock husbandry was found to be the dominant economic activity on Psilorites. Forests, shrublands and grasslands were all grazed by a large number of sheep and goats throughout the year, while agricultural lands were grazed part of the year (e.g. cereals in the summer months, after the harvest). In 1992, there were recorded 328,690 sheep and 128,105 goats with the majority of sheep (33%) found in Anogia and of goats in Livadia (28%) and in Anogia (23%) (Table 2). Both sheep and goats belong to local non-improved breeds and raised for milk and meat (Menjli, 1994).
Stocking density was calculated within each village community by dividing the total number of grazing sheep and goats or only goats, calibrated with their respective grazing period, with the grazed area, namely grasslands, shrublands and forests (Menjli and Papanastasis, 1993). Stocking density was expressed in sheep equivalents (sheep and goats) or only goats/ha.
In general, the correlation between any of the plant cover components used: namely open, medium, dense and total forest cover; open, medium, dense and total shrub cover; and total plant cover (forests and shrubs); with the stocking density was found poor with any of three models used, linear, parabolic and cubic. The relations that produced significantly different coefficients of determination (r^2) are shown on table 3. It is evident that stocking density of sheep and goats or only goats accounted for no more than 38% of the variation in forest cover. On the contrary, the stocking density of only goats accounted for a relatively high (71%) amount of variation in the bare rocks cover.

Slope	Village	Number			Stocking density	
		Sheep	Goats	Total	Sheep equivalents (sheep & goats)	Only goats
	Ag. Mamas	4500	1800	6300	2	0.6
	Anogia	110200	30100	140300	7.6	1.6
	Gonies	3900	5015	8915	2.4	1.4
	Kalyvos	19000	4800	23800	9.6	1.9
North	Krousonas	14000	12000	26000	7	3.2
	Livadia	51300	35300	86600	12.8	5.2
	Margarites	1940	1780	3720	3.1	1.5
	Prines	1300	300	1600	1.3	0.2
	Zoniana	57500	5400	62900	19.8	1.7
	Fourfouras	850	620	1470	0.7	0.3
	Gergeri	18000	6600	24600	4.6	1.1
	Kamares	7200	5800	13000	2.3	1.2
South	Kouroutes	3000	850	3850	2.7	0.6
	Lohriae	10000	3640	13640	4.7	1.3
	Nithavris	2600	1300	3900	1.2	0.1
	Platanias	3500	950	4450	1.7	0.3
	Platanos	6500	3500	10000	4.3	1.8
	Vistagi	3000	1700	4700	0.6	0.4
	Vorizia	6300	3500	10100	1.7	0.5
	Zaros	4100	2850	6950	2	0.7
	TOTAL	328690	128105	456795		

Table 2: Number of sheep and goats in 1992 and the stocking density of rangelands (animals/ha/yr) per village community (Menjli, 1994).

The results of the biomass measurements showed that there was an increase of all its components after burning but this increase was faster in the sites with good soil than in the sites with poor soil. Also, biomass was less in burned than in the unburned sites, especially the old growth of phryganic species (Fig.3).

As far as the effects of grazing are concerned, biomass of phrygana was higher in the grazed than in the ungrazed sites while the herbaceous biomass followed the opposite course in the phryganic sites dominated by unpalatable species (Fig.4). This means that animals favoured the dominance of the unpalatable species and suppressed the palatable ones.

Cover class	Equation	r^2	P
Open forest	Y = 16.66 - 0.78 Xs	0.23	0.033
Medium forest	Y = 10.74 - 2.79 Xg	0.21	0.04
Total forest cover	Y = 21.04 - 10.8 Xs	0.30	0.01
	Y = 20.68 - 3.59 Xg	0.21	0.043
	$Y= 19.86 - 0.55 Xs - 0.03 Xs^2$	0.31	0.042
	$Y= 14.21 - 3.54X - 0.62 Xs^2 + 0.02 Xs^3$	0.38	0.05
Total woody cover (forest + shrub)	Y = 58.89 - 7.82 Xs	0.19	0.05
Bore rocks	Y = 0.60 - 1.32 Xg	0.24	0.02
	$Y= 3.76 - 3.45 Xg + Xg^2$	0.66	0.0001
	$Y= 2.34 - 0.85 Xg- 1.59 Xg^2 - 0.35 Xg^3$	0.71	0.0001

Table 3: Relationships between plant cover (Y) and stocking density of sheep and goats (Xs) or only goats (Xg) (Menjli, 1994).

In the phryganic sites dominated by palatable phrygana such as *Ononis spinosa*, on the contrary, both phryganic and herbaceous species were suppressed by grazing resulting in significant reduction of biomass (Fig 5).
The interaction of wildfires and overgrazing is shown on figure 6. It is clear that these two factors interact in rangeland degradation and desertification.

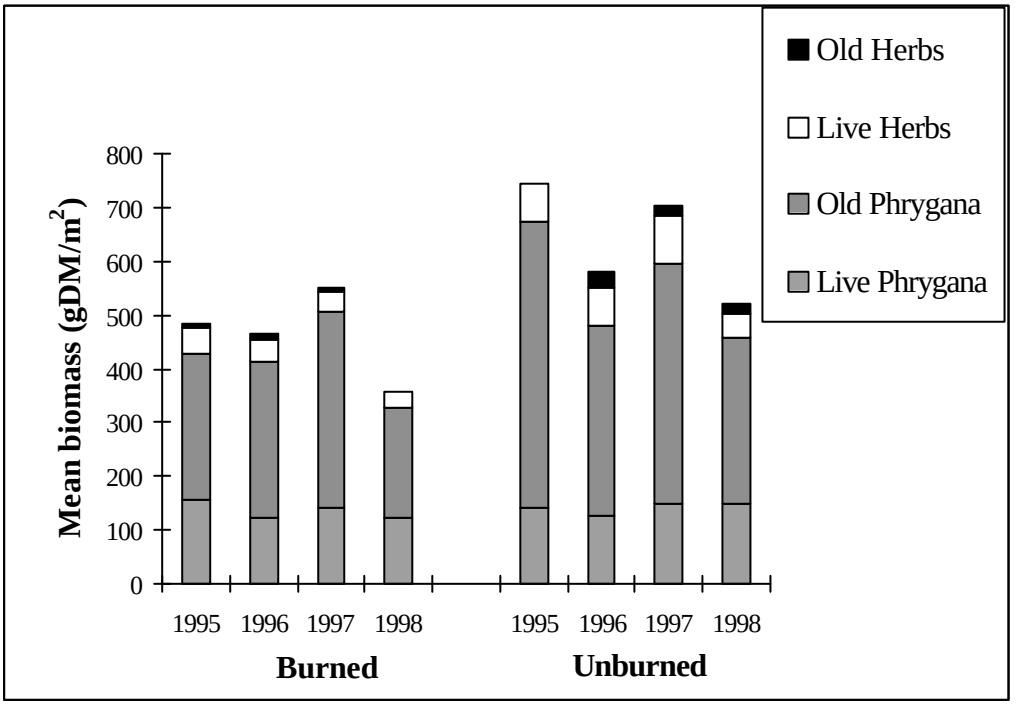


Figure 3: Biomass changes in burned and unburned sites of Psilorites mountain over the period 1995-98 (Papanastasis, 1999).

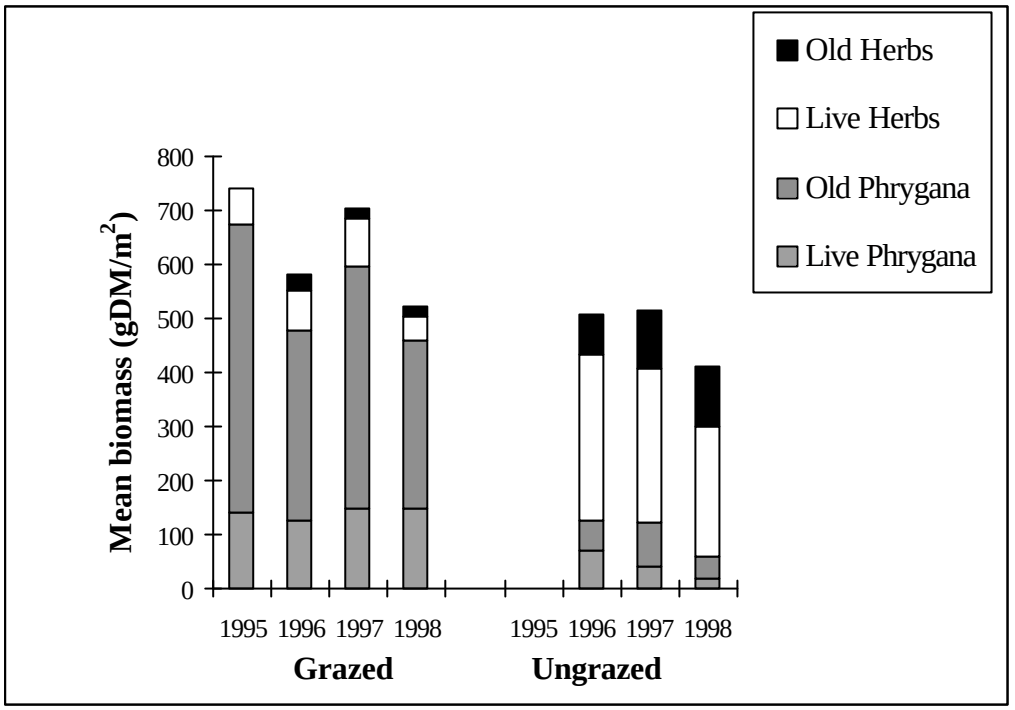


Figure 4: Biomass changes in grazed and ungrazed sites of Psilorites mountain dominated by unpalatable species over the period 1995-98 (Papanastasis, 1999).

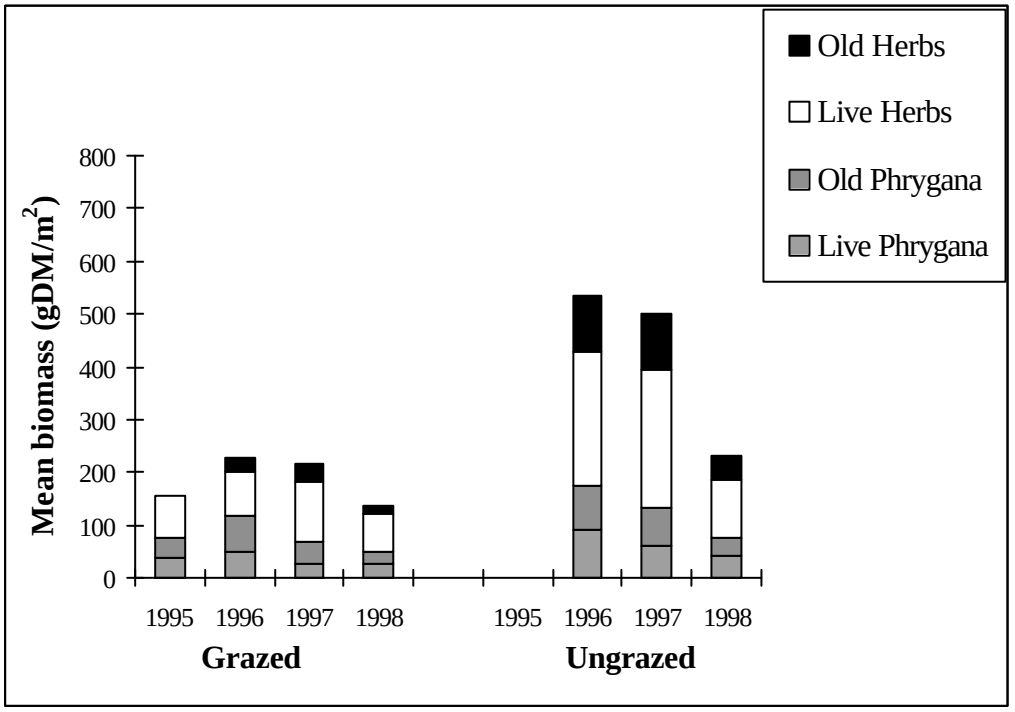


Figure 5: Biomass changes in grazed and ungrazed phryganic sites of Psilorites mountain dominated by palatable species over the period 1995-98 (Papanastasis, 1999).

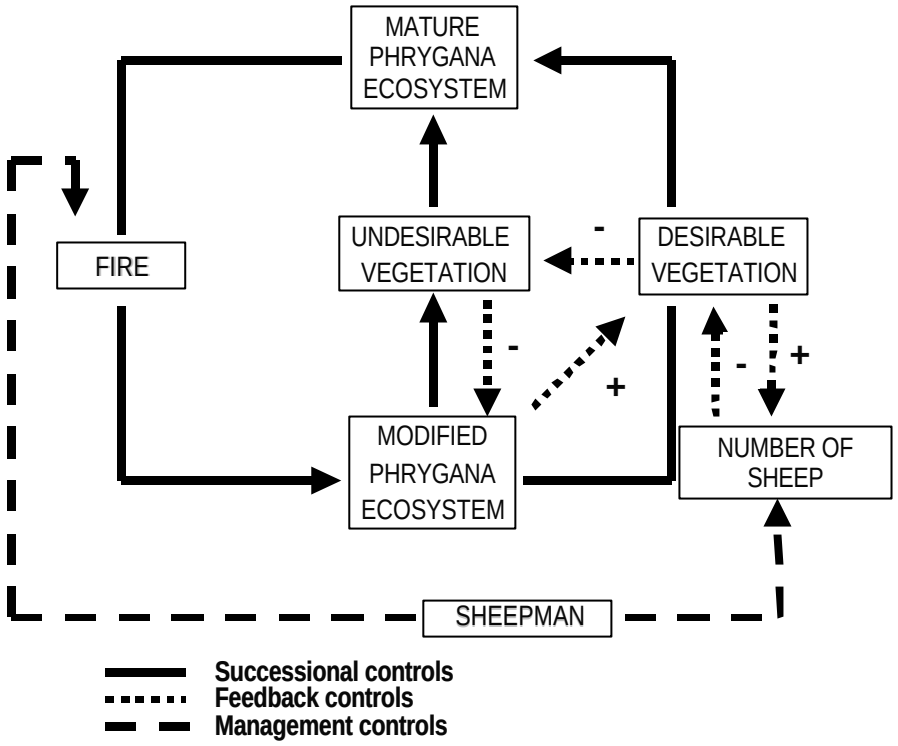


Figure 6: A compartmental model showing the interaction between wildfires and overgrazing practised by shepherds in phryganic rangelands (Papanastasis, 1977).

Management strategies

Grazing by domestic or wild herbivores is an ecological factor in the Mediterranean environment necessary to maintain ecosystem function and landscape diversity and stability. Mediterranean vegetation and landscapes have been evolved in a grazing environment and developed mechanisms to tolerate or to escape damage from herbivorous animals (Papanastasis, 1998) This grazing however must be rational and adapted to the specific conditions of each ecosystem and landscape. Problems arise only when it is excessive and irrational.

Fire is also an ecological factor in the Mediterranean environment and many plant species have developed special mechanisms to withstand burning. Such mechanisms include seed germination and stump spouting. Several phryganic species germinate readily after fire while germination is significantly reduced if not burned; it seems that fire breaks their seed coats and facilitates their germination (Papanastasis, 1977). Other species, such as oaks stump sprout vigorously after fire.

It comes out therefore that both grazing and fire are necessary in Mediterranean environments and strategies should be developed in order to efficiently and beneficially incorporate then into land management.

Grazing

In order for the grazing to be beneficial to the ecosystems it has to be proper. This means:

a.- the stocking rate should be equivalent to grazing capacity of a particular rangeland,
b.- the kind of grazing animal(s) should be appropriate for the type of vegetation to be grazed; in the Mediterranean rangelands, it is always necessary to combine grazers and browses for a better control of all kinds of plant species,
c.- the grazing system must be appropriate, namely the season and duration of grazing should be the proper ones for each rangeland.

There are several rules of thumb to test if proper grazing is applied in a particular rangeland. They include:

- **utilization percentage**: animals should not consume more than 50-60% of the annual growth depending on the particular species involved.
- **stubble height**: for herbaceous species, animals should graze down to no less than 6 cm of the palatable species by the end of the grazing period.
- **range trend**: range condition should be improved with grazing; deterioration is exemplified by the dominance of weeds, lack of organic matter on the soil and accelerated soil erosion; in shrublands, deterioration may be exemplified by the overgrowth of shrubs or by their dense structure.

Fire

In order for the fire to be beneficial in rangelands, it should be prescribed or controlled. A fire can be prescribed when it is applied on the right place, at the right time and with the right method. Also, a prescribed fire should be applied by the right people, namely trained technicians. Such a fire can greatly improve the grazing capacity of a particular rangeland and make no harm to ecosystem components.

Management plan

Grazing and fire can be combined in rangelands and silvopastoral systems provided that a management plan is drawn which specifies when prescribed fire should be used and how the burned areas should be grazed.

Overgrazed areas should be left aside for some time to recover before animals are again introduced so that the overgrazing effects are mitigated. The same is true for areas burned by accidental or arsonal wildfires. They should be also protected from grazing until the burned vegetation recovers and protects efficiently the soil from erosion. In grasslands, one year is enough for such a recovery but in phryganic rangelands grazing must be deferred for about 2-3 years while in shrublands the deferement must be much longer (4-6 years).

References

Arianoutsou-Faraggitaki M. (1985). Desertification by overgrazing in Greece: The case of Lesvos island. *J. Arid Environments*, **9**:237-42.

Aru A. (1986). Aspects of desertification in Sardinia-Italy, p. 194-198. In R. Fantechi and N.S. Margaris [Eds] Desertification in Europe. D. Reidel Publishing Co., Dordrecht.

Corine Land Cover Project (1992). In European Conference of the International Space Year, Munich, 22p.

Dregne, H. E. (1978). Desertification: Man's abuse of land. *J. Soil & Water Conservation*, 33: 11-14.

Etienne, M. (1996). Research on temperate and tropical silvopastoral systems: a review, p. 5-19. In: Western European Silvopastoral Systems (M. Etienne, ed.). INRA, Paris.

European Commission (1997). Addressing desertification: a review of EC policies, programs, financial instruments and projects. L-1985 Luxembourg.

Heady, H. A. (1975). Rangeland Management. McGraw-Hill Book Co. N.Y.

Karteris M. and Vila R.T. (1994). Land cover/use and terrain analysis of Psilorites region using photo-interpretation and GIS systems. Mimeo., 44 pp.

Le Houerou, H. N. (1981). Impact of man and his animals on Mediterranean vegetation, p. 479-521. In: Mediterranean-type Shrublands (F. di Castri et al., eds). Elsevier Sci. Co. New York.

Lyrintzis G. and Papanastasis V. P. (1995). Human activities and their impact on land degradation-Psilorites mountain of Crete. A historical perspective. *Land Degradation & Rehabilitation*, **6**:79-93.

Mabutt, J. A. (1984). A new global assessment of the status and trends of desertification. *Environmental Conservation*, 11 (2): 103-113.

Margaris, N. S. and E. Koutsidou (1998). Fires and overgrazing: the main driving forces of desertification in the Aegean islands, p. 167-170. In: Proc. Ecological Basis for Livestock Grazing in Mediterranean Ecosystems (V. P. Papanastasis and D. Peter, eds). European Commission, EUR 18308. Luxenburg.

Menjli M. (1994). Effects of pastoral activities on desertification of mountain Psilorites. MSc. Thesis. Mediterranean Agronomic Institute, Chania, Crete, 99 pp.

Menjli M. and Papanastasis V. P. (1995). Impact of pastoralism on desertification of Psilorites mountain in Crete, Greece. Vth Intern. Rangeland Congress: 361-62.

Papageorgiou N., Birtsas P., Bakaloudis D., and Sakoulis A. (1994). Wildlife in Psilorites. Mimeo, 14pp.

Papanastasis V.P. (1996). Silvopastoral systems and range management in the Mediterranean region, p. 143-156. In: Western European Silvopastoral Systems (M. Etienne, ed.). INRA, Paris.

Papanastasis V.P. (1977). Fire ecology and management of phryganic communities in Greece, p. 476-482. In: Proc. Symposium on Environmental Consequences of fire and Fuel management in Mediterranean Ecosystems (H. A. Mooney and C.E. Conrad, Tech. Coors). USDA Forest Science. Gen. Techn. Rep. Wo-3. Washington D.C.

Papanastasis V.P. (1998). Livestock grazing in Mediterranean ecosystems: an historical and policy perspective, p. 5-9. In: Proc. Ecological Basis for Livestock Grazing in Mediterranean Ecosystems (V. P. Papanastasis and D. Peter, eds). European Commission, EUR 18308. Luxenburg.

Papanastasis V.P. (1999) (Scientific Responsible). Land use systems in the mediterranean mountain and marginal lands. Fourth Annual Progress Report. Mediterranean Agronomic Institute of Chania (Mimeo).

Papanastasis V., Kyriakakis S. and Ispikoudis I. (1990). Forestry and grazing practices in Crete, p. 42-46. In: Stability and Change in the Cretan Landscape (Dick Grove et al.,eds),. Petromaroula 1, Corpus Christi College, England.

Papanastasis V.P. and Noitsakis B. I. (1992). Range Ecology. Yiahoudi-Yiapouli Publ. Thessaloniki (in Greek).

Pendarakis K.E. (1994). Identification of basic soil parameters related with the desertification process in two sampling zones of Psilorites area. Mimeo. 42 pp.

Thirwood J.V. (1981). Man and the Mediterranean Forest. Academic Press, N.Y.

Tsoumis G. (1985). The depletion of forests in the Mediterranean region- A historical review from the ancient times to the present. *Scientific Annals of the Department of Forestry and natural Environment*, KH : 281-300.

Villa R.T. (1994). Assessment of land degradation using remote sensing and Geographic Information Systems, Psilorites region, Crete, Greece. MSc. Thesis. Mediterranean Agronomic Institute, Chania, Crete.

METHODOLOGIES TO PREVENT AND MITIGATE LAND DEGRADATION PHENOMENA IN MEDITERRANEAN AGROSILVOPASTORAL SYSTEMS.

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Introduction

To begin, let me briefly describe what we mean by Agro-silvo-pastoral Systems.
If we analyse the word itself: pastoral is a way of breeding animals using traditional methods including direct use of pasture as the principal feeding method; silvo means that part of the land grazed by livestock is covered by bushes or trees; agro means that certain agricultural techniques, such as the cultivation of feedstuff and the use of fertilisers in natural pasture, are used to improve the quantity and the quality of the feed available to the animals, and thus improve stocking rate.
This productive system is used extensively in the Mediterranean basin, in particular for small ruminants but also occasionally for cattle. There are some 100 million head of grazers in LSU in the area.
Now let us consider what is the connection between this system and land degradation.
The agro-silvo-pastoral system is the oldest form of agriculture in the area, dating from 8,000 BC and until recently was a reasonably stable system. What threw this ancient system out the balance? Quite briefly, an irrational increase of stocking rate due to the following three factors. Firstly, the population increased rapidly after the eighteenth century and also became increasingly urbanised with a higher standard of living. This greatly increased the demand for protein food. Moreover, roughly double the initial quantity of animal proteins is required to supply urban people with the same protein intake as rural people, because of the losses linked to the longer food chain (slaughter, transport, preservation and utilisation). Secondly, the spread of agricultural facilities, such as drinking points and means of transport, made it possible for animals to remain longer in a place where there was a shortage of pasture or water. Finally, in the eastern and southern Mediterranean, livestock is used both as a form of currency and as a way of measuring wealth.
What is the difference between prevention and mitigation? Prevention is a series of actions that have to be applied to fragile ecosystems to avoid land degradation and desertification. By contrast, mitigation is a program that attempts to fight land degradation or restore degraded land.
Later I wish to go into detail about prevention/mitigation, but first let us analyse the effect of grazing on vegetation and soil.
What is the relationship between stocking rate and land degradation?
Animals, plants and the environment interact with one another in a complex way in agropastoral systems and human activities have a direct effect on them. The erroneous belief that grazing always damages vegetation and soil is widespread. This is because grazing is confused with overgrazing. Only the latter destroys plants and soil and it is only when overstocking occurs that the land is degraded.
What is grazing? Grazing involves the biting, pulling and breaking off of plant parts, which causes defoliation, or even pulling entire plants out of the ground, if they are not

well rooted. Furthermore the trampling and treading of the vegetation may damage the stand. Seed dispersal, internally through the animal digestive system, or externally by temporary attachment to animal hair, fleece, or hooves, is an ecological factor affecting a perennial forage stand, but the impact will range from favourable to unfavourable, depending upon the plant species and site being affected. Covering some parts of the vegetation with faeces and urine is another effect of grazing. Manure spots are generally avoided by animals visiting later, even though the nutritive quality (particularly rich in nitrogen) of the affected forage may be better than that on adjacent ground.

While correct grazing has certain positive influences on the vegetation and soil resources, other common agropastoral activities can have negative effects. Correct grazing delays maturation of the vegetation, keeping plants in a vegetative, forage producing state and stimulates growth by its pruning effect, maintaining the optimum Leaf Area Index and thus improving the nutritive value of available forage, and reducing excessive accumulation of standing dead vegetation and mulch. This reduces the vegetation biomass which, if allowed to build up, provides the undergrowth that favours fires and their propagation during hot dry periods.

Irrational practices, by contrast, have a negative effect: overgrazing compacts and denudes soil by trampling and fires used to destroy vegetation to clear land for pasture also remove valuable organic matter from the soil.

Undergrazing allows overgrowth and shading by senescent foliage, which reduces photosynthesis and increases respiration. Optimum grazing pressure improves effective LAI, whereas higher pressures, which result in excessive defoliation and a related decrease in forage yield, diminish it. In addition to the reduction in leaf area per plant by grazing, the thinning out of grass species, which is a consequence of the selective feeding action of the animals or of the exposure of roots to the cutting edge of the hooves, can have a strong negative impact.

Plant recovery from defoliation depends not only on the available carbohydrate reserves but also on the quantity of the remaining foliage and its photosynthetic capacity. The rate of development of new foliage and photosynthetic capacity of new leaves is also important. Generally, the lower the level of reserve carbohydrates, the more important the remaining leaf area is in promoting regrowth. Also, while perennial forage plants are influenced by the conditions in current and preceding years, annual forage plants are not, because their regrowth depends primarily on the remaining leaf area rather than storage compounds.

Optimum rational grazing management strategy means the maximum level of defoliation that will still maintain sustainable forage production and animal response. The definition of the optimum moment for grazing, the optimum frequency and duration of grazing, and the intensity of defoliation, by using a proper stocking rate are of great importance

What is the effect of grazing on the soil? Grazing damages the soil directly, through trampling, and indirectly, through the reduction of vegetation cover and the removal of organic matter from the soil.

The treading of soil by grazing animals is detrimental; causing soil compaction, surface horizon disruption, reduction of infiltration, creation of terracing on steep slopes, development of animal trails, and thus erosion. The degree of impact the animal treading has on a specific site depends on the interaction between vegetation, soil, weather and animals.

The hooves of animals compact the soil and thus reduce soil porosity. This reduces

water infiltration and percolation, leading to increased water runoff and erosion on sloping terrain and hydromorphism or stagnation in flat terrain. Soil compaction depends both on how the animals behave, such as their tendency to walk, run or jump, or to graze in groups, and on farming activities, such as the presence of concentration areas (shade of trees, areas protected from predominant winds, drinking and artificial feeding places, etc.). The animals' hooves are more likely to destroy the soil surface by penetration when soils are wet, or in clay soil and in areas of poor vegetation.

Terracing on sloping terrain, and trails on flatter terrain are the result of the routes chosen by animals while grazing and being transferred from one pasture to another. Trails are created in direct proportion to stocking rates and in inverse proportion to the availability of forage and sometimes may become a high proportion of the total pasture area, especially at waiting points near gates and drinking places. These areas may suffer from significant wind erosion during the dry season.

Overgrazing removes vegetation which causes an increase in raindrop impact and surface soil crusting, and a decrease in organic soil matter, aggregate stability, and water infiltration. All these effects increase water runoff, reduce soil water content, and increase erosion.

How can we know if land is overgrazed? There are some crucial parameters. This can be defined as the stocking rate index. This parameter is usually measured in Livestock Units (LSUs) per unit area (ha, km^2). This is the standard unit of 500 kg of body weight and is roughly equivalent to 1 cow, 1 horse or 10 sheep or goats. For our purposes it is no appropriate as it does not take into account the individual characteristics and behaviour of the animals, nor the activities linked to agropastoralism. Indeed it does not take into account:

i. the direct effects of the different species that constitute the LSU. Each species has its own grazing behaviour with a consequent different impact on soil (compaction) and on vegetation (sheep prefer grass, whereas goats and cattle graze shrubs also);
ii. the indirect effects. The farmers need to increase grasslands to meet feeding requirements of animals. They do this either by cultivation or by using fire to clear pastures;
iii. the productive level and function of animals. Mediterranean sheep and goats which are primarily used for milk, have far higher and more precisely distributed feed requirements (i.e. energy and protein per kg per DM taken in for 7 to 9 months) than sheep used for meat or wool. Thus high productivity , at equal body weight, can only be obtained through high quality and quantity of forage supplements;
iv. farm facilities, such as the presence of roads or drinking sites, that make it possible to maintain stocking rates that exceed pasture availability.

An indicator of stocking rate, able to take into account all factors influencing the impact of grazers on soil and on the land degradation and desertification processes, is therefore needed.

This indicator which is able to meet the aforementioned requirements is the one we call Environmental Impact Stocking Rate (EISR); it is expressed in Animal Units of Environmental Impact (1 AUEI = 500 kg live weight), and calculated as follows:

$$EISR = \left(\frac{b_1 X_1 N_1 + b_2 X_2 N_2 + ... b_n X_n N_n}{S} \right) \frac{1}{500}$$

where X_i is the live weight of a Mature Animal Unit MAU belonging to species n (1 MAU = adult female + part of replacement + part of the male unit. This reflects the normal ratio of female, young and males animals in a flock or herd). b_i is the weighing factor of the body weight and N_i is the number of MAU over a given area with surface S.
For example, in the case of dairy sheep, which is of particular interest for us, calculation of the mature unit can be seen in the following table.

	Sheep	Replacement	Ram	Mature Unit
Body weight	42	25	65	
Coefficient	1.00	0.20	0.025	
Value	42	5	1.6	48.6

Table 1: Criteria for mature sheep unit.

The last row is obtained by multiplying the body weight by the appropriate coefficient and the mature unit by summing all the elements of this row.
The same calculation can be made for other species and productive functions. One must also bear in mind the particular situation and species.
Coefficient *b* which refers to the body weight of a MAU assuming that the value for the minimum impact of the animal species is 1.00 (i.e. the minimum impact, SR and EISR coincide), is calculated as follows:

$$b = b_a + b_b + b_c + b_d$$

where b_a, , b_b, b_c and b_d express respectively grazers' impact on soil (compaction), grazers' impact on vegetation (cover reduction), animal production level and farm management (cultivation of pastures, use of fire to clear pastures, grazing systems etc..).
Estimated sub-coefficient values for three species in an extensive marginal area such as common lands of central Sardinia, are shown in table 2.

Species	b_a	b_b	b_c (production level)	b_d (farming systems)
Cattle (1÷1.4)	0.6	0.4	0 Local breeds	0 Extensive
			0.2 Crosses	0.2 Semi-extensive
Sheep (1÷1.8)	0.3	0.3	0.2 Low	0.2 Extensive
			0.4 Medium	0.6 Semi-extensive
			0.6 High	
Goats(1÷1.6)	0.2	0.6	0.2 Low	0 Extensive
			0.4 Medium	0.2 Semi-extensive
			0.6 High	

Table 2 : Subcoefficient values for the calculation of b in the different grazing species.

These sub-coefficients are of crucial importance as they have great influence on the final results. Thus they must be chosen with great care and only when there is clear

scientific or practical evidence to support them. In this case above the coefficients are the results of the experience gained from the MEDALUS project over many years.
Now let me give you a practical example.
A given area of Sardinia of 2,500 ha is grazed by the following animals: 300 local cattle raised on extensive farms; 4,000 dairy sheep with medium production level raised on semi-extensive farms, and 1,000 goats with a low production level raised on semi-extensive farms.
The environmental impact stocking rate can be calculated as reported in table 3.

Species	N	X	b_a	b_b	b_c	b_d	EISR
Cattle	300	450	0.6	0.4	0	0	0.11
Sheep	4,000	48.5	0.3	0.3	0.4	0.6	0.25
Goats	1,000	52	0.2	0.6	0.2	0.2	0.05
AUEI /ha							0.41

Table 3: Example of calculation of the environmental impact stocking rate in AUEI/ha.

In the case above if the sheep were raised in extensive farms (b_d = 0.2) the EISR would fall to 0.35. This fact is of great importance because it shows that the proposed index is very sensitive to all the factors that influence the impact of the animals on the environment.
The above table is, however, in general too crude as it does not take into consideration the differences between different land units. In the example it is assumed that all the various animals are of the same breeds, production types and are raised on the same type of farm. In fact in a large stretch of land we usually find a mosaic of situations. To attempt to reflect this complexity in a single index such as the EISR, we must make use of matrix calculus.
In our example, limited to only three homogenous species, the calculation is relatively easy if a spreadsheet such as Excel is used. It can be done as follows.
The EISR can be calculated for a given number (*k*) of data sets. Each data set is a unit of information referring to a particular piece of land, a specific species, a determined productive level and farming system. If we have three species bred in two different farm systems, we have 6 units of information. The resulting matrix will consist of 6 rows of 20 columns.
The EISR is obtained by the following matrix equation:

$$EISR = \mathbf{(X\ B\ b)} / S$$

where:
X is a (1, k) row vector in which the values show the number of adult units present for the different species in each piece of land.
B is the (k, 20) incidence matrix, of 20 *b*- sub-coefficients related to the *k* units of information (which coincide with the lines of the matrix). It is a mathematical operator whose structure is useful for vector column **b**.
b is the (20, 1) column vector of the *b* sub-coefficients shown in table 2. These are put in sequence of species, following the order of table 3. Once the coefficients are calibrated for the specific situation, this vector can be considered as a constant.

S is the surface area of the land being studied.
In our example, the figures are as follows.

X = (450*300)/500 (48.5*4000)/500 (52*1000)/500 = 270 388 104

These figures represent the number of MAU of cattle, sheep and goats respectively in the piece of land under consideration, expressed as AUEI.

	b_a	b_b	b_{c1}	b_{c2}	b_{d1}	b_{d2}	b_a	b_b	b_{c1}	b_{c2}	b_{c3}	b_{d1}	b_{d2}	b_a	b_b	b_{c1}	b_{c2}	b_{c3}	b_{d1}	b_{d2}
B =	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(cattle)																				
	0	0	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0
(sheep)																				
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1
(goats)																				

In this matrix in the first row the value 1 represents the subcoeffient which is associated with the particular unit of information for cattle, in the second sheep, and in the third goats.

b' = 0.6 0.4 0 0.2 0 0.2 0.3 0.3 0.2 0.4 0.6 0.2 0.6 0.2 0.6 0.2 0.4 0.6 0 0.2

b' represents the value of coefficient *b* for the species following the sequence of the lines of table 2.
S = 2,500 which is the area under consideration, expressed in hectares.

Now we first multiply matrix **B** by column vector **b** and then the result obtained by matrix **X.** Finally we divide the result by the land area thus obtaining the desired result as can be seen below:

B*b = 1.0 **X*B*b** = 1015.6; EISR = 1015.5/2,500 = 0.4062
1.6
1.2

This result agrees with that obtained using an algebraic method as shown in table 3.
This index may be used at a regional scale to compare stocking rate with land suitability. In pasture land the FAO Land Suitability Classification for forage cultivation can be used. I and my colleagues propose the following classes of sustainable stocking rate for pasture. It is weighted for Sardinia, but can be useful in analogous situations.

Suitability class	Stocking rate (AUEI ha-1)
Highly suitable (S1)	> 0.5
Moderately suitable (S2)	0.4 ÷ 0.5
Marginally suitable (S3)	0.2 ÷ 0.4
Currently not suitable (N1)	0.1 ÷ 0.2
Permanently not suitable (N2)	< 0.1

Table 4 : Scheme of the sustainable stocking rate by classes of land suitability to the creation of new pastures.

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References

Enne. G.. Pulina. G.. d'Angelo. M.. Previtali. F.. Madrau. S.. Caredda. S. and Francesconi. A.H.. 1998. Agropastoral activities and land degradation: the case study of Sardinia. In: J. Thornes. J. Brandt and N. Geeson (Editors) Mediterranean Desertification - A mosaic of processes and responses. (in press).

Evans R.. 1998. The erosional impacts of grazing animals. Progress in Physical Geography 22.2. 251-268.

FAO. 1976. A framework for land evaluation. FAO Soils Bulletin No. 32. FAO. Rome.

ISTAT. 1996. Annuario delle Statistiche agricole. Anno 1994. Istituto Centrale di Statistica. Roma.

Madrau S.. Loj G.. Baldaccini P.. 1998. Modello per la valutazione dell'attitudine al miglioramento dei pascoli dei suoli della Sardegna. Sassari. Università degli studi di Sassari. 51 p.

Seligman. N.G.. 1996. Management of Mediterranean grasslands. In J. Hodgson and A.W.Illius (Editors). The ecology and management of grazing systems. CAB International. Wallingford. pp.359-391.

van der Leeuw. S.E. (Editor). 1998. The Archeomedes Project. Understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean basin. European Commission - Directorate General XII. Brussels. EUR 18181 EN.

Zucca C.. Loda B.. d'Angelo M.. Madrau S.. Percich L.. Previtali F. (1998) - Sistemi agrosilvopastorali mediterranei: un approccio metodologico per la valutazione delle terre all'utilizzo agropastorale. Genio Rurale LX. 3. 47-56.

MITIGATION ACTIONS IN DESERTIFIED AREAS OF NORTHERN EUROPE

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Abstract. Desertification and other forms of soil erosion are rarely expressed as vividly as in Iceland. Overexploitation of the land for 1100 years has resulted in the loss of about 96% of the original woodlands and about 50% of the vegetation cover.
With one of the oldest soil conservation agencies in the world, Iceland has a long history of successes and failures in combating rangeland desertification. This experience has parallels in many parts of the world.

Keywords: Carbon sequestration; conservation incentives; land literacy; participatory soil conservation.

Desertification in a north european context

By global standards, soil erosion and desertification in Northern Europe caused by human impact is relatively small (El-Swaify *et al.*, 1999). Better farm management can overcome most of the effects on agricultural productivity, at least temporarily. However, soil compaction, build up of micro-elements in soils, and off-site impacts through transfers of nitrates, phosphorus and sediment to water bodies downstream, are increasingly-recognised problems. Thus, conservation policy is driven by environmental sensitivity to pollution rather than concerns about long-term food production. Further, most of the conservation focus is crop-agriculture oriented, with only a relatively small focus on mitigating soil erosion problems in rangelands and pastures.
There is considerable confusion about the definitions used to circumscribe the basic topic of this article. In the context of the Convention to Combat Desertification, the definition of desertification is confined to the arid lands of the world. In practise, the distinction between "land degradation" and "desertification" can be quite unclear, and desertification is indeed a problem global in nature (Arnalds, O., in press). Here, the perspective of van der Leeuw (1998: 5) will be followed, namely "to view desertification as a special case of very heavy and large-scale degradation, and look at the wider range of processes rather than focus on desertification."
Looking at the soil conservation problems of Northern Europe, only rarely are they of an extent to fall under such desertification definitions. However, there is one distinct exception. Iceland, with its severe soil erosion and degraded state of the vegetation resources, is the only nation in northern Europe fighting widespread desertification and other forms of land degradation. In this paper, the long history of soil conservation in Iceland is used to illustrate some perspectives of rapidly evolving mitigation strategies.

Ecosystem degradation and desertification

Iceland is predominantly rangeland, as the climate is borderline for grain production. Agriculture basically means grass-based livestock production. Farms and all urban areas are located in the coastal lowlands, and most farms are privately owned. The vast highlands of the interior are used for free-range summer grazing by sheep, in communal districts or commons. The farmers of Iceland own or have grazing rights to more than 70% of Iceland.
The history of the soil and vegetation resources of Iceland is a tragic example of the long-term consequences of the human battle for survival in a sensitive environment. As a result, there is an urgent need to halt erosion or restore vegetation over much of the island.

Climatic characteristics
Iceland is in the subarctic belt, touching the Arctic Circle in the north. A branch of the warm Gulf Stream nearly encircles the island. At the Northeast corner the Gulf Stream encounters the cold Polar Stream, which considerably reduces temperatures along the northeastern part. The climate in Iceland is maritime: cold temperate in the lowlands and low arctic in the highlands. It is thus milder than might be predicted from its global position.
Summers are short, windy and cool; spring and autumn, long: and winters relatively mild and characterised by frequent freezing and thawing. There are frequent and strong winds, mainly from the southeast and north, and rainfall is highly variable, from 400 mm annually in the northeast to 3500 mm along the south coast.

Soil characteristics
The bedrock of Iceland is mainly of basaltic origin, either basaltic lava or tuff (Hyaloclastite) which decomposes readily. The country is built up on the Atlantic rift and is crossed by a volcanic belt, where tuffs are the main rocks. Extensive soil erosion has taken place in most parts of Iceland, but particularly in this belt (Arnalds, O. *et al.*, 1997). The Icelandic soils are Andosolic in character and with a generally remarkably weak, or even absence of, horizontal zoning (Johannesson, 1960). Stratigraphically immersed in the tephra-loessial soils are a number of volcanic tephra layers of both basaltic and rhyolitic origin.
Icelandic vegetated dryland soil is to a great extent a result of wind-borne sedimentation, and thus of a homogeneous tephra-loessial type (Andisol), with medium content (2-12%) of partly decomposed organic matter and average pH (5-6.5). The wetland (Histosol) soils include high levels (20-60%) of organic matter, mainly as a result of slow decomposition in the absence of active oxygen, high pH (4-5), and low soil temperatures. The soils of the denuded areas (Entisols or Inceptisols), which cover 50-60% of the total area of the country, are characterised by a very low percentage of organic matter (>1%) and low pH (7) (Arnalds, O., 1990).

The fate of the icelandic ecosystems
Understanding the health, or the condition, of the land is one of the main foundations of defining restoration and management goals in degraded areas (Committee on Rangeland Classification, 1994). Key parameters are an understanding of ecological sites and thresholds for site conservation, and defining desired plant communities (Society for Range Management,

1995). Analysis of vegetation history, current state of vegetation and soil, ecologically possible vegetation, desired plant communities based on land use considerations, and soil protection characteristics reveals that a large part of the area of Iceland may be regarded as in poor health.

The settlers who came to Iceland 1100 years ago (about 874 AD) saw a fertile land. Vegetation may have covered more than 60% of the country, and woodlands, mainly birch (*Betula pubescens*), covered at least 25% of the land area. The vegetative cover provided good protection of fragile volcanic soils. With the settlement, a delicate balance between a hostile climatic environment and vulnerable vegetation was disrupted (Thorsteinsson, 1986; Arnalds, A., 1987). The woodlands were cut for fuel or burnt off to make pastures. High grazing pressure damaged the land and interfered with vegetation recovery after natural disturbances. Subsequent soil erosion has devastated large parts of the ecosystem, reducing vegetative cover by an estimated 50%. Trees now cover only 1% of the land area.

Arnalds, A. (1987) summarises some of the various sources that can be used to reconstruct the vegetation of the past and trace some of the major changes in cover and composition through the centuries. These include historical records, site names, pollen studies, remnants of former vegetation, and land use indicators.

The initial causes of soil erosion in Iceland vary from place to place. However the interaction of livestock grazing with weak soil structure, harsh climate and volcanic eruptions is considered to be the main reason for the great ecosystem disturbance. Climatic fluctuations have also sped up this process, reducing further the ability of the vegetation to meet the relentless pressure of man and livestock. The importance of time-scale and rare events as triggers of destruction should be stressed in the interpretation of the degradation processes and history.

Desertification continues to be a major threat to Iceland's natural resources. A national assessment of soil erosion indicates that 40% of Iceland is experiencing severe soil erosion (Arnalds, O. *et al.*, 1997; Arnalds, O., in press). Surfaces that become denuded are usually almost devoid of below-ground plant tissue, and subsequent vegetation succession can be considered primary.

Mitigating desertification

Most of the 90 years of state-organised soil conservation in Iceland have been characterised by localised efforts to contain the spread of catastrophic soil erosion. In contrast, the last decade has been characterised by an emphasis on natural resources conservation based on management for sustainability.

Historical overview

The rate of erosion is presumed to have been highest in the late 19th century and the first decades of the 20th century. Large districts were devastated by sandstorms during this period, forcing numerous farms to be abandoned. The existence of whole counties was threatened. Some farmers tried protective measures, which consisted mainly of erecting walls of stones

against the prevailing wind direction. However, their efforts to halt the destruction of their farms were of little or no avail.

The first formal and organised measures aimed at curtailing erosion were taken with the "Act for Resolution on Sand Erosion and Reclamation" passed by parliament in 1875. However, this resolution provided no means or incentives for erosion control and was of little value. The organised battle against erosion began in 1907, with the Act on "Forestry and Prevention of Erosion of Land," founding the Icelandic Soil Conservation Service (SCS). For a long time the law was confined strictly to measures against catastrophic soil erosion, and it was not until 1965 that protection of vegetation and soil conservation in general were incorporated. The main role of the SCS now is to prevent land degradation, reclaim denuded or damaged areas, improve degraded ecosystems, and encourage sustainable land use.

Halting desertification

Because of the fragility of the vegetation in areas of catastrophic erosion, complete protection from grazing is required when sand drifts are brought under control. Mitigation of other forms of desertification is also more efficient and cheaper if such land is protected from grazing. Reclamation fences have enclosed about 4% of Iceland, but this is only a small proportion of the area affected by desertification, and – in the quest for sustainability – protected areas are expected to reach about 40% of the island in the next decade.

Icelandic lyme grass (*Leymus arenarius*) has been used with good success to stabilise sand encroachment. It is usually seeded in strips perpendicular to the prevailing wind direction and fertilised until the most serious sand drift has been stopped. Fertilisation rates are commonly about 200 kg/ha of a mixed N-P fertiliser for three years. Once stabilised, native species invade from neighbouring vegetation and the pioneer species gradually disappears as the primary succession continues. Lack of local seed sources can adversely affect both the direction and rate of succession if large areas have become completely denuded.

Land reclamation

It is estimated that at least 30 000 km^2 have become denuded during the last 1100 years, or about half the vegetated area at time of the Viking settlement. These areas are not considered as wastelands, but rather as land in extremely poor condition, with potential for recovery.

Natural recovery of denuded areas is highly variable. Some areas at higher elevations apparently became desertified shortly after settlement, and still have little vegetative cover, whereas some lowland areas may recover by natural means in less than a century. The reasons for this wide range in natural recovery are many. Some of the highland vegetation may have become established in a warmer temperature regime prior to the settlement. Such vegetation might maintain its own microclimate favourable enough for maintaining the vegetation despite of climatic fluctuations. Once an external trigger, such as the effects of land use, disrupt this delicate balance the conditions can become unfavourable for re-establishment.

By the 1950s, when sand encroachment was no longer a threat to inhabited areas, reclamation of some of the denuded areas began. Traditionally grasses such as native Icelandic varieties of *Festuca rubra* and *Poa pratensis* are seeded and the area fertilised for 3-4 years with 300-400 kg/ha of a mixed N-P fertiliser. The use of this method is mainly intended to improve site conditions in order to speed up natural processes of recovery. The grasses start disappearing

soon after fertilisation ceases, and species from adjacent vegetation start invading. The direction and rate of this secondary succession depends on many factors, including availability of seed sources, but common ecological sites would be stable plant communities characterised by birch and willows.

Native legumes in Iceland are few, and none of them have been developed for reclamation on a large scale. The Alaska lupine (*Lupinus nootkatensis*) was introduced from Alaska in 1945. It has very good potential as an efficient and economic reclamation plant, and is used by both individuals and the SCS. It acts as a pioneering species, commonly giving way to other plants after 20-40 years. However, more research is required on disappearance rates and ecological implications.

Community involvement in soil conservation

Continuing soil erosion and the degraded state of the environment has many consequences for the well being of the whole Icelandic nation. These include a reduction in biological diversity, reduced agricultural productivity and food security, loss of shelter from frequent high winds and snowdrifts, degraded catchment hydrology and many other factors in land quality. In order to build a strong relationship between conservation and society, SCS has been developing new approaches in its operation (Arnalds, A., 1998; in press(a)).

In general, mitigating land degradation is becoming more participatory, involving a wide cross-section of Icelandic society in understanding the ecosystems and developing solutions. A need has also been recognised to widen the focus from localised problems of soil erosion to the more complex issues of ecosystem management for multiple use considerations. Icelandic policy development over the last decade has sought much inspiration to the Landcare community-wide programme, which has revolutionised conservation approaches in Australia (Campbell and Siepen, 1994, Marriott *et al.*, 1999).

It is important that all sectors of society are directly involved in the various aspects of mitigating land degradation. SCS is currently working on reclamation projects with a wide range of community groups, including municipal and rural authorities, a wide range of clubs and associations, and a large number of individual volunteers. The Presidents of Iceland have been enthusiastic advocates of increased conservation, and set a public example in caring for the soil.

The leaders of the future are in school today, and SCS has therefore emphasised cooperation with school authorities.

Creating land stewardship

It is now generally agreed that soil conservation programmes can only succeed if there is a widespread and genuine participation by the land users themselves in the whole planning and implementation process (Sanders, 1997). This is based on the principle that people involved in their own problem-solving and subsequent action planning will have more commitment to the

process and outcomes than those who are on the end of the delivery line (Hobson, Forge and Walters, 1992).

Making soil conservation attractive to the land user

Various means can be used to motivate land users to adopt more sustainable management practices and improve land quality (Arnalds, A., in press(b); Hannam, 1998; Hurni, 1996; Sanders, in press; Sombatpanit, in press). These include internal motivation, which implies that the landholder receives a sense of reward and value by participating and acting within the programme, without there having to be "incentives" provided (Hobson, Forge and Walters, 1992). A large proportion of farmers cooperating with the Icelandic SCS may be participating in reclamation projects for this motive alone (Schmidt, 1999). The motivation may also be external, which implies that a landholder needs some external reward or "incentive" applied. Such incentives might include tax deductions, grants and a wide range of legislative control.

Among the many negative aspects of the top-down approaches to soil conservation in the past is that farmers often saw little personal benefit in the soil conservation measures. Mitigating desertification and improving degraded land is more attractive to the land users if such measures are productive or meet some immediate need. To help develop such practices, soil conservation professionals are increasingly looking at whole-farm systems and not just confining themselves to the problems of immediate erosion (Sanders, 1997).

The role is rapidly changing of those working with land users on mitigation actions (Marriott *et al.*, 1999). It is becoming that of facilitator, constantly encouraging the land users to analyse their problems, seek solutions and develop self-reliance. Assistance is needed, but the resulting programme must remain that of the land user, run and implemented by the farmers themselves to the extent possible. In addition to this focus on local leadership, there should also be an emphasis on environmental quality, rather than single-issue soil conservation (Molleur and Loser, 1998).

Farmers heal the land

Based on the abovementioned principles, programmes that motivate and provide livestock owners with voluntary incentives to adopt sound conservation practices have been evolving in Iceland (Arnalds, A., in press(a)). The most extensive operation is *Farmers heal the land*, a partly locally-led programme centred on assisting landowners to reach their reclamation goals. The long-term goal is to increase conservation awareness and make the land users the true custodians of the land.

The farmers currently receive 85% of fertiliser cost and grass seed as needed for reclamation. They conduct all the work with own machinery, and this, coupled with their 15% contribution to the cost of the fertilisers, can amount to 50% of the full cost of a project. Cost sharing is considered very important, as it helps to create a feeling of ownership in the results.

The bottom-up nature of the project has facilitated positive communication. The farmers are proud of their achievements, and enjoy discussing their mitigation work. They are also seen as a part of a solution to the degradation problems. This in turn opens up positive channels for discussing and resolving other resource issues – topics that traditionally were difficult to

approach prior to this cooperation. More than 25% of the sheep farmers are now actively participating, plus a number of other land users.

The programme demonstrates the great "research" power that exists at grass-roots level. Through the co-operation of farmers healing their land, scientists and SCS staff, methodologies have been evolving that might be termed "adaptive reclamation." The farmers are encouraged not to slavishly follow standardised guidelines, but rather to tailor their work to the needs of the land, based on increasing levels of land literacy. The main goal is to speed up natural processes of recovery with only minimal inputs. For example, many farmers have noticed that by applying low levels of fertilisers to sparse vegetation, using no seed, they enhance the reproduction rates of the native species. A fertilisation programme that is evolving involves spreading 150 kg/ha of a mixed N-P fertiliser for 2-3 years, then re-applying once or twice after 2-4 years, depending on the status of the land.

No technology is of any consequence unless it is carried to ultimate users in a useable form and adopted. With the land user, extension workers and researchers all becoming active team players in action-development for mitigating land degradation, the relationship between them must also change (Sanders, 1997). Taking an initiative in adapting to this partnership will be very important for the research community.

The change from traditional "top-down" to "grass-roots" approaches requires significant organisational changes. New types of professionals will also be required, as described by Marriott *et al*. (1999) as emerging for the Landcare programme in Australia: "practical but still visionary, combining broad technical knowledge with administrative, managerial, communications and community skills." The role of such people will be one of facilitation: leading, but in a subtle way. In Iceland, such personnel will be partly within the SCS; in larger countries, probably more at the community level, as in Australia.

Strengths of the grass-roots approach

The success of the *Farmers heal the land* programme is derives from a wide range of elements attuned to Iceland's culture, system of government and communal needs. Although this programme is still evolving, and more individualistic rather than group oriented, it shares many of the elements listed by Marriott *et al*. (1999) that brought success for the Australian Landcare community-wide programme. These elements include:

- There is a strong respect for local knowledge and recognition of the strong research power of farmers and other individuals if linked with scientific knowledge.
- Government supports strongly, but does not lead. The programme is based on mutual trust, and bureaucracy is kept to a minimum.
- The partnership is a strong educational tool, which stimulates dialogue on the concepts and practice of sustainability, which in turn encourages people to take a longer-term view of resource use and ecosystem conservation.
- Local decision making is a key factor, with strong links to education and extension, planning and monitoring.
- Flexibility is encouraged, and participants can experiment and tailor work to their needs.

Land user perceptions

A survey of perceptions among the participants of the *Farmers heal the land* programme was made in 1999 (Schmidt, 1999). It revealed several findings, which will be very useful in advancing this cooperative project.

The age distribution of the farmers reflects the tough times of the farming community, as only 17% of the participants were younger than 40 years. This has several implications, including that a high proportion of the farmers went through school before topics such as "sustainability" and "ecosystem quality" became important in school curricula.

About 95% of the participants were either content (41%) or very pleased (54%) with the projects. Most of the farmers said they would continue their reclamation work without financial support, but – given their financial constraints – at a much smaller scale. The importance of personal communication with the soil conservation people was rated very high, not least for its role in creating mutual understanding and trust. As one farmer said:

"The reclamation work is planned with SCS assistance, which then evaluates and approves its success. The "pat on the back" the farmers are receiving is encouraging, and we want to do our best."

The survey indicated that 70% of the participants regarded soil erosion in Iceland as a rather big (31%) or severe (42%) problem. None considered the erosion a small or non-existent problem. Farmers' perceptions of the severity of soil erosion in Iceland have often been questioned, so these findings are therefore encouraging, whether or not they can be attributed directly to the extension power of the project.

A third of the participants had changed grazing management since they began in the programme. In part because improving land quality by reclamation increased their management flexibility, but several added that such a project made them more environmentally conscious. The improved land literacy made them more responsive to the needs of the land, resulting in better management.

The farmers were asked why they participated in the *Farmers heal the land* cooperative programme. About 26% said their highest priority was to "improve the appearance of land in rural communities," 25% cited "because of environmental considerations," and 24% said "in order to be able to bring the land to a better state for the next generation." Only a few put personal benefits, such as economic gains, or peer-pressure as their main concern.

The use of mass media

Mass media are powerful means to bring attention to land problems, and also to means of mitigation (Sombatpanit *et al*., 1997). "Media is here taken to include not only newspapers, magazines, radio and television, but also interpersonal communications, such as through meetings, tours and field days. Research shows that farmers obtain their information from a variety of sources. Hence mitigating desertification and other forms of severe land degradation should use a combination of different forms of media to promote their work.

While it is important to bring to the public the problems of degradation, it is crucial also to present the means for combating those environmental problems, and also success stories. In Iceland the media coverage of desertification and unsustainable land use practices has at times been quite merciless. This has made almost every Icelander aware of the resource problems. However, it has at times tended to drive a wedge between farmers and urban dwellers. For a while, it also may have made some farmers antagonistic towards conservation. However, this

may have been an unavoidable first step in the creation of land literacy and a willingness to meet increasing demands for more sustainable land use. An understanding has now been gained of soil erosion as a common enemy of the nation.
Well-balanced media coverage is of great importance. Too much focus on the problems of desertification creates a kind of pessimism. However, a more even balance with a high profile on solutions and success stories creates both a desire for action and a belief in the restoration work.

Agricultural policy

Agriculture is by far the biggest land user in Iceland, although it employs only 4% of the labour force. Livestock production is the mainstay of agriculture, and most of the island can be classified as rangeland and lowland pastures.
Changes in agricultural policy, especially in relation to agricultural support measures, offers great opportunities to influence land use and management in a more strategic way. Historically, the full potential of this opportunity has seldom been used. On the contrary, the Icelandic experience illustrates clearly that in the absence of linkages to sustainability goals, production incentives can become highly detrimental to the environment (Gisladottir and Preston-Whyte, 1998; Arnalds, A., in press(a)).
Without linking agricultural support to conservation, the government could be accused of actually maintaining, or even encouraging, land degeneration (Arnalds, A., in press(a)). In effect, all governmental support aimed at maintaining the livelihood of the farmer, such as subsidies, should be regarded as a social contract. It should take into equal consideration food security, sustainable management of natural resources – with land improvements where needed – and the vitalising of rural communities. This requires new policies and legislation to protect the public interest and clarify land-user responsibility. Furthermore, publicly funded research and extension should be directed towards helping agriculture fulfil its part in such a social contract. This means much more than a simple target such as increasing agricultural productivity.

Carbon sequestration – a new incentive for landcare

In the April/May 1999 issue of *Conservation Voices*, the Soil and Water Conservation Society presents the view that carbon both a dangerous greenhouse gas and also a valuable resource. Carbon dioxide is one of the principal culprits named in the global warming debate. The same carbon, when located in soil, becomes organic matter, the key to soil fertility and increased food production for the world's growing population.
Based on such views, mitigating desertification and improving land quality may become a large part of Iceland's response to the challenge of climate change. At the same time, reducing greenhouse gases by carbon sequestration has a great potential as an economic incentive for such actions.
One of the consequences of the extensive ecosystem disturbance in Iceland is a high potential for carbon sequestration in both soil and biota. Such factors are increasingly shaping conservation projects, and restoring ecosystems and reducing atmospheric carbon can be

combined for multiple benefits. Furthermore, halting soil erosion has a major role in preventing release of stored carbon to the atmosphere.

The long history of successful soil conservation work, and the great need for increased soil fertility, inspired the Icelandic government in 1995 to include carbon sequestration as an important part of the National Climate Change Action Programme for the period 1990-2000. Many projects have been initiated or expanded for combating desertification and healing eroded land. Projects aimed at reforestation of damaged land were also greatly expanded, partly under the theme of "reclamation forestry."

The role carbon sequestration can play as a tool for meeting targets for greenhouse gas emissions has resulted in a 30% increase in exchequer budget allocations for forestry and soil conservation in Iceland. The linkage between the goals of the Conventions of Desertification and Climate has thus become one of the biggest economic incentives developed for soil conservation and forestry in recent years.

Globally, there is a great potential for increasing soil carbon through restoration of degraded soil and other soil conservation practices. This potential varies greatly, but can be high, both in soil and biota, as the Icelandic experience illustrates. Recognition of this potential by formal approval within the Climate Convention would greatly encourage the use of carbon sequestration as an incentive to combating desertification and improving degraded land in vast areas of the world, including Iceland.

Conclusion

The ecosystem degradation and desertification that has taken place in Iceland over the last 1100 years has no parallels in Northern Europe, and possibly is matched in only a few countries in the world. Vegetation maps and a national survey of soil erosion in Iceland, completed in 1997, have confirmed the severity of the desertification problems.

Since the foundation of the Icelandic Soil Conservation Service, mitigation strategies have been evolving from localised, single aspect, soil conservation work, towards more comprehensive and holistic ecosystem management, guided by principles of sustainable development. The main aim is to prevent further ecosystem degradation and restore land quality in accordance with growing conditions and land use needs of the various user groups. A new economic incentive for such projects, with great potential, is carbon sequestration with regard to the Climate Convention.

The degraded state of the Icelandic vegetation and soil resources makes clear guidelines for sustainable land use essential. Large areas must be taken out of grazing use: by negotiation if possible, or, as a final resort, by law, which also must allow imposition of penalties in case of unsustainable land use. Agricultural policy also must be better adapted to the goals of sustainability.

Locally-led community involvement, based on growing land literacy, is one of the foundations of the currently evolving conservation strategies. About 25% of sheep farmers in Iceland are now cooperating with the SCS in reclamation of desertified land. Participation, from initial planning through to implementation of projects, stimulates awareness and initiative, and attracts funding. The long-term goal is the creation of a conservation ethic, or land stewardship.

References

Arnalds, A. (1987). Ecosystem disturbance in Iceland. *Arctic and Alpine Research*, **19**(4): 508-513.

Arnalds, A. (1998). Strategies for Soil Conservation in Iceland. *In:* H.-P. Blume *et al.* (eds) Towards Sustainable Land Use. Vol. II. *Advances in Geoecology*, **31:** 919-925. Reiskirchen, Germany: Catena Verlag.

Arnalds, A. (In press(a)). Incentives for soil conservation in Iceland. *in*: D. Sanders, P.C. Huszar, S. Sombatpanit, & T. Enters (Eds) *Incentives in Soil Conservation*. Oxford & IBH Publ.

Arnalds, A. (In press(b)). Evolution of rangeland conservation strategies. *In*: O. Arnalds & S. Archer (Eds) *Rangeland Desertification*. Advances in Vegetation Sciences series. Dordrecht, the Netherlands: Kluwer.

Arnalds, O. (1990). Characterization and Erosion of Andisols in Iceland. PhD Thesis, Texas A&M University, College Station, Texas.

Arnalds, O. (In press). Desertification in Iceland. *In*: O. Arnalds and S. Archer (Eds) *Rangeland Desertification*. Advances in Vegetation Sciences series. Dordrecht, the Netherlands: Kluwer.

Arnalds, O., Thorarinsdottir, E. F., Metusalemsson, S. M., Jonsson, A., Gretarsson, E., & Arnason, A. (1997). *Soil Erosion in Iceland* [in Icelandic]. Gunnarsholt: Soil Conservation Service, and Reykjavik: Agricultural Research Institute. 157 p.

Campbell, A., & Siepen, G. (1994). *Landcare - communities shaping the land and the future*. Sydney: Southwood Press.

Committee on Rangeland Classification, Board on Agriculture, National Research Council. (1994). Rangeland Health: New Methods to Classify, Inventory and Monitor Rangelands. Washington DC: National Academy Press. 190 p.

El-Swaify, S.A., with an international group of contributors. (1999). Sustaining the Global Farm – Strategic Issues, Principles, and Approaches. International Soil Conservation Organisation (ISCO), and the Department of Agronomy and Soil Science, University of Hawaii at Manoa, Honolulu, USA. 60 p.

Gisladottir, G., & Preston-Whyte, R. (1998). Policy changes on sheep farming in Iceland. *In: Environmental Characterisation and Change in Southwestern Iceland*. Department of Physical Geography, Stockholm University, Sweden.

Hannam, I.D. (1998). Soil conservation policies in Australia: Successes and failures and requirements for ecologically sustainable policy. p. 618-638, *in:* T.L. Napier & S.M. Camboni (Eds). *Soil and Water Conservation: Successes and failures*. Iowa: Soil and Water Conservation Society.

Hobson, M., Forge, K.M., & Walters, R.T. (1992). Action Research – Everyone can do it with *Pasture Watch*. p. 158-169, *in: People Protecting Their Land*. Proc. 7th Int. Soil Conservation Conf., Australia, Sept. 1992.

Hurni, H. (Ed). (1996). *Precious earth: From soil and water conservation to sustainable land management*. International Soil Conservation Organisation (ISCO) and the Centre for Development and Environment (CDE), Berne. 89 p.

Johannesson, B. (1960). *Soils of Iceland*. Reykjavik: Menningarsjodur. 134 p.

Molleur, R.T.& Loser, J.R. (1998). Environmental Quality Incentives Program (EQIP): A new approach and tool to conservation and environment protection for America's farmers and ranchers. *Proc. 1998 Soil and Water Conservation Society Annual Conference*, July 1998, San Diego, CA.

Marriott, S., Nabben, T., Polkinghorne, L., & Youl, R. (1999). *Landcare in Australia – founded on local action*. Landcare Australia. 27 p.

Sanders, D.W. (1997). Implementation of Soil Conservation Extension. p. 237-243, *in:* S. Sombatpanit, M.A. Zöbisch, D.W. Sanders, & M.C. Cook, (Eds). *Soil Conservation Extension: From Concepts to Adoption*. New Hampshire: Science Publ.

Sanders, D.W. (In press). The Implementation of Soil Conservation Programmes. *In:* O. Arnalds & S. Archer (eds), *Rangeland Desertification*. Advances in Vegetation Sciences series. Dordrecht, the Netherlands: Kluwer.

Schmidt, G. (1999). Baendur graeda landid [Farmers heal the land]. BSc dissertation. Agricultural University of Iceland, Hvanneyri. 67 p.

Society for Range Management. (1995). Evaluating Rangeland Sustainability: Evolving Technology. *Rangelands*, **17**: 85-92.

Sombatpanit, S. (In press). Soil Conservation Extension. *In*: O. Arnalds & S. Archer (Eds), *Rangeland Desertification*. Advances in Vegetation Sciences series. Dordrecht, the Netherlands: Kluwer.

Thorsteinsson, I. (1986). The effect of grazing on stability and development of northern rangelands: A case study of Iceland. p. 37-43, *in*: O. Gudmundsson (Ed) *Grazing Research at Northern Latitudes* New York, NY: Plenum Press.

van der Leeuw, S.E. (Ed). (1998). The Archaeomedes project – Understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean basin. Luxembourg: Office for Official Publications of the European Communities. 440 p. ISBN 92-828-3226-0.

RESTORATION STRATEGIES AND ACTIONS IN MEDITERRANEAN DEGRADED LANDS

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Abstract. Mediterranean landscapes have suffered profound transformations during the last quarter of the 20th century due to land-use change and forest fires. During this same period, the social perception of nature has changed as well, and ecological issues such as biodiversity, desertification and global change have become of general concern. Therefore, land restoration has to be adapted to the current social demands for seminatural ecosystems. We have developed a land-restoration strategy for dry Mediterranean conditions where wildfires and desertification are the main degrading processes. The objectives considered are soil and water conservation, and the reconstruction of resilient ecosystems in relation to wildfires.

Emergency seeding techniques proved to be efficient in protecting the soil after fire. The plantation of sclerophyllous shrubs and trees is proposed to reduce the combustibility of plant formations dominated by fuel accumulators, and to increase the regeneration capacity of the system in case of fire. A variety of native species show good survival rates in the Region of Valencia (E Spain) under semiarid and/or subhumid climate: *Quercus ilex ssp. ballota, Pistacia lentiscus, Rhamnus alaternus, Rhamnus lycioides, Juniperus phoenicea, Pinus halepensis, P. pinaster*. However, survival rates are very much affected by the meteorological conditions of the first post-plantation year, showing high mortalities for drought periods longer than 3 months. *Quercus ilex ssp. ballota* has generally shown poor growth in the field. We have developed a new technique for avoiding root pruning in the nursery, so as to preserve the integrity of the tap root in this species.

The addition of sewage sludge to the plantation hole enhanced *Pinus halepensis* and *Quercus ilex ssp. ballota* growth, as did the use of tree shelters. New developments are required to improve seedling survival and growth under extreme drought events and for very shallow soils. Seeding techniques and seedling quality are promising areas to be focused in the near future.

Key words: Land restoration, reforestation, seedling, *Quercus spp.*

Introduction

In a general sense, restoration is applied to stop ecosystem degradation and to promote its regeneration, considering both ecosystem structure and function. This definition implies the creation of a pre-determined ecosystem from a degraded one. It is often assumed that if ecosystem degradation has not progressed too far, a spontaneous return to the predisturbance ecosystem is possible simply by removing the anthropic stresses (Aronson et al. 1993).

However, when degrading forces have been deep and/or acting for a long enough time, restoration actions are likely to be necessary. Restoration is envisaged once the human degradation has stopped, when natural regeneration is improbable or too slow for the objectives proposed, and especially when no intervention could allow further degradation or the risk of disasters.

The extensive and intensive land use in the Mediterranean over millenia (Wainwright, 1994) has produced land degradation by forest overexploitation, overgrazing, fire, cultivation/abandonment, and, what is worse, the sequential combination of several of these disturbances, as for example cultivation – abandonment – fire – grazing. In this paper we will discuss strategies for wildland restoration in dry Mediterranean conditions, that is from subhumid to semiarid according to the UNESCO index (1979), with especial emphasis on those developed from the experiments carried out in Eastern Spain under the EC projects REMECOS and REDMED from the Environment and Climate programme.
[1]

The problem

Land degradation and water shortage have become major threats to the sustainability of the seminatural and cultivated ecosystems in the Mediterranean. Arid, semiarid and subhumid areas are considered to be susceptible to desertification processes (UNEP, 1992). Recent EC projects such as MEDALUS and EFEDA have identified the main factors driving desertification and the areas especially affected in the northern Mediterranean. Generally the most critical areas were identified as having less than 600 mm of rainfall per year, conditions of chronic water stress, very high rainfall variability and high intensity rainfall. They commonly present prolonged dry periods followed by heavy rainfall, particularly in autumn. An uneven relief with steep slopes in large parts of the territory and the great spreading of unconsolidated substrata coming from the erosion of uplands, and marl and clay bedrocks, enhance the soil degradation hazard (López-Bermúdez & Albaladejo, 1991). In addition, anthropogenic disturbances resulting from the uncoupling of man from resources are key factors in developing desertification processes.

As an indirect consequence of the deep land-use changes that had occurred in the European Mediterrarranean countries by the middle of the 20th century, wildfires have become a major disturbance for Mediterranean ecosystems. Wildfires remove the plant cover and litter layer which play a major role in the prevention of soil erosion caused by raindrop impact and wind velocity (Francis & Thornes, 1990). Fire can also affect several of the physical and chemical soil properties related to erodibilitity (Giovannini et al., 1988; Soto et al., 1991). As a consequence, burned lands are especially sensitive to erosive agents, and relevant soil losses can be generated while an effective soil cover is absent. The risk of soil degradation is very high immediately after a fire and decreases exponentially with time as the plant cover regenerates, i.e. soil losses are comparable to unburned lands two to three years after fire. In many cases, the regeneration of vulnerable areas requires external intervention after fire to help the initial steps in plant succession (Barro & Conard, 1987). The treatments should be

[1] This paper summarises the research developed under the EC projects REMECOS and REDMED, including the work carried out by J. Bellot, D. Fonseca, F. Maestre and E. Rubio from the University of Alicante, and J.A. Alloza, S. Bautista, and C.Bladé from CEAM.

designed to be efficient by the period of maximum erosion risk, that is from the first autumn after a summer fire.

The challenge

Vegetation is the key factor for decreasing desertification processes. In general, vegetation is the main subject of land-use and climate change (Margaris et al. 1996), and plant cover is commonly manipulated as a management tool among the factors affecting land degradation. So, actions for combating desertification should include measures aimed at producing sustainable vegetation cover.

The challenge is to determine to what extent degraded lands and desertification processes currently operating in European dry lands can be reversed into aggradative processes, with the artificial addition of energy in the form of adapted plant species and field treatments. Also, to what extent are these aggradative processes sustainable both in ecological and economical terms. Establishing (seeding or planting) adapted native tree and tall shrub species, especially deep rooting resprouters, could enhance aggradative processes (Vilagrosa et al.1996). This establishment requires initial amendments so as to overcome the limiting factors to plant growth present in the degraded lands.

Land restoration is not a new activity in Europe. In Spain, the first relevant restoration actions were performed a century ago for watershed protection and dune fixation. Those objectives, together with the improvement of forest quality and productivity were the traditional goals of forest restoration. However, in the last few decades new challenges have appeared driven by the profound socioeconomical transformations produced and the consequent changes in the social perception of nature. Wood production is generally unimportant in Mediterranean Europe nowadays, whereas the ecological and recreational value of forests has become more relevant and forest exploitation is mostly addressed to non-woody products (e.g. truffle). Nowadays, land restoration and land management must take into account ecological values, biodiversity issues, the threat of desertification and global change, wildfire prevention, and the demand for cultural and recreational use of forests. In addition, both in the past and in the present, land restoration has been a means of improving rural economies. Therefore, land restoration practices must be adapted to these new challenges.

Constraints for restoration in dry Mediterranean conditions (i.e. precipitation < 500 mm)

Climate: Water shortage is the critical factor in seedling survival in dry Mediterranean climates. A relatively predictible limitation is the summer drought, especially during the first year after plantation or seeding. We observed that plantation mortality during the first post-plantation year was higher the longer the period without any significant rain (higher than 5 mm) (Fig. 1). In addition, there is a less predictible drought which is often produced out of season, but which is relatively frequent (the more frequent the drier the climate). In Valencia (E Spain), with an average annual precipitation of 400 mm, the probability of having 30 or more days without any significant rain is 60 % in the transition autumn-winter (plantation period) and 50 % in the winter and spring seasons (immediate postplantation). Furthermore, the probability of having 60 or more days without any significant rain is almost 50 % in the transition spring-summer and almost 40 % in autumn-winter (Vallejo et al., 1999). These out of season droughts are very

relevant for restoration because they may affect the seedling in the installation stages, when it is very sensitive to water shortages, much more so than mature plants.
Soils: forest and rangeland Mediterranean soils are often shallow, stony, discontinuous, with poor structure - prone to soil surface crusting -, poor in soil organic matter and biological activity. Many of these properties enhance water limitations induced by the climate. In the same dataset of Fig. 1 we can see that differences in plant mortality related to soil type are produced for intermediate drought lengths, whereas for very wet or dry years, soil type did not affect seedling mortality.

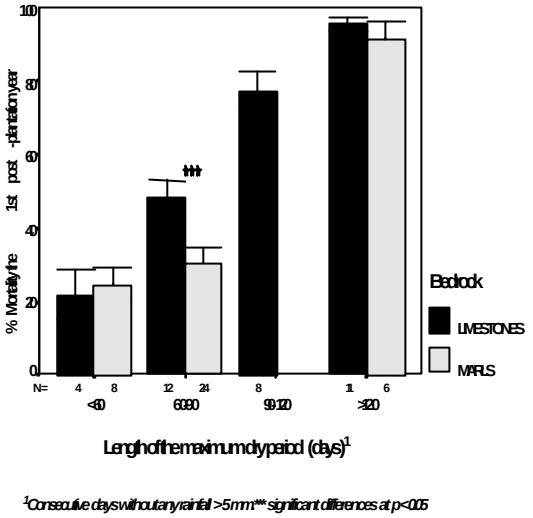


Figure 1: Seedling mortality measured one year after outplanting in the Region of Valencia (E Spain) in different years. The species considered are Pinus halepensis, Quercus ilex ssp. ballota and Q. coccifera. Mortalities are recorded at intervals of consecutive days without any rainfall higher than 5 mm for two representative soils in the Region: soils developed over limestones (clayey, shallow, stony and discontinuous) and over marls (silty, relatively deep and compact).

Disturbance regime: Recurrent fires suppose a risk for the integrity of restored lands, especially for pine plantations because young pine cannot survive a fire nor produce viable seeds until an age of ca. 15-20 years (for *Pinus halepensis*). Grazing can also be a threat for the introduced seedlings, so it must be controlled in restored lands. Finally, extreme events and especially extreme drought events may produce the complete failure of recently planted or seeded stands, as happened during spring-summer 1994 in Eastern Spain. The latter is a risk that is difficult to predict and to overcome in restoration.

Target areas

Critical situations that especially require restoration actions and that are representative of large desertified areas in Mediterranean Europe are:

- Under semiarid and dry subhumid climate, dwarf shrublands with poor plant cover on degraded soils, produced by a combination of long term grazing and/or cropping .

- Under the transition between subhumid and semiarid (from fire-prone to desertification-prone lands), recurrently burned shrublands on vulnerable soils (Vallejo & Alloza, 1998).
- Overgrazed shrublands (semiarid to subhumid), including fire-grazing sequences.

A strategy for restoration in desertification-prone and fire-prone lands

Under the semiarid and subhumid Mediterranean climate in Southern Europe, a main objective of land restoration is soil protection and water conservation, for which sufficient plant cover should be promoted - a threshold value of 30 % plant cover has been proposed by Thornes (1990) for effective soil protection -. In the case of burned lands with poor recovery capacity, there is a critical postfire period with low plant cover and high risk of torrential rainfall in autumn (just after a summer fire). In these cases, emergency seeding is a technical option for short-term soil protection.

In large areas with a subhumid climate, soil conservation is not threatened in the short-term, but vegetation cover and/or composition may be impoverished by the dominance of a few opportunistic species that in many instances are fuel accumulators (e.g. *Cistus ssp., Ulex parviflorus, Sarcopoterium spinosum*). The re-introduction of sclerophyllous trees and shrubs is proposed to improve the quality of these ecosystems and their resistance and resilience to wildfires. Most of the suggested species are resprouters, which regenerate very efficiently after fire (Vallejo & Alloza, 1998) and constitute communities less combustible than those mentioned before. Interesting sclerophyllous species are: *Quercus spp., Pistacia lentiscus, Arbutus unedo, Phillyrea spp., Rhamnus spp., Ceratonia siliqua,* and *Olea europaea.*

When the objective of land restoration is to recover a forest, we suggest introducing both conifers and hardwoods, either sequentially - first the early successional pine and then the late successional oak, as stated in traditional forest practice – or simultaneously, which is more feasible in economic terms, and permits the combination of the relatively fast growth features of pines with the resilience features provided by oaks.

As these restoration options introduce new elements with respect to current reforestation practices, specific research is required to shape and validate them, both in the laboratory and in the field. Next we present some experiences conducted under the EC projects REMECOS and REDMED addressed to develop the restoration strategies proposed above.

Seeding and mulching to control soil erosion after wildfires in the Valencia Region

Emergency seeding treatments were applied in selected erosion sensitive areas affected by summer wildfires in the Valencia Region under subhumid and semiarid climate. The principle of this technique is to obtain a fast plant and mulch cover to protect the soil. We used commercially available seeds of Mediterranean species, mostly legumes and grasses, combining annuals and perennials, with the addition of straw mulch and inorganic fertilizer (Vallejo & Alloza, 1998). In semiarid conditions, seeding+mulching and mulching alone significantly reduced soil losses and surface runoff. They also promoted water infiltration and

lowered soil-surface compaction. Treatments remained effective at least two years after their application. Herbaceous seeding and straw mulch application in areas burned in the summer of 1992 increased plant cover during the first year after the treatment application, especially in semiarid conditions. In the same experience, straw mulch significantly improved soil conservation. Native grasses that resprouted after fire, especially *Brachypodium retusum*, produced greater plant cover than seeded species. Nevertheless, some seeded species provided appreciable plant cover during the first year after seeding.

The erosion control and improved soil-surface conditions may not be attributable to the effect of the treatment on the plant cover. The differences in plant cover between the treated and the control plots were too small and, although they had nearly disappeared one year after treatment, the effects of the treatment on soil protection lasted much longer (Fig. 2). That is, no relationship was found between plant cover and runoff or erosion. Nevertheless, both total runoff and total soil loss showed an exponential dependence on total (plant + mulch) cover, pointing out the role of mulching in post-fire soil conservation. On the other hand, both treatments (seeding+mulching and mulching) affected all the erosion parameters similarly, suggesting that seeding did not add any significant variation to the mulching effects. The treatment reinforces two interacting components in soil protection: (i) plant and mulch cover directly affect runoff and erosion by intercepting raindrops and obstructing overland flow, and (ii) cumulative indirect effects prevent soil-surface structure degradation by sealing and crusting processes.

Mulching and seeding immediately after fire proved to be an effective measure for soil protection and for stimulation of the first phases of plant regeneration in degraded plant formations. Soil erosion losses decreased after the addition of mulch (with and without seeding) in subhumid and semiarid climate (Fig. 2) and this could be an effective treatment for the reclamation of burned areas with high erosion risk. Seeding effectiveness is more unpredictible as it largely depends on the rainfall conditions during the first months after the application.

Plantation experiments

Results from plantations in the Valencia Region (E Spain) showed the strong relationship between plant survival and water availability (represented by different rainfall regimes: subhumid and semiarid climate).

Summer drought was the main factor that influenced seedling mortality. Rainfall effect was observed in *Pinus halepensis:* survival and growth values for pines were higher in subhumid than in semiarid conditions. In dry mesomediterranean climate (Fig. 3), good survival levels were obtained for *Arbutus unedo*, *Erica multiflora*, *Juniperus phoenicea* and *Rhamnus alaternus* installed on marls (70-80% survival rates); they were remarkably lower for limestones (40-55%, and a minimum of 20% for *Arbutus unedo*). The same substrate differences were observed for *Pinus pinaster* and *Quercus ilex* ssp *ballota. Pinus halepensis* had 50% survival rates for both substrates. *Pinus halepensis* planted on marls in semiarid conditions showed survival rates slightly lower than in subhumid conditions. *Rhamnus lycioides*, *Tetraclinis articulata* and *Pistacia lentiscus* showed similar survival percentages

to Aleppo pine, and high survival rates in all the tested conditions. These four species could be recommended for semiarid land restoration. It is important to emphasise that the experimentation period had rainfall values below the mean for the sites studied.

The effect of soil type was evident for most of the species and climate conditions tested, although it was more acute in the semiarid. Better survival rates were obtained in soils derived from marls than those from limestones, because the former were deeper and with more equilibrated texture (loamy). That is, soils from marls provided a higher water-holding capacity.

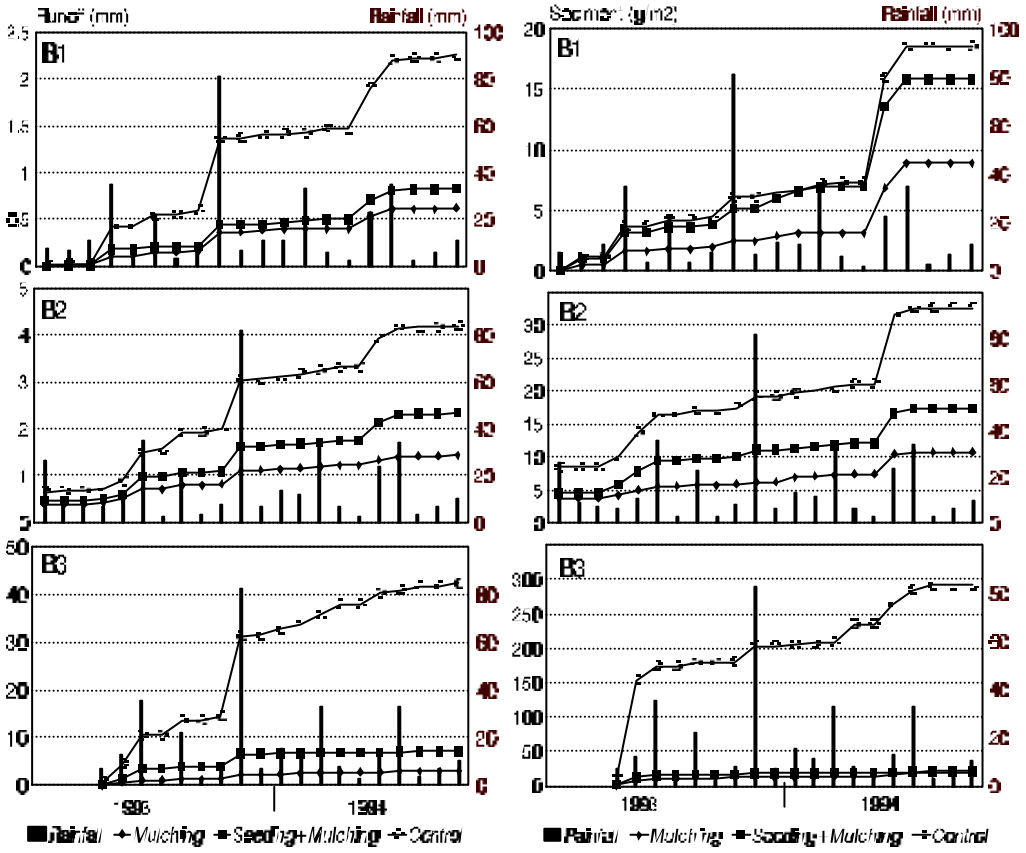


Figure 2: Cumulative runoff (mm) and sediment yield (g/m^2) in treated (mulched and seeded + mulched plots) and control plots for the years 1993 and 1994. B1, B2 and B3 are the experimental sites.

Plant quality had relevant effects on seedling success in the field. Fig. 4 shows how for some species, especially *Pinus pinaster* in this experiment, two nursery provenances yielded contrasted survival rates in the field. Plant quality should be refined to acclimate plants to field conditions.

Root growth and seedling performance

Root development is one of the key factors in understanding seedling survival and growth.

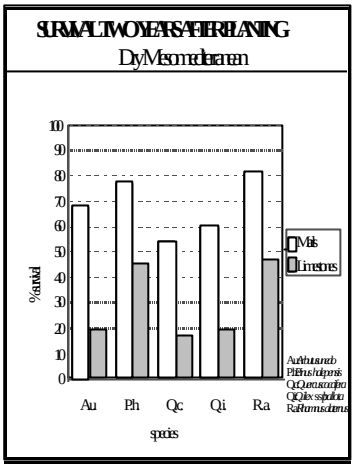


Figure 3: Seedling survival for different species planted in marl and limestone soil in dry-mesomediterranean (subhumid according to UNESCO 1977) climate in the Valencia Region.

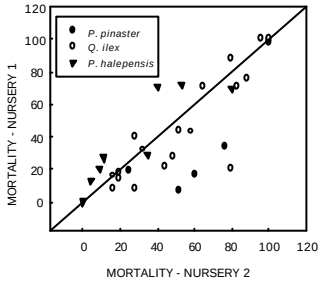


Figure 4. First-year mortalities in the Region of Valencia (E Spain), under subhumid climate, for seedlings cultivated in two different nurseries. Different results were obtained for Pinus pinaster and, to a lesser extent, for Quercus ilex.

Maximising root growth is fundamental for seedling establishment in the field (Burdett, 1990). The ratio between root biomass and aboveground biomass (the root to shoot ratio) may help to characterise carbon allocation to the rooting system (Kummerow, 1981). We carried out a study of the rooting system of seedlings of several tree and shrub species, comparing the rooting system of nursery seedlings with that of two-year-old planted seedlings. The aim was to find the optimum nursery and field techniques to achieve a well developed rooting system, capable of successfully colonising the surrounding soil.

The root-to-shoot ratio (R/S) of *Pinus halepensis* seedlings from the nursery was similar to those in the field (around 0.3-0.4). Thus, in terms of the R/S ratio, Aleppo pine seedlings produced in the nursery appear to be well balanced. In contrast, the R/S ratio of *Quercus* sp.

seedlings growing in the field (from 1.1 to 2.9) was quite different from those in the nursery (range from 0.9 to 2.1). This reinforces the idea proposed below in this paper that nursery techniques for the production of successful *Quercus ilex* ssp. *ballota* and *Quercus coccifera* seedlings for reforestation should promote the growth of the rooting system. *Pistacia lentiscus* seedlings showed relatively high R/S ratio in the nursery, and it was one of the species that performed best in the field. The R/S ratios may change from the seedling to the juvenile and mature stage. However, the R/S ratios observed here were within the range presented by Kummerow (1981) for adult Mediterranean sprouters.

Belowground biomass of seedlings growing in the field for two years was well correlated with aboveground biomass for Aleppo pine (r^2=0.93), for holm oak (r^2=0.79) and for kermes oak (r^2=0.51), as well as for all the resprouter species together (*Quercus ilex* ssp. *ballota*, *Quercus coccifera*, and *Pistacia lentiscus*) (r^2=0.97). Therefore aboveground biomass may be a good predictor of belowground biomass, particularly for Aleppo pine. The constancy of the R/S ratio of Aleppo pine seedlings grown in the nursery and in the field suggests a relative insensitivity of this parameter to environmental conditions. The biomass of roots colonising the soil surrounding the root ball ranged from 18 to 46 percent of total root biomass, and it was well correlated with the biomass of roots growing inside the root ball. Species differed substantially in root length and degree of branching.

The problem of Quercus spp.

Attempts by the Forest Service to plant holm oak on open lands have obtained poor results so far. In degraded lands young oak plants must cope with many climatic and soil constraints. The rooting system that characterises *Quercus* sp. seedlings from the nursery is very different from those of field-germinated seedlings. Root pruning, spiralling and upward root growth in nursery containers commonly result in the inhibition of the main root. In contrast, field-germinated seedlings show an early development of the main root, a root that may eventually become a tap root reaching a great depth in the soil. In evaluating to what extent a proper rooting system is responsible for the survival and growth rate of *Quercus* sp. seedling, we carried out assays by seeding acorns directly in the field (Valencia Region) and by using acorns germinated in the lab and transferred to containers once the root reached some 10-12cm . The objective was to avoid the great mortality of acorns seeded in the field as well as that of seedlings.

In the Valencia Region, holm oak (*Quercus ilex* ssp. *ballota)* seedlings planted in 1992 showed high survival in dry mesomediterranean climate and soils developed on marls (Fig. 3), but low rates on limestones. These results were better than the ones from thermomediterranean climate, and similar to those of Aleppo pine, a species that has been widely used in reforestation in the Mediterranean area. However, the aboveground growth of these holm oak seedlings was very poor. Holm oak seeded plants exhibited survival results of 54%, similar to the 60% showed by one year old seedlings during normal rainy years on marly soils and dry mesomediterranean climate.

In a second experiment under semiarid climate conditions, direct seeding, pre-germinated and conventional one-year-old seedling plantations were compared for *Quercus coccifera*. The germination of seeded corns was relatively low (28 %) although later survival was high. Pregerminated acorns (root unpruned) showed much better emergence (around 90 %) than seeded acorns and similar survival rates to conventional seedlings although better growth rates.

These results suggest that acorn seeding and pre-germinated acorns can be considered an (cheaper) alternative to plantation in marly soils, provided that the predation risk is controlled.

Field techniques

Soil preparation is very important in optimising water collection and storing, and facilitating root growth. The volume of the plantation hole had a significant effect on plant survival over limestones (Vilagrosa et al., 1996), and runoff harvesting techniques have proven to be effective (De Simón et al., 1993) in semiarid lands. Current trends in soil preparation tend to use soft and low impact techniques. We will discuss in more detail some soil and plant amendments that are currently in expansion in land restoration:

Sewage sludge application

Sewage sludge was applied in the plantation hole of *Pinus halepensis* and *Quercus ilex ssp. ballota* seedlings in a rate equivalent to 10 $Mg \cdot ha^{-1}$ in dry weight. For the sake of comparison, inorganic fertilisation was also tested at a rate of 250 kg $N \cdot ha^{-1}$ and 125 kg $P \cdot ha^{-1}$. Seedling growth was affected by the treatments but not plant survival which was high anyway for all treatments. Total shoot length and shoot diameter were higher in both sewage sludge treatments than in the control seedlings for both species studied (Fig. 5). 20 months after planting, these oaks receiving sludge (especially liquid) showed higher belowground growth than those with inorganic fertilisation or with no amendment. Pine seedlings amended with sludge showed a less developed rooting system than the control ones. Pine seedlings had low N concentration in all treatments and *Quercus ilex* increased N concentration when fertilised. It seems that for pine the level of N was not limiting whereas holm oak was N deficient. It can be concluded that the addition of sewage sludge as a soil organic amendment increased seedling growth by improving the soil fertility and that it could be a good field technique to help plant establishment. In an experiment performed in the Region of Murcia (SE Spain), under semiarid climate conditions, *Pinus halepensis* growth was greatly enhanced by the addition of solid urban refuse (Querejeta et al., 1998).

Figure 5: Quercus ilex ssp. ballota and Pinus halepensis growth measured 20 months after plantation in dry subhumid climate.

Techniques to reduce transplant shock: Tree shelters and hydrophilic gels

The use of hydrophilic gels is a field technique that improves root-soil contact at the early stages of seedling plantation. In extremely dry environments, these hydro-gels could provide the critical water supply to reduce transplant shock and enhance the root seedling capacity to colonise the plantation hole and withstand the first summer drought. In high evaporative demand environments, the use of tree-shelters to modify the physical environment of introduced seedlings would probably improve seedling establishment, also.

First results obtained in subhumid climate in the Valencia Region with *Quercus ilex ssp. ballota* showed similar survival rates for the two treatments, tree-shelters and hydro-gels, compared to the control seedlings. However a big difference in seedling growth was observed between treatments, with the seedlings from the tree-shelter treatment being taller (Fig. 6). No clear differences between the hydro-gels and control treatments were observed.

Figure 6 . Growth of Quercus ilex ssp. ballota seedlings for two years after plantation in subhumid climate in the Valencia Region.

Concluding remarks

Though the restoration topics developed in this paper are far from being exhaustive, the results obtained so far suppose a widening in the current procedures for land restoration in the Mediterranean. However, new developments are required to ensure successful restoration in extremely dry conditions and shallow soils. Seedling quality should be improved in order to withstand transplanting stress, for example through water stress preconditioning. This should be accompanied by refined low impact soil preparation techniques. Mycorrhiza inoculation

may increase seedling quality, especially for the restoration of soils showing very low biological activity.

Finally, seeding techniques should be developed in order to decrease germination and early survival uncertainties. The low cost of broadcast seeding, the possibilities of applying it by aerial means, and the low impact of the operation on the landscape are important advantages of this technique, which may be an interesting alternative to plantation in many situations.

Acknowledgments

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References

Aronson, J., Floret, C., Le Floc'h, E., Ovalle, C. & Pontanier, R. (1993). Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A view from the south. *Restoration Ecology* 1: 8-17.

Barro, S.C. & Conard, S.C. (1987). Use of ryegrass seeding as an emergency revegetation measure in chaparral ecosystems. Gen. Tech. Rep. PSW-102. Pacific Southwest Forest and Range Exp. Station, Forest Service USDA. Berkeley.

Burdett, A.N. (1990). Physiological processes in plantation establishment and the development of specifications for forest planting stock. *Can. J. For. Res.* 20: 415-427.

De Simón, E., Mintegui, J.., García, J.L. & Robredo, J.C. (1993). La restauración hidrológico-forestal en las cuencas hidrográficas de la vertiente Mediterránea. Junta de Andalucía, Granada.

Francis, C.F. & Thornes, J.B. (1990). Runoff hydrographs from three mediterranean vegetation cover types. In: Vegetation and Erosion. J. B. Thornes ed., John Wiley & Sons, 363-384, London.

Giovannini, G., Luchesi, S. & Giachetti, M. (1988). Effect of heating on some physical and chemical parameters related to soil aggregation and erodibility. *Soil Science*, 146(4): 255-261.

Kummerow, J. (1981). Structure of roots and root systems. In: Mediterranean type shrublands. Di Castri, F.; Goodall, D.W. & Specht, R.L. (eds.). Elsevier Scientific Publishing Company. Amsterdam.

López-Bermúdez F. & Albaladejo J. (1991). Factores ambientales de la degradación del suelo en el area mediterránea. *In*: Albadalejo J., Stocking M.A., Díaz E. (Eds). Degradación y regeneración del suelo en condiciones ambientales mediterráneas. 15-45- CSIC, CEBAS. Murcia.

Margaris N.S., Koutsidou E. & Giourga Ch. (1996). Changes in traditional Mediterranean land-use systems. *In*: C.J. Brandt & J.B. Thornes (Eds). Mediterranean desertification and land use. Pp.29-42. Wiley, Chichester.

Querejeta, J.I., Roldán, A., Albaladejo, J. & Castillo, V. (1998). The role of mycorrhizae, site preparation, and organic amendment in the afforestation of a semi-arid mediterranean site with *Pinus halepensis*. *Forest Sci*., 44 (2): 203-211.

Soto, B., Benito, E. & Díaz-Fierros, F. (1991). Heat-induced degradation processes in forest soils. *Int. J. Wildland Fire*, 1(3): 147-152.

Thornes, J. (1990). The interaction of erosional and vegetation dynamics in land degradation: spatial outcomes. In: Vegetation and Erosion (edited by J. Thornes), Wiley, New York, pages 41-54.

UNEP (United Nations Environment Programme) (1992). World atlas of desertification. Edward Arnold. Sevenoaks.

UNESCO. (1979). Carte de la répartition mondiale des régions arides. Notes Techniques MAB 7, Paris. 55 pages.

Vallejo, V.R. & Alloza, J.A. (1998). The restoration of burned lands: the case of eastern Spain. *In*: J.M. Moreno (Ed) Large forest fires. pp 91-108. Backhuys publ., Lieden.

Vallejo, V.R., Bautista, S. & Cortina, J. (1999). Restoration for soil protection after disturbances. In: L. Trabaud ed., Life and Environment in the Mediterranean. WIT Press, Southampton.

Vilagrosa A.; Seva J.P.N.; Valdecantos A.; Cortina J.; Alloza J.A.; Serrasolsas I.; Diego V.; Abril M.; Bellot J. & Vallejo V.R. (1996): IX Plantaciones para la restauración forestal en la Comunidad Valenciana. *In*: Vallejo V.R (Ed) La restauración de la cubierta vegetal en la Comunidad Valenciana. Fundación CEAM.

Wainwright J. (1994). Anthropogenic factors in the degradation of semi-arid lands: a prehistoric case study in Southern France. *In*: Environmental change in drylands: biogeographical and geomorphological perspectives. J. Wiley & Sons. London.

INTERNATIONAL ASPECTS OF DESERTIFICATION: TOWARDS THE IMPLEMENTATION OF CCD ANNEX IV

Antonio Marongiu

Introduction

Having had the chance and the duty to participate in the Rio Conference – or Earth Summit – in June 1992 – and to the follow-up to Rio, on behalf of the European Commission, I would like to draw your attention on the main topics of the Rio Conference, its results and its follow-up.

Key words: In doing so, I prefer to split into three points this lesson, say:

point A) General considerations on the Conference of Rio;
point B) International aspects of desertification;
point C) Towards the implementation of the CCD Annex IV.

Point A) General considerations on the Conference of Rio

The Rio Conference on Environment and Development – or Earth Summit – was attended by 120 Heads of State and Government.
The main topics were:

- the acceptance of the Agenda 21 which is the global program of action on environment and development for the first century of year 2000;
- the signature of the following conventions:
  - Climate Change Convention
  - Biodiversity Convention
- The launching of the negotiations of a Convention to combat desertification, particularly in Africa;

The practical reason to launching negotiations of a convention to combat desertification was due to the fact that the "benefits" of the two conventions – say "Climate Change" and "Biodiversity" – would go almost to the developed world (USA and Europe) and also to some developing countries in Asia and Latin America (GEF – Global Environment Facility).
For this, it was decided that a third Convention should be negotiated whose major benefits would go to Africa. So that decision was the "starting point" of the negotiation of a **"Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa"**. This is the official title of the Convention.

Point B) International aspects of desertification

During the "negotiation exercise" which took place under the United Nations umbrella in various cities like New York, Geneva, Nairobi, Paris, etc., it was discovered that all the developed and developing Countries in the world were interested in a "global convention", with "operational annexes:
Annex 1 for Africa;
Annex II for Asia
Annex III for Latin-America
Annex IV for Northern Mediterranean
Thanks to this, we can confirm that the Convention to Combat Desertification is – let's say – "more operational" than the two "sister Conventions" like "Climate Change" and "Biodiversity".
Just to give a concrete example, if we take into consideration the Annex 1 for Africa with the ACP-EU Lomé Convention, especially those sectors which are devoted to combat desertification, land degradation, effects of drought and the fight against poverty, we can easily find a very strong linkage between these two international Conventions.
We can find also a similar linkage in the Annex IV for Northern Mediterranean with the co-operation agreements between the EU and the developing countries in Northern Africa, like Maghreb, Macharak and Middle East.
I have just said that the mandate received in Rio de Janeiro in the Earth Summit was to negotiate a Convention to combat desertification, particularly in Africa.
So it was decided from the beginning that a world-wide convention would be negotiated with an overall programme of action for Africa.
This was done.
But during the negotiations, the Group of the "77" of the United Nations – which represents all the Third Countries in the world - requested to negotiate also a protocol for Asia and Latin America respectively. The first reaction from the "donors community" was not positive to this request. But it was accepted at last, with another request coming from Spain, Portugal, Italy and Greece to negotiate also a protocol for the northern Mediterranean Countries affected by desertification and/or land degradation.
The final result of these negotiations – which were concluded in Paris in October 1994 during the first "signature cerimony" - was a world-wide convention to combat desertification with four operational annexes.

Point C) Towards the implementation of the CCD Annex IV

Now, one can ask: are all the four Annexes of the Convention the same?
The answer to this question in "No!", not in legal terms but in "financial terms".
So if in legal terms these four annexes have the same statute because they are "legal binding" for all the Parties to the Convention, in financial terms the countries affected in the three Continents - Africa, Asia, and Latin America – are developing Countries which receive the

financial aid for development from the developed Countries and from the international financial institutions.

As far as the financial aspect is concerned, the article 9 of the Annex IV specifies the "non-eligibility for financial assistance" in favour of developed country Parties.

But this "non-eligibility" does not exclude to receive financial support from the several financial funds in favour of the structural regional programmes and from others financial mechanisms of the EU managed by the European Commission in Brussels. A good example is the "MEDALUS Program" financed by the EU, since 1991, so even before the existing Convention to combat desertification.

The application of this article 9 of Annex IV does not exclude the financial assistance in favour of "developing country Parties" underlined in the articles 8 and 10 of the same Annex IV, particularly those in northern Africa: Maghreb, Macharak and Middle East.

References

For more information on the fighting against desertification in the Mediterranean basin, please do refer to:

The Euro-Mediterranean Conference in Barcelona especially Barcelona Declaration focused on the co-operation between Mediterranean Countries in environmental issues –NOV. 1995;

The Euro-Mediterranean Conference in Helsinki (desertification document) 1997;

The international seminar in Porto Torres in September1998

The workshop on desertification information systems which took place in Marrakesh, in November 1998

The COP 2 Conference in Dakar in December 1998 (for all the four annexes of the Convention to Combat Desertification).

MANAGING DESERTIFICATION IN A NATIONAL CONTEXT

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Abstract. The combat to desertification at the national scale is the object of the National Action Programme (NAP) that the affected countries have to prepare and develop according to the provisions of the United Nations Convention to Combat Desertification (CCD). An structure of NAP for northern Mediterranean countries is proposed based on the Spanish NAP. The main units of the proposed NAP as a response to the combat to desertification are explained. The assessment of the socio-economic and legal framework and the need for sector policies co-ordination is stressed.

Keywords: Desertification, environmental policy, land reclamation, national action programme to combat desertification.

Introduction

Since the entry into force in December 1996 of the *United Nations Convention to Combat Desertification (CCD),* the managing of desertification in the national context is the subject of the National Action Programmes to Combat Desertification (NAP), that the affected countries should prepare according to the CCD provisions. This circumstance has promote a process of reflection and planning about policies and means to combat desertification in the involved countries.

Some national policies, like those of forest restoration, land reclamation and soil conservation, aimed to the prevention and mitigation of land degradation have been applied since the beginning of the century, but the CCD claims for the amplification of the scope in the formulation of plans and policies to combat desertification at the national level.

The NAP is the expression of the plans and actions to combat desertification in the national context and has to address three essential aspects of the problem:

- ***Objectives and scope of the combat to desertification,***
- ***Assessment of the status of desertification and the policies involved and***
- ***Formulation of specific actions and policies***

These points are explained in the following pages as the essential components of the management of desertification in a national context.

Objectives and scope of the combat to desertification in the Northern Mediterranean countries

The fundamental objective of NAP is to reach the sustainable development in the arid, semi-arid and dry sub-humid areas of the country, and particularly the prevention of

land degradation, the rehabilitation of partly degraded lands and the reclamation of the desertified lands.

The principles to inspire the preparation of NAP are:

- Define long term strategies integrated in the national policy of sustainable development
- Pay special attention to the prevention of the degradation of non-affected areas
- Promote the institutional co-ordination and the development of the different policies required for the implementation of the actions
- Consider the existence changing circumstances and different territories by the provision of adaptation mechanisms
- Facilitate the participation of all the involved actors

In the Annex IV of CCD for the Regional Implementation in the Northern Mediterranean Countries the priority aspects to be addressed by the NAP in those countries are mentioned such as: legislative, institutional and administration aspects, the modalities of land use, water resources planning, forest fires protection, and research and development.

The existence of he Annex IV of the CCD represents the international consensus about the presence of the phenomena in developed countries of the sub-region. Those countries share specific features in relation to the development of the desertification and the ways and means to combat it.

The scope of desertification should be established in two senses: *conceptual scope* and *spatial scope.*

The conceptual scope is defined in the article 1 of the CCD which points out that desertification is the "*…loss of the biological or economic productivity and complexity of rain fed cropland, irrigated crop land, or range pasture, forest and woodlands resulting from processes such as: soil erosion, deterioration of the properties of soil; and long term loss of natural vegetation"*

The CCD notes that "*…desertification is caused by complex interactions among physical, biological, political, social, cultural and economic factors"*

This complexity is the main difficulty in clearly establishing the scope of the specific mitigation actions. Many of the measures advisable to combat desertification concern different thematic policies such us agriculture, nature conservation, environment, water resources planning and management, urban planning and development, etc… (Rojo Serrano 1998). *" is the policy co-ordination the response that requires the complexity of desertification"* (PAND, 1999).

It is essential to realise that in the affected countries member of the European Union most of the fields of action integrated in the combat to desertification have been the subject of attention by the Public Administrations as well as the involved sectors of the civil society since a long time. The policy to combat desertification and the NAP as their documented expression, have to identify what are the involved sector policies, which of their measures are implied, what other have to be incorporated and act as trigger of all of them when needed.

The geographical scope is defined by the arid, semi-arid and dry sub-humid areas which constitute the potential space of desertification according to the CCD definition. These areas are those which the relation of Precipitation (P) divided by the Potential Evapo-Transpiration (ETP) is comprised between 0.05 and 0.65. The figure 1 represents the extension of such areas in Spain.

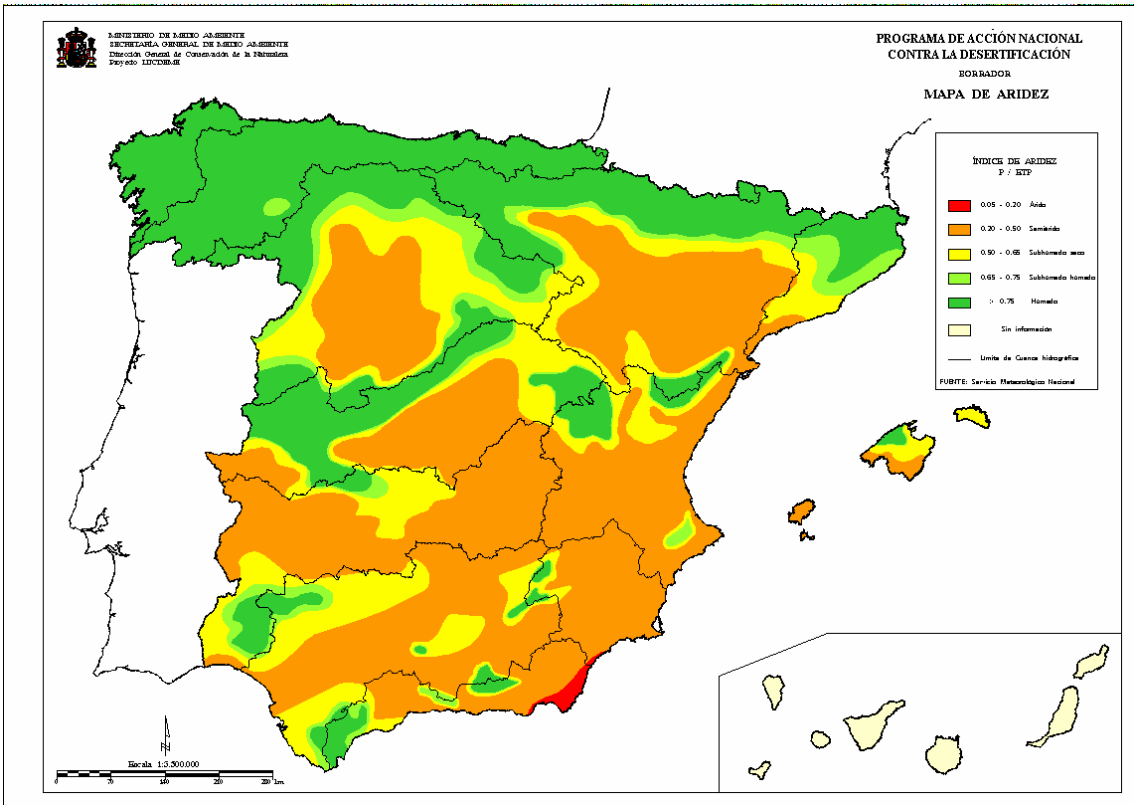


Figure 1: Desertification susceptibility in Spain, defined by the extension of arid, semi-arid and dry sub-humid zones.

Assessment of the status desertification and the policies involved

The assessment of the status of desertification at the national scale as a previous necessary step to the definition of policies and actions should be perfo rmed at two levels:

- ***Assessment of the factors and processes of desertification***
- ***Survey of the institutional and legal framework of the actions to combat desertification in the country. The diverse sector policies with incidence in the desertification.***

These two points are developed in the following lines.

Assessment of the factors and processes of desertification

The factors could be of physical or socio-economic nature. It depends on the methodological approach adopted which factors/indicators are considered. In the case of the Spanish NAP the physical factors studied are: aridity, drought and soil erosion. The socio-economic factors/indicators are: forest fires frequency, ground water over-exploitation, relative changes in the population density during the last 30 years.

All these factors are evaluated at the level of the national territory. That involves the survey and production of maps which represents the degree of every factor and its geographical distribution.

Figure 2 presents the map of the soil erosion factor for Spain.

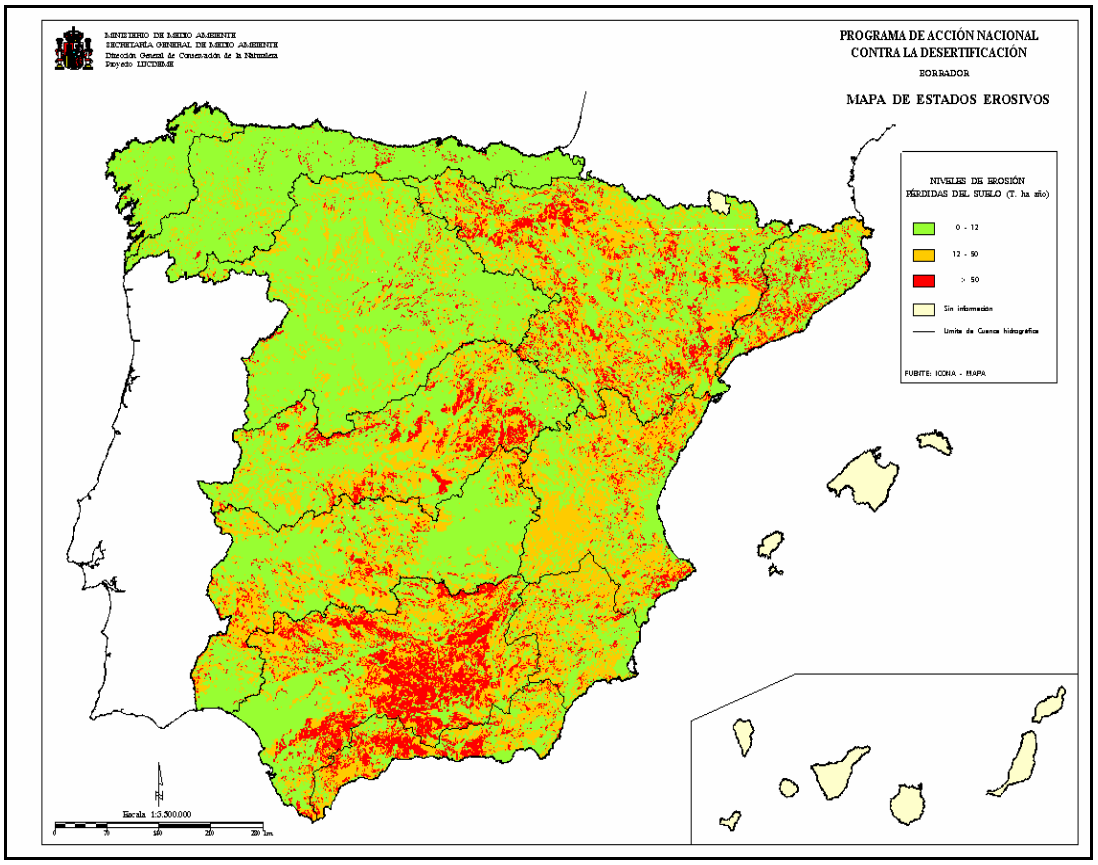


Figure 2: Geographical distribution of soil erosion in Spain.

In addition to the analysis of the individual factors the correct understanding of the phenomena calls for the identification and description of the relevant, real and current landscapes of the desertification in the country. These landscapes represent the different combinations of desertification factors that are really present in the country. That description is essential to understand the complex network of relationships that exist among them and the applied policies in order to provide guidelines for the target policies to combat desertification.

The Spanish NAP identify as specific desertification landscapes the ligneous rain fed crops, herbaceous rain fed crops, marginal agricultural fields abandoned, over-grazed ranges, irrigation with salinisation problems, degraded ranges and shrub, areas affected by repeated forest and wild fires.

Survey of the institutional and legal framework of the actions to combat desertification in the country. The diverse sector policies with incidence in the desertification

There is a large number of actions and policies in operation in any country, and particularly in the EU Mediterranean member countries, which are related directly or indirectly with desertification. It is necessary to know which are those policies and what role they play in the degradation/sustainability of the arid and semi-arid lands.

This is a previous step to the establishment of a policy co-ordination scheme. The complex nature of desertification and the multiplicity of policies active in the affected

territory and its socio-economic context make this point one of the more extended in terms of the analysis as well as one of the key factors to reach an efficient formulation of desertification control actions and measures at the national scale.
The structure of this survey in the Spanish NAP follows to illustrate the content of his point:

- Agricultural policies and actions
  - Soil conservation policy
  - Environmental elements of the EU policy of prices and markets. Land retirement.
  - Complementary measures of the PAC reform of 1992
- Forestry actions
  - The Forest Hydrology Restoration and erosion control plans and actions
  - The aids to agricultural lands afforestation. R 2078/92 EEC
  - Spanish strategy forests
- Forest fires control and prevention
- Planning and management of water resources
  - Hydrologic National Planning
  - The white book of water in Spain
  - National Plan of irrigation
  - The proposal of modification of the water law in Spain
  - The proposal of directive of the European Council to establish an European water policy (COM (97)49)
- Drought prediction and reduction of drought vulnerability to combat desertification
- Research and development in desertification
- Non governmental organisations actions to combat desertification
- Relationship with other conventions. The Framework convention of climate change and the Biological diversity convention
  - The Spanish strategy for climate change
  - The Spanish strategy for the conservation and sustainable use of the bilogical diversity

The detailed explanation of those point are far from the scope of this lecture and can be consulted in (PAND, 1999).

Formulation of specific policies and actions

The formulation of policies and specific actions could be approached from very diverse methods. The unique starting condition is that should be formulated with full awareness of the country context and background in terms of desertification and land degradation control. This is important in the EU Mediterranean countries, particularly in Spain, which present a long tradition in those actions and a complex network of institutional, political, socio-economic and technical relationships as corresponds to developed countries with more than one century of earth resources administration, regulation and management.
Three points are considered for the formulation of policies and action:

- Policy co-ordination
- Target areas identification

- Specific actions formulation

Policy co-ordination

The figure 3 scheme represents the different levels of co-ordination the the NAP should comprise.

The first level of the figure represents the vertical co-ordination and integration. It is filled by the existing sector plans related to the NAP. In the case of Spain those plans are *inter alia:* National Plan for Forest Hydrological Restoration, National Plan of Hydrology, National Programme about Climate.

The co-ordination is based on a detailed analysis of the objectives and actions included on every of the related sector plans and the determination of the level of co-ordination required for them.

The co-ordination level could be:

- Informative
- Monitoring
- Design

The Informative level is limited to an interchange and flow of information with the aim to fulfil the requirements of CCD in relation to the monitoring of the processes and policies related to desertification.

The monitoring level implies the incorporation of the criteria and requirements of the combat to desertification into the management of the actions and policies.

The design level implies a participation and consideration of the criteria and needs of the combat to desertification into the design of policies and actions that have a very close relationship with desertification.

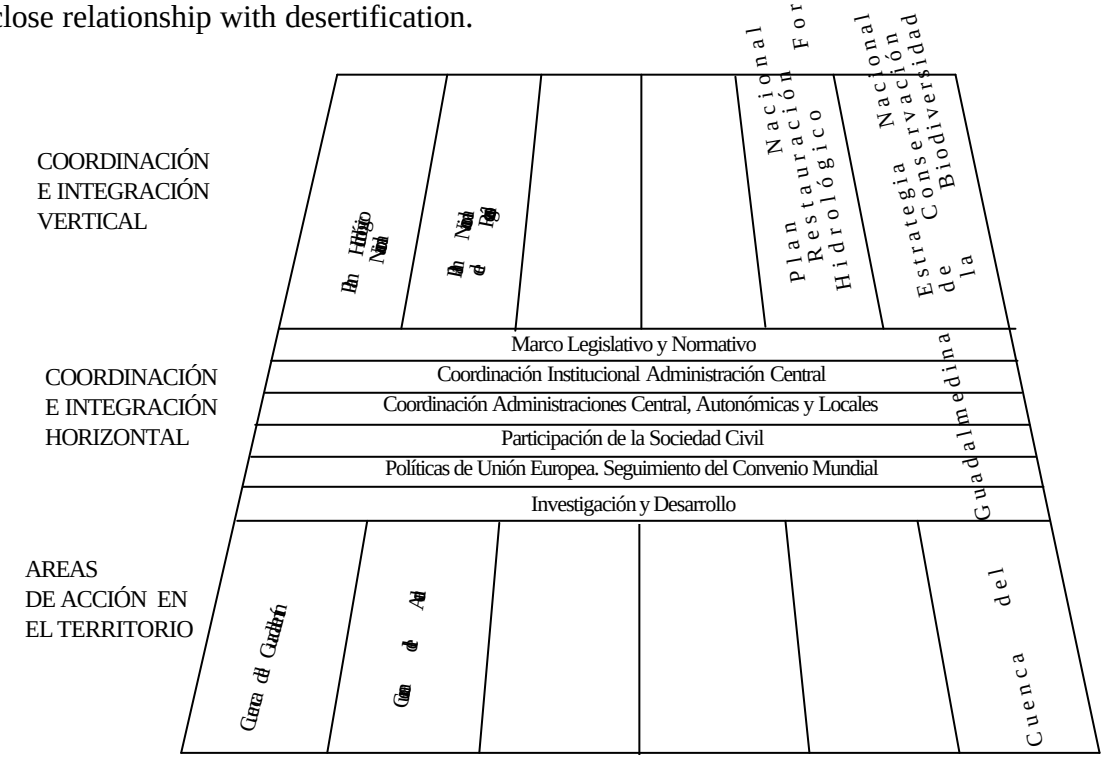


Figure 3.

The second level of the figure represents the horizontal co-ordination and integration. This level addresses the different aspects that should be considered for the implementation of the co-ordination in the institutional and legal environment. Among these aspects the most important are those included in the figure:

- Legislative and regulations framework
- Institutional co-ordination among the Central Administration units
- Institutional co-ordination among the national, regional and local level administrations
- Co-ordination civil society participation and involvement
- Co-ordination of the national policies and actions developed in the framework of EU policies
- Co-ordination with the CCD and its monitoring
- Co-ordination with the related Research and Development programmes

The third level of the figure refers to the target areas identification as the real scope where the effects of the co-ordination and furthermore the effects of the desertification mitigation policies should be materialised .

Target areas identification

The territorial framework adopted in the Spanish NAP is configured by hydro-graphical basins as the territorial unit which integrates the natural processes as well as the human influences on them particularly in the field of water, soil and vegetation natural resources. A division of the Spanish territory on basins as units for the desertification control is established in the NAP. Figure 4

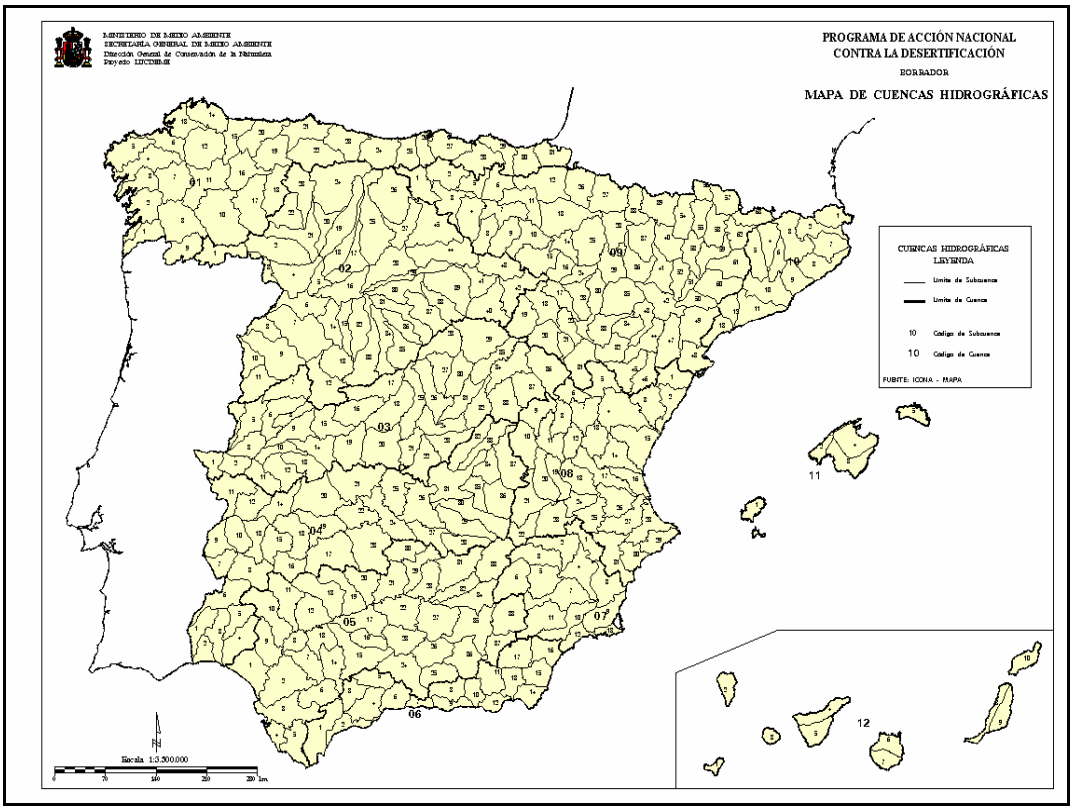


Figure 4.

The target areas selection in the Spanish NAP is performed by a qualitative methodology which is valid for the first phase of national policy formulation . In this methodology intensity classes are established for every of the factors and processes which determine desertification,in the Mediterranean according to CCD, that is: aridity, soil erosion, wild fires, and over-exploitation of aquifers. According to the available data and intensity class on every of the factors is assigned to every basin unit. The composition of these factors qualify the desertification intensity on each basin. The methodology used for factors combination is far from the scope of this paper and could be consulted in PAND, 1999. It is a very simple formulation in order to do it easy to be understood and accepted.
The result of the target areas identification is the following map (Figure 5)

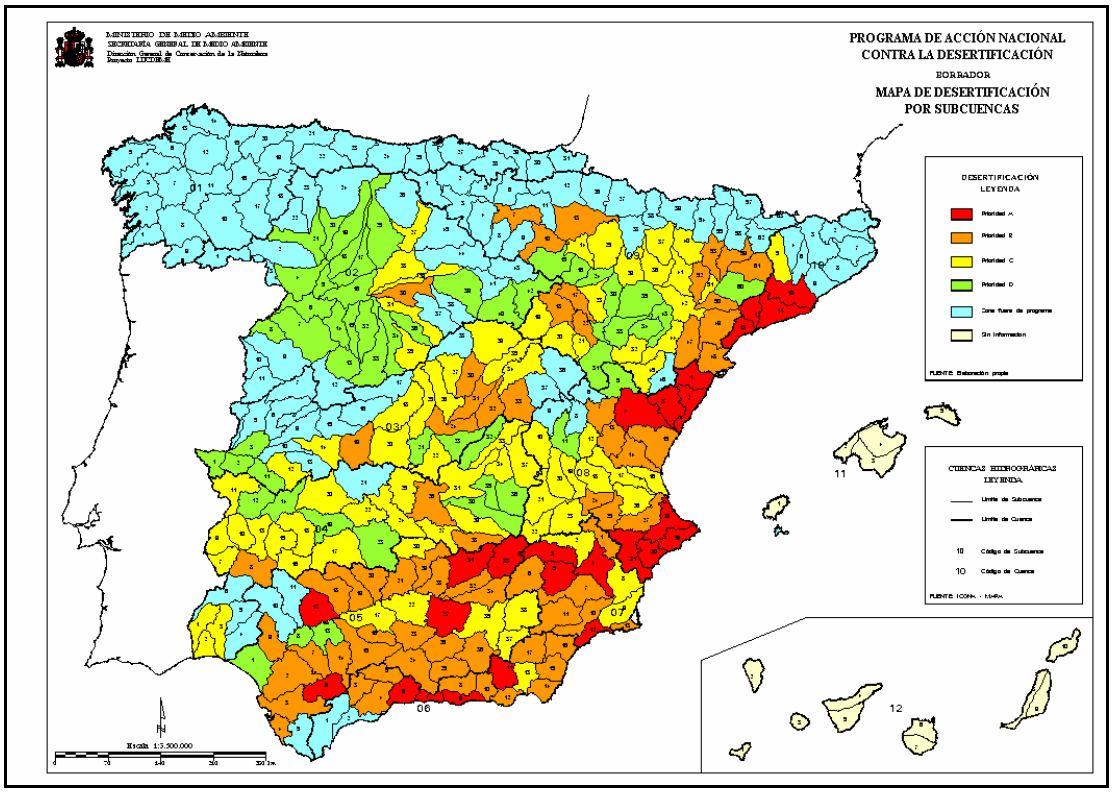


Figure 5.

Specific actions formulation
Not all the actions required to combat desertification are covered by the sector policies and so addressed through policy co-ordination. There are several specific desertification mitigation actions that should by developed in an autonomous way.
In the case of Spain those actions are:

- Analysis, diffusion and exploitation of the results of the research programmes on desertification initiated in 1981 . Selective promotion of R&D on desertification based on the results analysis
- Assessment and monitoring of desertification in Spain
- Network of demonstrative projects on restoration and management of lands affected by desertification.

- Forest hydrological restoration of degraded arid and semi-arid basins.
- Identification and promotion of the technological private sector linked to the control of desertification
- Extension and public awareness.

References

Rojo Serrano (1998), Programmes of national agencies for mitigation of desertification in Spain. In Actions taken by national governmental and non-governmental organisations to mitigate desertification in the Mediterranean. European Commission. EUR 18490 EN. 349 pp. Brussels.. (**211-242**)

PAND (1999) . Programa de Acción Nacional contra la Desertificación. BORRADOR (DAFT) Ministerio de Medio Ambiente,. Dirección General de Conservación de la Naturaleza. Madrid 119 pp.

SOME POTENTIAL PROBLEMS WITH THE IMPLEMENTATION OF ANNEX IV OF THE CONVENTION TO COMBAT DESERTIFICATION

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Introduction

Negotiating an international treaty such as the Convention to Combat Desertification (hereafter CCD) is not at all the same thing as trying to apply it. If such negotiations are full of power struggles, cultural clashes and other pitfalls causing difficult moments in elaborating a compromise, at least such negotiations are conducted between a limited number of people, generally among the most able and best educated in the countries participating in the negotiations, and belonging to the classes which have some power in the countries involved.
Implementing an international treaty such as the CCD, on the other hand, involves very large numbers of people (millions at least), many of whom have no formal education, belong to the poorest in their society, have lived relatively isolated lives, and have become suspicious through a long tradition of exploitation by others, among whom the people or the social groups which have negotiated the treaty figure large.
In this contribution, I will not focus on the negotiations themselves, as Ambassador Marongi , who represented the EU at the negotiations, is the ideal person to do so. What I will try and do is to point to some of the problems which we which are likely to encounter in the implementation of the treaty in the Mediterranean basin. Many such problems occur have been encountered elsewhere, for example by the non-governmental organisations (hereafter NGO's) working in developing countries in Africa, Middle and South America, Central Asia and the Far East, and by the like of the ARCHAEOMEDES and MEDALUS projects in Southern Europe. As we are here concerned with the implementation of Annex IV to the treaty, which specifically addresses the Mediterranean basin, I will notably draw upon the former, of which I am the overall coordinator . The reader should be aware, however, that the basic issues in the Mediterranean basin are the same as in other parts of the developing and developed world.
Finally, I wish to expressly state that I am not a specialist in any one of the many disciplines which are touched upon in the present paper, nor do I have first-hand experience with the implementation of measures to combat desertification. My justification for nevertheless contributing to this volume is twofold:

Firstly, I have an excuse. I believe that the subjects presented here are as important as some of those presented by others in the context of this 'Advanced Study Course', and as it befell me to present them in Alghero, I would not wish them to be absent from the Proceedings of that course.

Secondly, I have a reason. I wish to draw attention to the fact that in preparing the implementation of Annex IV, the European Union (hereafter EU) is not sufficiently taking into

account the experiences accumulated by those working in the developing world. Doing so would avoid many potential mistakes.

Some aspects of the CCD which merit attention

I can, of course, not anticipate all the difficulties which the introduction and implementation of the CCD, and in particular its Annex IV, might encounter, nor all the things which the treaty might eventually achieve. Not only is the space allotted to me too small for this, but I am no better at guessing what might happen in the future than anyone else. At best, I can try to act as a 'prophet turned backwards', to let the reader profit from the benefits of hindsight.

In doing so, I will confine myself to discussing some advantages and difficulties of implementing the treaty which relate to one of its own most fundamental and innovative characteristics, the combination of 'top-down' and 'bottom-up' approaches in preparing and executing the implementation of the treaty, notably:

- the CCD introduces an inter-active perspective on the relationship between people and their environment;
- the CCD is intended to deal with both purely natural phenomena and clearly socio-economic ones, and must therefore deal with cultural differences in the widest sense, and particularly cultural differences in the perception of, and the interaction with, the landscape and other aspects of the natural environment;
- the CCD attempts to integrate 'top-down' and 'bottom-up' approaches to management of the environment, and will therefore have to deal with different ways of formulating and legitimising knowledge and understanding;
- the CCD attempts to deal with essentially local phenomena at world level, as opposed to, for example the CO2 (Kyoto) treaty, which tries to deal locally with a world-wide phenomenon;
- The CCD attempts in certain areas to deal with resource shortages, and not with produced overabundance as does the Kyoto treaty;
- the CCD is multi-level, applying as it does to all levels from the whole planet to local populations;
- the multi-level collaboration which the CCD proposes suffers from a lack of legal framework, and in implementing it, the process of consultation and negotiation will be handicapped by issues of legitimation
- the CCD involves the relationships between social institutions which derive their form and legal status from different principles (democratic, federative, autocratic, multinational), and which are thus difficult to integrate into a working structure;
- the CCD deals with nations and populations of widely varying degrees of development, and will therefore encounter the political struggles between rich and poor at every step.

Together, these elements make the CCD a very ambitious treaty, which is likely to encounter a number of difficulties during implementation.

An inter-active perspective on the relationship between society and its environment

The Convention is a major step forward both from the perspective of the way in which we deal with environmental problems and from the perspective of international law. Firstly, it represents a step forward in our thinking about the environment in general. In the last twenty years or so, researchers, politicians and the general public (but not necessarily in that order) have moved away from a perspective in which human beings were viewed as principally adapting their behaviour (and ultimately, possibly, themselves) to the environmental conditions in which they were living, and to the changes occurring in them, to a position in which the fact that human beings interfere in the environment in ultimately unsustainable ways was considered more important than the way in which they were able to adapt. In essence, therefore, we moved from a predominantly *re*-active perspective on humans to a *pro*-active point of view.
The interesting thing about the CCD is that it goes a step further, and effectively stresses the *inter*-action between people and their natural (and social) environment, and strives to achieve a resilient interaction between the two sides. The former two perspectives are anthropocentric in that either we make exceptions of ourselves by taking no responsibility, or by taking all the responsibility; in the latter, humans become 'just another unique species' (Foley 1986) and take part of the responsibility - and that is much more difficult, as it necessitates determining where the limits of our responsibility as human beings lie.
In the area of our interest today, these changes in perspective are reflected in successive shifts from the study of land *desertification* (essentially a natural phenomenon, initially attributed to changes in climate), to the investigation of land *degradation* (essentially a phenomenon caused by human activity, be it through pollution, overexploitation or human-induced climate change) and its mitigation, and more recently to a focus on land *abandonment* as one of the possible results of socio-natural interaction. Not only is the latter what ultimately, of course, concerns us most as human beings, but, at least for the northern Mediterranean rim, it is demonstrable that much more potentially useful agricultural land is lost through abandonment than though desertification or even degradation.

The relevance of cultural differences in perception of the landscape, and the environment in general

One readily observes major differences in the way people look at their environment between, for example, northern and southern Europe. While in most northern European countries, waste disposal is strictly regimented and limited to very particular areas, in some southern European countries, waste disposal sites are found in each village, or — worse — there are none at all and everyone is free to get rid of his or her garbage wherever seems fit.
Such differences seem at first superficial, and easily regimented by ordinance or law. Upon closer consideration, however, these differences are often part of completely different world views, different perspectives on nature and on society, and different ways of defining individual and group identities. The consequences of ignoring such differences can be quite disproportionate. Take, for example the project initiated by the mayor of Delvinaki, a village in northwestern Epirus, not far from the Albanian border. In order to attract tourists, a wild boar

reserve was to be set aside on common land, a hotel built with a subvention from the EU, and a number of buildings restored to make the village more attractive. The restorations were completed, but after many delays, the mayor had to give up his idea of implementing the wild boar reserve, because of strong opposition in the village. Superficially, the reservations concerned the fencing in of part of the common land owned since the distant past by the villagers together. But when the mayor argued that the fencing in would also be for the common good of the villagers, instead of questioning his arguments on this point, another set of reasons was slowly brought forward. These concerned the fact that the project would have consequences for the way of life of the villagers. They would have to adapt to the arrival of tourists, and live with some aspects of foreign (or at least urban) ways of doing things.

Ethnographic research in other parts of southern Europe — and elsewhere — has confirmed the fact that changing things in the natural environment, even if it is in order to preserve certain aspects of that environment, often triggers a questioning of very basic values by the people affected: what is 'natural' and what is not, what is 'clean' and what is 'dirty', what is 'ours', and what is 'theirs', etc. This implies that certain aspects of the identity and the value system of many rural communities are in effect anchored in the landscape in which the people live their daily lives. As a result, NGO's working in rural areas in the developing world have routinely adopted the need for discussions with — and education of — the local population whenever they attempt to change anything.

In the context of the implementation of Annex IV, this poses all sorts of problems, mainly because the 'bottom-up' habit has not spread to Europe. This is in part because many European nations have administrative systems — and attitudes— which still show remaining traits of the authoritarian systems of the Middle Ages and the early modern period, but also because the ideology of 'Europe' attempts to weld together the continent by underlining time and again the similarities rather than the differences. Scientific research, which is in the west almost by definition internationalist and not linked to local cultural differences, is used to reinforce the message, especially where that relates to the natural environment. Thus, it is not common practice to take cultural differences into account when proposing policies relating to the environment.

Combining 'top-down' and 'bottom-up approaches'

In terms of international law, the CCD is very innovative in that it explicitly combines 'top-down' and 'bottom-up' approaches by binding the top to consult the bottom, linking international and national law, and attempting to accord credibility and status to local knowledge which is not formalised in the usual way. It sets out to construct an international partnership which does not only involve nation-states, but equally addresses itself at supranational organisations, NGO's, regional federations, etc., all the way down to the individuals whose living is the most directly affected by the phenomena of desertification, land degradation and land abandonment.

It is clear that the Convention presents the only way to deal with the subject matter it is addressing, if only because the socio-natural circumstances involved vary so widely between nations, regions and different localities within these nations that no approach devised at the

level of the individual nation would be able to effectively improve, over the whole territory or even the majority of it, the circumstances under which local populations are attempting to make a living off the land.

But by taking this approach, it firstly implicates a much wider range of actors and stakeholders than usual, and thus has to deal with a much wider range of opinions and interests than other treaties, if only because these actors have very different cultural backgrounds, interests and social positions. The mere fact of directly addressing itself to them, rather than limiting itself to involving different nation-states and depending on the existing structure which regulates socio-political and economic relationships between actors within each nation internally, makes the implementation of this treaty into a challenge.

Secondly, depending for implementation on a combination of 'bottom-up' and 'top down' approaches confronts those responsible for the CCD's implementation with the practical difficulties of integrating two very different kinds of understanding of the phenomena concerned, one couched in academic or administrative terms, and the other in terms of 'local knowledge'.

To fully understand the importance of the difference between the 'top-down' and 'bottom-up' approaches, it is necessary to briefly explain the background to the distinction. Understanding may be viewed as the result of a negotiation between, for example, certain observed natural phenomena and the individual observing them. The latter literally 'bends' his or her mind around the phenomena, time and time again, until he or she has defined the correct categories of observation and the appropriate scales of measurement, formulated the right questions and obtained the right answers to be able to understand different observations in similar terms. As a result of such negotiation between subject and object, variations between observations become, to a certain extent (which varies with the phenomena as well as with the individuals concerned), 'predictable', i.e. understandable without further negotiation, wherever they are observed.

Once more than one individual is concerned, of course, it is important for the observer to be able to communicate his or her understanding to the other people with whom he or she shares his or her life. Without such communication, concerted action with respect to the environment (or anything else) is impossible. The negotiations are therefore also influenced by the social and cultural context in which observer and observed phenomena find themselves - the language shared by the people involved, the cultural traditions and the general outlook of the community. As a result, the negotiation involves three partners: community, individual and phenomena. It is as a result of such — complex — negotiations, that a group of people attains what might be called with an old-fashioned term 'intersubjectivity' - a certainly subjective, but shared view of the phenomena involved.

The difficulty in combining 'top-down' and 'bottom-up' approaches to dealing with the environment is that these approaches are based on different levels and ways of negotiating understanding. Whereas 'top-down' understanding is generally acquired through school or university education, and is thus to quite an extent theoretical in form and presumably widely applicable, 'bottom-up' understanding is gained through practical confrontation with local conditions and is much less easily generalised. In the former case, practical understanding is deduced from extant theoretical knowledge by specification of local circumstance, whereas in the latter, local circumstance is to some extent generalised by comparison and induction. As

'local knowledge' is essentially based on local observation, the range of instances compared is narrower than that which is generally used to formulate widely applicable theories, and the understanding derived from it, accordingly less widely applicable. But what local understanding misses in range of phenomena to which it can be applied, it gains in depth and detail of understanding concerning the local phenomena with which it was initially negotiated.
In some parts of Europe, these problems are compounded by the absence of an administrative culture which systematically and effectively integrates 'bottom-up' approaches, as well as by the emphasis on similarities which we have mentioned earlier as an essential part of the European ideology. Subsidiarity is beginning to change this, as it leaves the implementation of certain policies, and decision-making about the form they will take, to the nation-states. But, within the latter, such decision making is only very partially left to the regional and/or local authorities who are most familiar with the situation.
Undoubtedly, the fact that many rural populations are not among the most concerned with environmental matters makes finding the right balance between 'top-down' and 'bottom-up' approaches far from simple. But much more of an effort will have to be made if one is to implement the CCD's Annex IV as intended.

The scale of the phenomena and the scale of the proposed remedies

A related aspect is the relationship between the spatial scale of the problem and that of the treaty proposed to combat it. In a treaty like the one dealing with CO2 emissions, the scale of the problem is worldwide, and thus the treaty apportions tasks in dealing with it. First it (attempts to) get(s) the signatories to agree to a reduction of the problem, and then it prorates the effort to be undertaken by each of them in calculations which take economic as well as technical and other conditions in each country into account. Difficult enough, but simple in comparison to what needs to be done in case of the CCD.
Here, it is firstly much more difficult to define the phenomenon, or the phenomena, which have to be addressed. The 'Rio' definition of degradation and desertification is acceptable in general terms, but only because it is general. In each local instance, the form which such degradation and desertification takes, is different. In order to be effective, the implementation will therefore have to define in each and every instance what it is implementing measures against.
If we limit ourselves to the mediterranean basin for a moment, the situation is very different on its northern shore than it is in North Africa. Whereas in large areas of Southern Europe, desertification is due to a complex set of interacting processes, none of which absolutely dominates the dynamic, the absence of sufficient water is so dominant as a factor in North Africa that finding solutions to combat desertification other than bringing in a massive and permanent flow of water will only be of limited effect anywhere but in the coastal zones.
Within the affected areas of southern Europe there are, for example, very important differences between (1) areas in which a natural lack of water causes hardship, (2) areas in which the water is available, but for one reason or other too expensive to be sufficiently abundant for a wide range of crops (in these cases, crops with more added value might be introduced), (3) areas where the socio-economic circumstances have, little by little, brought many of the inhabitants to give up cultivating their land, and (4) areas where massive

emigration for reasons not tied to the natural environment has caused the land to be underused and overgrown. In all these cases, the end result may be highly similar — loss of land with agricultural potential and depopulation — but the ways to combat this phenomenon will be different in each case.

Some of the implications will not be immediately evident in the National Plans to Combat desertification which the southern European nations are presently preparing. An initial set of phenomena ('desertification') to combat can readily be agreed upon, for example in southern Portugal, many areas of Spain, southern Italy and the Greek islands. But as these plans reach the stage in which they will be implemented in the field, many dissimilarities will emerge which have until then been hidden by the apparent similarity of the natural phenomena observed. Once these differences emerge, one will have to ask oneself again: "Which are the causes to attack, which the remedies to propose?" The more we move away from the 'natural science' definition of the problem, and the more we understand its causes, it is inevitable that we will have to redefine what the treaty is combating.

At that point, combining the 'top-down' and the 'bottom-up' approaches to thinking about the causes of desertification and the measures to be taken will both be very useful and lead to conflict and confrontation. From the 'bottom-up' perspective, large differences will emerge between different regions and localities and the ways in which they view and propose to remedy the situation, whereas from the top down, certain perspectives will be favoured over others, differences will be ignored, and choices imposed. We will discuss this kind of confrontation in more detail below. Suffice it here to say that everything will depend on the extent to which these two perspectives can, with time, find mutually acceptable and beneficial compromises. And for that to happen, it seems that a better vertical flow of information is essential, in which, notably, lengthy presentation and discussion of multiple alternative solutions at the regional and local level will have to play an important part. Unfortunately, there is so far little experience with that process.

The definition of 'needs': resource shortage vs. overproduction.

In the case of the Kyoto treaty the aim is to combat overproduction of something undesirable, a pollution, by introducing technological alternatives, but there is no resource scarcity at the root of the phenomena being fought against. In the case of the CCD, we are in many areas (notably, but not only, in North Africa) dealing with what at first sight seems a completely different situation because a scarcity of fresh water is in those cases indeed one of the components of desertification and degradation. Redistribution of water may, of course, locally or regionally be used to mitigate degradation or desertification (for example by means of long-distance transfer, such as between the Ebro and other regions in Spain, and possibly in the near future between the Rh™ne and the Emporda). Thus, the geographical water balance may be altered and water availability may well be spread more evenly between desertified or degraded areas and areas which have not thus far been considered a problem. But in the end fresh water as a massively available resource is finite. If we leave for the moment aside the possibility of desalinisation of sea water on a scale sufficient to meet the needs of North Africa, for example, the only possible solution seems to be a complete rethinking of the situation which

starts from a perspective generally not envisaged by the economists who deal with such matters.
Generally, the need is for sufficient (or even surplus) water, enough or more than enough water to cover one's needs. But what if one were to define 'sufficiency' as 'needing less water than one has at one's disposal'? In doing so, one would transform the choices faced 'bottom-up' from: 'we need more of such-and-such-a-resource!' into: 'what kind of activities can we develop that allow us to survive on the resources we have?'. And with that, the debate changes direction and tone. In doing so, one transforms to some extent a debate about resource shortage into a debate about (local) overproduction and the need to either find other means to produce the same substances, or to move production of such substances elsewhere and produce other things in the areas affected by resource shortage. As Escarr remarked to me recently (pers. comm.): "if you cannot grow cereal or anything else in an area, you could always grow shoes there ...". Absence of change is a choice like any other.
Granted, such a change of perspective will not occur overnight. But in the case of water, although Europe is reasonably well-placed from a climatological and a resource perspective, the implementation of the CCD should be one of the contexts in which one begins to change perspectives. One only has to look at the role of water and its absence in the geopolitical balance of power in the Near East to realise how tricky a problem we are dealing with.

The interaction between different levels

Thus far, we have brought in the discussion only the contract between moving up and moving down between the different levels implicated in the CCD and Annex IV. We have briefly outlined the difference between 'top-down' and 'bottom-up' approaches to gathering information and implementing change. Let us now look more closely at what constitutes the relationship between the levels, the perspective(s) on desertification, and the articulation between levels and perspectives.
To do so, I wish to begin with a simple and artificial example. Suppose a farmer observes a problem to do with his land that relates to areas not in his possession, a shortage of water, or a source of pollution, or even a market price level which is too low for him to survive on growing the crops for which his land is eminently suited. One of his reactions will be to go and talk to the mayor of his village, or someone else 'in authority'. The mayor will listen and, while reflecting on the problem, place it in a wider context. A context which includes the farmers' neighbours, or even the inhabitants of the whole village. As a consequence, the mayor's perception on the problem will be different from the farmers'. Similar transformations will occur every time the problem is taken a level up in the administrative hierarchy. In the end, at the national level (or even the European one) the problem will either seem infinitely small and not worth dealing with, or will have changed so much in nature that it may be seen as an example of a problem appropriately dealt with at that level, either because it occurs much more widely or because it has other dimensions over and beyond the ones of which the farmer was aware.
The nub of the phenomenon we are dealing with here is the fact that perception is contextual, and that therefore the phenomena perceived, as well as they ways in which they are perceived,

are scale-dependent. Their scale-dependency stresses, again, the need to combine 'top-down' and 'bottom-up' approaches, but what we wish to discuss here is how these approaches should be combined, rather than the mere fact that they should be.

Let us first look at how that interaction occurs at present. Information moves up through at least three different channels, the political, the administrative and the scientific. In each channel, information from a lower level (for the sake of argument, the level where the farmer confronts his local problem) is generalised by *condensation, abstraction* and *recontextualisation*. as it moves up the chain. Condensing the information inevitably entails choices, and whatever information is not transmitted to the higher level is irretrievably lost, as it has not been taken into account in the process of abstraction; it has simply not been transmitted. Abstraction also impoverishes the information it is (at least ideally) done in such a way that the detail may later be reinstated by (re-) combining knowledge formulated at the higher level with observation at the lower level. The difference between the two resides in the context.

Condensation is done without knowledge of the context in which the information is to be used; it is usually done from the perspective of the lowest of the two levels, by conscious or unconscious omission of detail. If such omission is conscious, it is inherent in the perspective of the person involved, and the information omitted is considered insufficiently relevant. If the omission is unconscious, it either is because that person is unaware of the significance of the information (the information does not fit anywhere in the person's perspective), or because its significance is so self-evident that it is not worth mentioning (in that case the person presumes that the information can be reinstated upon applying his perspective, but may be unaware that the person who is going to try and do something about the problem may not (be able to) do so of his own accord). Abstraction, on the other hand, is done 'from above' in full cognisance of a particular context (which more often than not is not the one of the person submitting the problem), because the person doing the abstraction feels that he or she will be able to omit the information without affecting the understanding of the problem. That often implies that it is felt that such information is reinstatable.

The end result of repeatedly condensing, abstracting and recontextualising the information as it moves up the chain of command is that decisions at higher levels are taken in very different contexts, and based on information which only partially resembles the information available at, and transmitted by, the lowest level. And this, even though it as at that lowest level that the decisions will be applied.

When information goes back down the different levels of a policy implementation chain, the problem is compounded by the fact that the information is again recontextualised at every step. But this recontextualisation has a different effect, because now the information is enriched instead of impoverished. At each step, new dimensions are added, dimensions which are relevant to the new context in which the information is being digested, but which have in general not been taken into account at the higher level. And even if they have been taken into account, the exact ways in which the new 'reading' of the policies would affect the situation is never to be predicted, if only because the information on which the decisions were based no longer reflects the reality at the bottom of the chain of command when the proposed measures reach that level.

Evidently, what complicates these matters is that at each level, there is a multitude of different interests and stakeholders concerned, a large number of different perspectives, and generally

more than one chain of command. Each individual concerned has a different assessment of the situation, and its risks and advantages and no one has a complete insight in the situation (complete information). Yet the outcome of the process are changes in behaviour at each level, which in turn impact on the behaviour of the system at every other level.

Legalisation and legitimation

Although at first sight the next point may be less relevant than other ones in a European context, it is nevertheless worth remembering that the CCD deliberately requires the input of a range of institutions which have very different legal forms, and whose legitimation is grounded in very different customs. Not only do we have to deal with national authorities and the institutions that hold part of their authority by delegation from them, but the Treaty (and its Annex) also involves NGO's, associations, individual citizens, etc. in the discussions around measures to be taken against desertification. In effect, the treaty is careful to suggest finding as wide a consensus on which to base its proposals as is possible. The potential problems are, as far as I can see at present, of two different kinds: legal problems and problems of legitimation (these are not at all the same).

Potential problems would seem to stem from the fact that there are in most of the countries concerned, especially outside Europe, no formal, legal procedures for the kind of consultation that is proposed by the CCD, let alone that this kind of procedure is an accepted routine. The way may thus be left open, at least in theory, for stakeholders who is are not happy with the results of the consultation, to try and obtain redress, modification or even cancellation of the measures taken. Thus, one of our researchers is presently involved in a lawsuit brought by angry agriculturalists against the consequences of aquifer recharge, a measure which was undertaken after sound scientific research had indicated that this was the best way of dealing with seasonal water shortage in the area. In general, it seems however that the potential legal problems can be circumvented by ensuring that the consultations are open to anyone, regardless of their position or stake in the area and/or the measures discussed, and by ascertaining that the national government bears the final responsibility for the measures in accordance with the rules set for its decision-making and good governance.

The question of legitimation is more complicated. In essence, legitimation is the process of referring to a context when justifying the opinions, values or choices and individual expresses, or the actions he or she undertakes. This process is not formal, and cannot be regulated. In essence, it determines the size and solidity of the consensus which is sought for each and every measure proposed, by according personal or institutional (but not legal) 'authority' to certain people and refusing it to others. In discussions or negotiations, legitimation is at least as important as legalisation, but much more difficult to objectify and regulate. An important part of the process of legitimation escapes all attempts of clarification because it is not explicit, and refers to subjective values which are not expressed clearly. Yet, the acceptance or rejection of opinions expressed during consultation often stands or falls with their legitimation, whether conscious or not. An opinion expressed by an expert may be based on solid research, and may, moreover, coincide with the opinions of the agriculturalists concerned, yet the latter may reject the opinion because the individual which expresses it is not a 'legitimate' exponent of the

group. Why? The reasons are not always clear, and may have to do with anything from personal idiosyncrasies to class differences or conflicts of interest, whether avowed or hidden. Thus, practical experience shows that in confrontations between people who possess 'local' and 'generalisable' kinds of knowledge, respectively, many kinds of misunderstanding usually occur due to differences in scope and formulation of concepts, differences in level of applicability of understanding gained, differences in the relation between aims and purposes of the observers and the formulation of the pertinent questions to be answered, etc. Such differences are exacerbated by the fact that the different stakeholders legitimize their authority in different ways, claiming that they are 'right' because the way they formulate things is the most generally applicable, and they have studied at school or university to apprehend it, or alternatively, because they have acquired their understanding through observation of the local circumstances under which it will be applied. In the worst case, this may lead to insoluble confrontations of the kind: "I am right because I am smart because I do not live here (and have an academic education)" versus "I am right because I am smart because I do live here (and know better than those who have an academic education)".

If we recall that, in situations like these, the definition of the identity of the various different groups of stakeholders is often under review (see above, p. 00), it will surprise no-one that the tangles resulting from appeals to different forms of legitimation can be quite insoluble.

The implication of different legal systems

Among the nations adhering to the CCD, many different legal systems prevail, and many different kinds of wielding authority. Even within the restricted space of western Europe, which is relatively uniform culturally when compared with China, India or the Muslim countries, there are at least three principal legal systems, originating in Germanic, Anglo-Saxon and Latin traditions respectively. The increasing importance of the European Court of Human Rights, for example in deciding on the compatibility of national legislation with EU-decisions, shows some of the difficulties in implementing measures on a scale which exceeds that of the individual nation-states in terms of which we are used to thinking. But all of the countries of the EU are very similar in that they are basically democracies. As the CCD includes many other nations, some of which have traditions of law and authority much further removed from such democratic principles, the difficulties of implementing a combined 'top-down' and 'bottom-up' approach will major.

But we should not be beguiled by the presumed 'rightness' of our own democratic tradition into believing that it does not have its own ways of posing problems in the context of the CCD. By way of example, let us take one of the problems with which Sardinia has to cope, the trend towards 'improved grazing' which is slowly but surely gaining converts among the pastoralists on the island. This tendency leads to a number of visible changes in the landscape, among which figure:

- the 'homogenisation' of the landscape in some ways, increased contrast in others because the random presence of the bushes and other *garrigue* vegetation is suppressed, and a more 'orderly' pattern of larger grazed areas limited by denser garrigue is put in place;

- a brief increase in yield, followed by yield reduction after two years. This reduction becomes sufficiently important after some five years to prompt renewed ploughing of the area, or even its desertion in favour of another patch. The 'fallow' period of deserted 'improved grazing' lands is disproportionate with the temporary increase in yield;
- an important increase in potential erosion over the long term, which is due to the need for renewed downslope ploughing every five years.

When one searches for some of the socio-economic factors behind such 'improved grazing' and its — mostly nefarious — consequences for the landscape, it becomes clear that the areas most or almost uniquely affected are the 'commons', the land which is jointly owned by all the inhabitants of the village and which generally serves as a backup resource permitting the poorest in the village to survive. Because they are commonly owned, such commons are impossible to divide by barriers.

Among the driving forces behind increased grazing are the desire to have more milk for Pecorino cheese, which is one of the principal exports of the island, and the nature of the EU-subsidies, which are determined by the number of head of sheep and cattle, rather than by their milk yields. Thus, the pastoralists earn more from increasing their yield by acquiring a larger number of animals, even if the yield per animal is lower.

These and other socio-economic factors are essentially the result of choices made by the community in order to organise and regulate its existence with respect to both internal and external dynamics. Among them, we could count :

- the choice to keep the community together socially, following the traditional pattern in southern Europe, rather than, for example, giving in to the individualism which is the hallmark of many northern european countries, the anglo-saxon ones among them. It is this difference which is at the root of many countries' resistance against US-style globalisation based on an unbridled market economy;
- the choice to maintain the commons as an indivisible resource for everybody in the community, acknowledging that fortunes may change over the long-term and that the availability of a resource for those who do not own the necessary means of subsistence at any time, or who have suffered some kind of setback in their attempts to ensure their subsistence, is therefore essential in maintaining the above-mentioned solidarity within the community;
- the choice to maintain the commons as pasture, rather than give it some other use (such as a reserve for hunting and/or gathering), which imposes that the herds grazing there can roam around freely, and thus precludes a rotation system to counteract overgrazing.

In all these choices the well-being of the community as a whole prevails over any advantages for any of its members, and that situation is to a large extent reinforced by the fact that we are dealing with a democratic community, in which the officials making the decisions are elected. As a consequence, here, the oft-quoted 'Tragedy of the Commons' (Hardin 1962) is avoided at the expense of exhausting the commons' soil, which is in itself a tragedy of another kind. In an authoritarian situation, such overgrazing could have been avoided by imposing fencing and rotation, and imposing another means of compensation to the poorest for losing this resource.

Desertification and wealth

I have left what is maybe the most evident issue until the very end of this long list: the relationship between poverty and desertification. Recently, it was argued that democratic societies had a markedly lower incidence of famine than did nations based on other principles of governance. Similarly, it is striking that desertification is most frequent in very poor parts of the world. It would be too easy to say that the presence of drought and desert is the cause of such poverty. We now know enough about the ways in which human beings can, and do, cause desertification at the local and regional level to exclude the role of society in changing the environment.

Viewed from the perspective of the availability of alternatives and resources, the role of society in maintaining, if not causing, degradation and desertification is even clearer. Over-use of agro-pastoral resources is linked to the absence of alternatives, and alternatives are absent either because the resources are lacking to implement them, or because the knowledge and know-how to do so are absent. Whereas in many periods of the past such reasons were valid in that no entity could muster the resources needed to turn the tables on large-scale desertification, and the necessary knowledge and know-how may at particular times and places have been lacking, at present there is no reason why we should not be able to find ways to profitably exploit desertified regions by means of suitable techniques. After all, if we cannot grow any vegetation there, we can always grow shoes, or toys, or yet something else ...

For my part, while fully aware of the need to transfer wealth to the areas concerned, it is also clear that such transfer cannot go without the transfer of information and understanding. However, such transfer should be aimed at enriching the insights and understanding which is already locally available, rather than confronting such understanding with new knowledge, developed elsewhere, which may very well be useful in the long run, but is not yet useful at present. One cannot simply initiate 'bottom-up' methods of consultation and implementation without seeding the confidence and the desire to implement such approaches where it counts, at the bottom of the chain of command.

In that sense, the CCD is an important but insufficient step forwards, in Europe as elsewhere. Or maybe even more so in Europe than elsewhere, because in many parts of the third world the experience of NGO's over the last forty years has made the use of education an inherent part of the implementation of technical and economic changes which help to combat desertification, and in many parts of southern Europe we do not yet see such an automatic association between the two among those who are responsible for policies and their implementation, notwithstanding that in this respect, too, the situation in Europe is changing.

Conclusion

This brief summary of some problems which might be encountered during the process of implementation of the Convention to Combat Desertification's Annex IV (concerning the countries surrounding the Mediterranean Basin) is no more than a first prospection of a subject on which very little systematic work has been done. I am aware of many other aspects I could

have touched upon, for which there was no place in the present context, but which will be dealt with somewhere in the near future.

Compared to the sophistication of the research with which we try and find out what might be the best ways to combat the physical phenomena which result from desertification and land degradation, the investigation of the socio-economic aspects of these problems is at a relatively primitive stage. Yet a more thorough insight into the cultural and social aspects of the dynamics of socio-natural systems is essential if we ever want to be able to find long-term solutions to the problems which face us in this area. It is too simple even to search for ways to implement resilient landscapes under potential conditions of desertification and severe land degradation. True resilience resides not in the natural environment but in the symbiosis between that environment and the society which interacts with it.

From that perspective, we urgently need not only to further our knowledge of the socio-cultural dynamics of degradation and desertification, but to initate in Europe a systematic reflection on how the 'top-down' and the 'bottom-up' approaches might best be combined in an equitable way to profit from the available scientific and local knowledge and the appropriate administrative skills at every level.

PROCESSES OF DEGRADATION AND DESERTIFICATION OF SOILS OF COASTAL SLOPE TERRITORIES OF LIMANS OF THE NORTH-WESTERN BLACK SEA.

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Abstract. To determine degree of degradation under the influence of natural and anthropogenic of coastal slope lands of limans and to find ways of making use of them in conditions of protecting unique ecosystems.

Key words: Limans, coastal-slope lands, degradation, desertification.

In the coastal zone of Black Sea lowlands the limans of the northwestern Black Sea are situated between the Danube estuary and the Sasyk liman reservoir on the southwest and the Tiligul liman on the northeast. Two types of plains can be distinguished in the coastal zone: denudated strata in the central part and accumulative strata in the southwestern and southeastern parts. Neotectonic movements have caused a slope of the plain surface towards the south (in the west), the southeast (in the centre) and southwest (in the east). This determines the arrangement of the surface elevation from 100 m in the north and 30-50 m near the edge of the sea coast bluff to 2-10 m in the lower reaches of the Danube (Shvebs G. I. Et al., 1988).

The frequency of indentation of the valley-gorge net work is more evident in the north (Dniester-Tiligul interfluve) reaching 0.6-0.8 km/km^2. In the coastal zone it declines to 0.1-0.4 km/km^2. In contrast to the slight horizontal indentation is the large depth of the downcutting especially between the Dniester and Tiligul limans where it reaches 50 m. Correspondingly, the upper marks of the coastal slope lands in the central part of the limans (Khadzhibey, Kuyalnitsky, Tiligulsky) rise 40-50 m above the water mirror. For the limans of the Tuzlovsky group the elevation is less than 5 m. (Shvebs G. I. Et al., 1988).

Two stages can be defined in the history of the development of Black Sea liman basins - river valley and liman. The latter can be divided into two: 1) the stage of existence of the open estuary which today occurs in some limans; 2) the liman stage proper in which the water body has no connection with the sea or it is impeded.

Most of the limans have a long length of abrasive shores with characteristic forms: cliffs of diverse heights, wave cut niches, abrasive outliers, a bench covered with few deposits (table 1) (Molodsht I. I. et al.,1984). The abrasion proceeds differently depending on the geological structure. If the whole cliff is made up of loess rock, the abrasion process is cyclic: wave cut niche, downfall erosion of downfall, a new niche etc. If the liman slopes are made up of Meotic and Pontic clays, limestone, red-brown clays covered with loess rocks, then during active erosion different types of landslides occur. On the slopes composed of loess rocks,

there are suffosion funnels, burrows, underground channels and also forms of meso and micro relief created by temporary channels (gorges) and non river bed drainage of surface waters. The occurrence of gorges during downcutting of talus is retarded at the limestone layer. Most of the gorges have hanging estuaries which confirms the dominance of abrasive processes over erosive. Landslides, landfalls, mud streams are characteristic for gorge slopes (Shvebs G. I. Et al., 1988).

Southern, saline in the coastal strip and non saline (towards the north) chernozems predominate in the lands under study in the Danube-Tiligul interfluve.

The climate of these lands is moderately continental with not sufficient moistening in the summer. The temperature regime in the cold part of the year is influenced mainly by atmospheric circulation; in the warm part - by local circulation and radiation balance. The region is in the zone of insuffcient moistening (320-350 mm). The amount of precipitation is lowest in the areas adjacent to the Black Sea (in the cold part of the year - 125 mm, in the warm part up to 225 mm). Evaporation makes up 650-750 mm annually which is 1,5-2 fold the annual total precipitations. However their irregularity and frequent heavy rainfalls lead to intense soil degradation, and dissection of the slopes with gorges. Meanwhile, the precipitation may not be sufficient for growth of the vegetative cover (Shvebs G. I. Et al., 1988).

It should be noted that the local climate is influenced by the sea, limans and river deltas. The daily and annual amplitudes of temperature variations, cloudiness and amount of precipitations in the coastal zone are reduced, although moisture and number of solar hours increase. Depending on the dimensions of the limans, their influence extend from several hundred meters to several kilometers in coastal lands.

The land under study is located in the belt of maximum erosion which within the limits of Ukraine and Moldova covers the southern part of the forest steppe zone and the northern subzone of the steppe with the maximum on the boundary between. Thus, all the land under study is erosion hazardous, and its soil cover is characterized by a high degree of erosion. In the basin of the Maliy Kuyalnik the mean frequency of indentation reaches 6,0 km/km^2. In these conditions ravines and washed off soils compose the main external element of the landscape today (Shvebs G. I., .Ambroz J. A. et al., 1979).

A degradation of natural landscapes occurs in areas with intense water erosion. The restructuring of their morphology and generation of new facies has been observed. The consequences of landscape degradation are many fold. The results of our studies have shown that deposits entering the surf zone of limans cause siltation and bogginess of the land. As a result the level of the bottom is elevated. In the summer arid period these zones are drained and are never flooded again, even in periods of spring floods (Adobovsky V. V., 1996). This leads to retreating of the limans. The drained shores and parts of the bottom are transformed into infertile, deserted lands which because of high salt content (5-9 %) resemble Middle East takyrs with spots of rare saline vegetation.

Eroded soils of coastal-slope lands lacking most (40-60 %) of the soil profile and having lost up to 50-80 % of the humus reserves and nutrients have poor water physical properties and low antierosion resistance (table 2). The decline of soil fertility and crop harvest on eroded lands will lead to worsening of conditions of soil formation and plant photosynthesis.

Erosion is defined as water erosion (plane wash off, linear washout) and deflation - wind erosion. Deflation in the spring can harm and sometimes completely destroy plant shoots. The

meaning of deflation for agriculture in our conditions is analogous to unfavorable enviromental conditions such as ground frosts, droughts etc. Meanwhile, the degradation of lands which is manifested in irreversible decline of natural fertility, the occurrence of gorges, siltation of valleys takes place exclusively due to intense water erosion. It is evident that water erosion of the land under study is due to heavy rainfall.

The lands adjacent to the limans are zones of intense agriculture activity. They are mostly used for farming. Ploughed lands make up 70-80 % which is due to the lowland features (Black Sea lowlands) and the steppe zone with highly fertile chernozem soils. Grain and fodder crops are grown, as well as vegetables and gourds. There are many orchards and vineyards.

The slope lands include those of liman slopes and river valleys. The slopes are steep (from 2^0 to $15\text{-}20^0$). In some places they are precipitous, deeply downcut by gorges and ravines with bare Neogene-Quaternary red-brown clays and Pontic limestones. Less steep slopes are noted in the upper reaches of limans and along the valleys of rivers. The surface of slopes has many landslides, gorges, ravines, fragments of super floodplain terraces (1 to 6). Loess and loesslike loams, talus deposits and in the upper and middle third part of the slopes - outcrops of red-brown heavy clays. Here chernozems were formed in washed out soils. In those places of limestone outcrops on the day surface, specific short profile soils (chernozemlike) have been formed. Processes of soil growing over with meadows are characteristic for the slopes as well as bogging with formation of permanently wet land in places of outflow of underground waters (Shvebs G. I. Et al., 1988).

The rather complicated relief of slope lands their dissection with a deep gorge-ravine network, marked colour irregularity of the soil cover and conditions of moistening impede the use of slope lands. Depending on the existing natural-ameliorative conditions, use of these areas (contours) on the slopes should be differentiated.

In particular, the upper, less steep (up to $3\text{-}5^0$) third of the slopes with poor, rarely with average washedout soils is usually used for ploughing. In these areas it is strictly necessary to adhere to measures preventing possible erosion of soils proventing their restoration and increasing their potential fertility. An efficient solution of this problem is the use of contour slope farming.

More steep slope areas with landslides and gorges are traditionally used for pastures. The stands of grass need to be ameliorated by additional sowing with valuable fodder grasses and ridding of weeds. The most steep slopes indented by gorges and ravines should be allocated to soil protective and water protective afforestation.

Each of the limans is bound by an aqueous-coastal strip, formed by contemporary liman terraces and riverine estuaries. As a rule, during flood water these strips are flooded. In the summer and autumn they are fed not too deeply by underlying (from depths of 0,3-0,6 to 1 m) ground waters. Meadow and meadow-bog salt bottoms have been formed here and saltern soils. Usually these areas are used us poorly productive natural fodder lands. Halophytes and meadow-bog grasses dominate. Marsh bog reeds occur. The lands need radical or superficial amelioration with additional sowing of valuable fodder grasses and grass mixtures (Shvebs G. I. Et al., 1988).

One of the examples of degradation of coastal-slope lands used in agriculture is the use of soil irrigation with poor quality water. The Sasyk reservoir is one of the main elements of the Danube-Dniester irrigation system, in which the entrance is the Danube-Sasyk canal and the

Kogilnik and Sarata rivers entering the northern part of water body. The exit is the outflow pumping station, marine sluice and main pumping stations supplying water to the fields of irrigation. The system was set up in 1978 when the dam was filled in separating the liman from the Black Sea (Adobovskaya M., 1998).

At present, after the liman was cut off from the sea and Danube water was supplied through the canal, the mineralization of water in the water in the reservoir fell to approximately 1,0-1,5 g/l. Prior to this it was a mean 14-15 g/l. The liman silts had a great effect on mineralization of water which in turn affected the quality of irrigation waters. It has been established on the basis of experiments that water soluble salts easily and quickly wash out from the top layer of deposits in the Sasyk liman. However, this layer in places does not exceed 15-20 cm. In spite that the upper silty layer at present has become salty, salts continue to enter the liman from highly mineralized springs at the bottom of the water reservoir, underground and pore waters of bottom sediments (Enaki I. G.,1986).

Before the dam was built the Sasyk liman was a natural complex in a hydrochemical equilibrium state. It was a shallow water body separated from the sea by a barrier beach periodically washed away allowing sea waters to enter. The liman was an accumulator of salts of surface and underground waters of the drainage basin of Kogilnik and Sarata. In the process of the Sasyk water reservoir becoming salty, three types of water became mixed. They were the hydrocarbonate - calcium waters of the Danube, the sulfate - sodium waters of inflowing rivers and chloride - sodium underground and pore waters of bottom sediments of Sasyk liman. It shoud be noted that the ionic composition of the Sasyk water reservoir is the same chloride - sodium. The alkalinity has risen markedly. If in the Danube - Sasyk canal (during its functioning) the water retains its quality close to Danube water, the total mineralization is about 0.5 g/l and the ratio of Na^{+}:Ca^{2+}<1, then in the lower part of the liman it is enriched with sodium which is three times greater than calcium. Total mineralization (from 1.2-1.5 g/l) increases more than twice and alkalinity rises (Gogolev I. N. et al., 1992). In the southern part of the water reservoir in the area of the station pumping into the sea, the water is even worse towards the north of the liman where the main pumping stations for supplying water to the irrigated lands are located. Here water mineralization reaches 2.0-2.2 g/l. The ratio of Na:Ca reaches 4.5-5.0 while the pH rises to 8.4. The properties of Danube water entering the Danube - Sasyk canal deteriorate. Further in the liman it becomes worse still and near the main pumping stations it becomes unsuitable for irrigation.

The use of liman water has led to secondary salinization of soils particularly Danube - Dniester irrigation system up to a moderate level. The soil structure is deteriorated and is transformed into coarse lumpy. A crust 2.0-2.5 cm thickness is formed from the top which significantly worsens the water - air regime of soils (Tortik N. I., 1992). As an ameliorative measure gypsum is added to water and soils where in the latter, 10-12 t/ha are used.

Long-term monitoring by researchers of the Department of Soil Science and Soil Geography has shown that the soil cover of the irrigation zones of the Danube - Dniester irrigation systems have two subtypes of chernozems - usual and southern. Studies have shown that as a result of irrigation of the chernozems of southern far Dniester lands of Ukraine with poorly mineralized waters of unsatisfactory quuality, a wholseries of unfavorable soil forming processes occur. Under the influence of them significant changes in the soil morphology, composition and properties occur leading to reduction in productivity. Signs of secondary

salinization become evident and the soil mass structure is significantly changed. Along with changes in structure, the soil density increases and the porosity changes. The amount of capillary pores is decreased and the fraction of pore cracks is increased. Besides, in the arable layer often fragments of ploughed over, brightened eluvial surface crusts are encountered.

Conclusion

In the whole the issue of coastal - slope lands of Black Sea limans is quite acute. As these limans are situated in the zone of intense agricultural activity up to 85 % have been developed. Anthropogenic impact on the aquatories of limans and adjacent lands is accompanied by degradation of these lands with signs of desertification.
To protect the unique ecosystems of limans and their coastal - slope lands, it is necessary to elaborate and implement a complex programme of protection and use of these facilities.

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References

Adobovskaya M. (1998). Dynamics of the hydrological and hydrochemical regime of the Sasyk liman - lake for the past 60 years. In: Collection of scientific papers of young scientists and students, Issue 1, Geological - Geographical Series, dedicated to 65th anniversary of the Geological - Geographical faculty, Odessa State University, Odessa, p.33-36 (in Russian).

Adobovsky V. V. (1996). A new stage in the drying up of closed limans (Dofinovsky liman). Geography and Natural Resources 2, Nauka, Novosibirsk, p.167-169 (in Russian).

Gogolev I. N., Baer R. A., Kulibabin A. G. et al. (1992). Irrigation in Odessa region. Soil - ecological and agrotechnical aspects - Odessa, 436 pp. (in Russian).

Enaki I. G. (1986). Hydrochemical regime of the Sasyk liman and water reservoir. In: Hydrobiology of the Danube and limans of the northwestern Prichernomorya. Kiev: Naukova dumka. H.36-42 (in Russian).

Molodsht I. I., Palatnaya N. N. et al.,(1984)Geology of the shelf of Ukr. S.S.R. Limans. -Kiev. Naukova dumka, -176 pp. (in Russian).

Tortik N. I. (1992). Soil - genetic consequences of irrigation of chernozems of southern Zadnestrovya of Ukraine with poorly mineralized waters. - Preprint Phd thesis M., 26 pp. (in Russian).

Shvebs G. I. et al. (1988). Liman estuarine complexes of Prichernomorya: geographical grounds for economic development . L.: Nauka, 1988, 304 pp. (in Russian).

Shvebs G. I., .Ambroz J. A. et al. (1979). Nature of Odessa region. Resources, sustainable use and conservation, Kiev - Odessa, Visha Shkola, Main ed. Office, 144 pp. (in Russian).

Manifestatim of slope processes	West limb				East limb			
	Liman slope							
	Right		Left		Right		Left	
	êì	%	êì	%	êì	%	êì	%
Abrasion and landslides lacking	50	40.7	43.5	45.1	63.5	35.8	79	49.4
Abrasive-landfalling slopes	64.5	52.4	39	40.4	55	31.1	66.5	41.6
Abrasive-landsliding slopes	8.5	6.9	14	14.5	58.5	33	14.5	9.1
Abrasive-landfalling-landsliding slopes	73	59.3	53	54.9	113.5	64.1	81	50.6

Table 1:Extension of coastal forming processes on liman slopes in relation structural elements of Odessa elevation. Limans of the west limb: Sasyk, Shagany, Burnas, Dnestrovsky, Sukhoi
Limans of the east limb: Kadzhibey, Kuyalnik, Bolshoi Adzhalyk, Maliy Adzhalyk,Tiligul.

	Distance from shore line			
	50 m Foot of slope	400 m Middle of slope	1100 m Watershed, washed off soils	1500 m Watershed, non washed off soils
Humus content in upper layer (%)	1.95	0.95	3.0	3.3
Depth of humus layer (m)	0.37	0.3	0.46	0.55

Table 2: Layer of humus on the coastal - slope lands

A PRELIMINARY CLASSIFICATION OF AGRO-SILVOPASTORAL SYSTEMS IN THE MEDITERRANEAN BASIN

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Abstract. The aim of this paper is to give a preliminary classification of agro-silvopastoral systems. Four criteria (potential productivity of pastures; farm specialisation and productive level of animals; farm organisation degree; socio-economic aspects) are proposed to identify three different types of systems: the extensive ones, the quasi-extensive ones and the medium-intensive ones. The shift from extensive to quasi-extensive and to medium-intensive production systems results in a decrease in woodland and in a marked increase in cultivated pastures; in unsuitable areas it often leads to land degradation.

Key words: agro-silvopastoral systems, land suitability

Introduction

Livestock farming probably represents the main activity of the agricultural sector in the Mediterranean basin. The amount of herbivores in this area is approximately 100 million livestock units (LSU), of which 53.8% are in Europe, 23.2% in Africa and 23% in Asia (FAO, 1994).
When the main feeding source for these animals is grazing of natural or cultivated fodder resources, both in woods and in fields, we talk of agro-silvopastoral systems.
In the last century, the population increase and the introduction of more and more intensive natural resources exploitation systems modified the pre-existing equilibrium between natural forage availability and stocking rate. This led, on one hand, to an extension of agropastoral activities in not very suitable or unsuitable areas and, on the other, to an increase of grazing intensity in areas already used.

Classification criteria of agro-silvopastoral systems:

The agro-silvopastoral systems can be identified and separated using the following four criteria:

1. *Potential productivity of pastures:* the potential productivity of pastures can be defined by the quanti-qualitative evolution of fodder resources (Brandano and Rossi, 1975). Where the grazing pressure is too high, theoretically the best thing to do would be to reduce the stocking rate or to substitute a more demanding species with a less demanding one. In practice in recent years there has been a considerable increase in the number of the bred animals, because of the booming market of

animals product (ISTAT, 1982; 1992). Thus it was necessary to find new land to increase the fodder resources of the farms, which has led to the use of less suitable lands and to the use of irrational agricultural techniques to improve pastures. Ploughing and using fire as an agricultural technique have often been used to increase the potential productivity of fodder resources. But, even though these practices have had a positive effect in flat areas, they cannot be used on hilly land where the elimination of shrub and tree cover to sow grasslands or artificial pastures, has produced important degradation. Therefore the rise of potential productivity should take into consideration land suitability. Thus, it will be of great use to refer to an objective scheme of the potential use of an area, such as the FAO land suitability evaluation (1976). This will permit land improvement to be planned taking into account the real land suitability.

2. *Farm specialisation and productive level of animals:* in different agropastoral systems we can recognise several degrees of farming possibilities. These systems could be distinguished on the basis of present species, types of production or production level of animals. Grazing species have different nutritive levels, depending on their requirements, and distinct feeding behaviour, because sheep don't adapt themselves very well to graze on shrublands and prefer grass, whereas cattle and goats can graze on shrublands and woodlands. As far as the specialisation is concerned (milk or meat production) the degree of adaptability to environmental conditions influences the animal species location on land very much. Indeed it is true that the milk production needs an absolutely steady availability of fodder resources, whereas meat production doesn't. Autochthonous breeds however are very environmentally adaptive and highly efficient in using available fodder resources (Brandano *et. al.*, 1998). Sardinia is a good example because different types of farm specialisation are clearly located on particular terrain: dairy cattle and/or sheep in the most suitable lands; sheep and goats and very environmentally adaptive cattle on hilly lands (as far as 600-700 m a.s.l.); only goats and very environmentally adaptive cattle in higher and rougher areas (higher then 600-700 m a.s.l.) (Brandano, 1984a). The last, but not the least important is the productive level of animals: for the same body weight, higher animal production needs a higher fodder resource and a higher fodder quality. This aspect is very important for lactating animals because their feed intake can also be twice as much as the dry animals and the dietary nutritive content must be very high. Unfortunately a farm productive index doesn't always agree with the real potential productivity of an area, and so, to prevent the land degradation increasing, it would be better to plan the improvement of pasture areas on the basis of a land suitability evaluation scheme.
3. *Degree of farm organisation:* the shift from traditional farming systems (nomadism and transhumance) to more and more complex and developed systems, always needs a modification of the ratio between productive factors and their effect on the value of final output (VFO) (Idda, 1978; Idda and Nuvoli, 1981). Work is still the only productive factor in a lot of agro-silvopastoral farms in the Mediterranean basin, closed systems where production barely satisfies the farmer and his family needs. Thus it seems correct to use the work/VFO ratio as an index of the evolution degree of above-mentioned systems. Indeed, as the capital of the system grows, as permanent investments are made and as the information (higher cultural level, computerisation, profits reinvestment) and organisation increase, the new input

effect on VFO makes the work/VFO ratio decrease.

4. *Socio-economic aspects:* new discriminatory elements among agro-silvopastoral systems come from socio-economic considerations. Traditionally grazing is the prevailing system in the countries of the Mediterranean basin. But often agropastoral activities aren't well managed and the overgrazing and the fires use to clear pastures are the main animal farming management methods. Differences have been observed between countries on the South and on the North shores of the Mediterranean basin: in the former, the increase in the number of sheep and goats, which is still one of the investments able to provide protection against the uncertainty of the prospects which come from social and political instability, has led to more intensive utilisation criteria of the natural resources being adopted and, as a consequence, to a strong imbalance between fodder resources and stocking rate and to an intensification of land degradation. In the latter, new economic activities are prevalent and this has led to a progressive abandonment of the most marginal areas, and has led, even though for different reasons, to land desertification too. To all these things we have to add, as in the past, the free use of public pastures: these areas, in the past, had only sometimes been used for livestock activities but, suddenly, they had to support unsustainable stocking rates, land improvement works and pastures cultivation, all carried out without considering pedological, morphological and vegetation characteristics. Therefore we can say that "different agro-silvopastorali systems are, on the one hand, bound by resources and, on the other forced by social and political necessities".

Three different agro-silvopastoral systems

In accordance with what was said in the previous chapter it is possible to assume the following classification:

- *Extensive agro-silvopastoral systems:* they are systems with a low pastures suitability, a low or a medium animal productive level (medium meat production for sheep and goats, low-medium meat production for cattle; low milk production only for goats), a work/VFO ratio near 75% and with a lot of socio-economic ties. In Sardinia these types of farm are mainly on lands with medium or strong limitations of use, on mountains or on high hills, without irrigation. Only animals with high capability to live in very difficult environmental conditions can be kept there (Brandano, 1984b).
- *Quasi-extensive agro-silvopastoral systems*: they have, on average, a higher pastures suitability and a higher animal productive level with regard to the previous type. The work/VFO ratio is near 50%. When natural fodder resources increase (because pedo-agronomic ties decrease), socio-economic ties decrease and, as a consequence, farm flexibility become higher. In Sardinian farms, the minor pedo-agronomic limitations allow to obtain a high level of meat production from sheep and goats and a medium level from cattle; it is also possible to obtain a low milk production from cattle, low-medium from sheep and medium from goats.
- *Medium-intensive agro-silvopastoral systems:* they have a better farm organisation than the other two systems. The work/VFO ratio still decreases to near 30%. In Sardinia we can mainly find this type of farm on plains or on low hill (maximum 500 m a.s.l.) with low limits of use, where it is possible to irrigate during the whole

dry season. Dairy cattle with low-medium milk productive level; dairy sheep with a medium-high milk productive level; dairy goats with medium-high milk productive level are kept there. In this case there are both a high suitability and a high farm flexibility, due to the absence of limitations of available resources, and a greater reduction of socio-economic tics which almost disappear.

The classification is summarised in the following scheme:

			Extensive	**Quasi-extensive**	**Medium-intensive**
Potential productivity of pastures			low	low-medium	medium-high
	Meat production	**Sheep**	medium	high	-
		Goats	medium	high	-
Potential productivity of animals		**Cattle**	low-medium	medium	high
	Milk production	**Sheep**	-	low-medium	medium-high
		Goats	low	medium	medium-high
		Cattle	-	low	low-medium
Work/VFO			~75%	~50%	~30%
Pedo-agronomic ties			high	medium	low
Socio-economic ties			strong	medium	few
Farm flexibility			low	medium	medium-high

Table 1 – Classification criteria of the three agro-silvopastoral systems

Conclusion

This preliminary classification may represent an important step in assessing the processes of land degradation due to agro-silvopastoral activities. The uncontrolled development of modern agricultural practices and the shift from extensive to quasi-extensive and to medium-intensive production systems have resulted in a decrease in woodland and in a marked increase in cultivated pasture. These actions on unsuitable areas have often led to land degradation (Enne *et al.*, 1999; Pulina *et al.*, 1998). The NRD group of the University of Sassari, starting from a past land suitability classification (FAO, 1976), have developed a regional land suitability to pasture improvement scheme by using GIS methodologies, which classifies the land into five land suitability classes (highly suitable, moderately suitable, marginally suitable, currently not suitable, permanently unsuitable) (d'Angelo *et al.*, 1999). This approach is the basis of a land conservation programme for unsuitable areas to identify sustainable agro-silvopastoral systems that might be accepted by farmers.

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References

d'Angelo M., Enne G., Madrau S., Percich L., Previtali F., Pulina G., Zucca C. (1999). Mitigating land degradation in Mediterranean agro-silvopastoral systems: a GIS based approach. Catena. In press.

Brandano P., Rossi G. (1975). La razionale utilizzazione dei pascoli ed i problemi inerenti la determinazione del carico. L'Informatore Agrario, **32:** 20139-20148.

Brandano P. (1984a). L'allevamento del bestiame in Goceano - I problemi dell'allevamento zootecnico. VII Comunità Montana "Goceano" Bono (SS), **2:** 29-39.

Brandano P. (1984b). L'allevamento del bestiame in Goceano - Le prospettive dell'allevamento zootecnico. VII Comunità Montana "Goceano" Bono (SS), **3:** 41-48.

Brandano P., Enne G., Pulina G., Macciotta N.P.P. (1998). Biodiversità e salvaguardia dei gruppi etnici delle principali specie di interesse zootecnico della Sardegna. Atti del IV Congresso Nazionale "Biodiversità: germoplasma locale e sua valorizzazione". Alghero, 8-11 settembre. In press.

Enne G., Pulina G., d'Angelo M., Previtali S., Madrau S., Caredda S., Francesconi A.H.D. (1999). Agropastoral activities and land degradation in Mediterranean areas: the case of study in Sardinia. Thornes J., Brandt H.J., Geeson N., (Eds) Mediterranean desertification – A mosaic of processes and responses. Chichester, John Wiley. In press.

Pulina G., d'Angelo M., Madrau S., Zucca C. (1998). Indicators of land use in agropastoral ecosystems. Proceeding of the International Seminar for Assessing Desertification in the Mediterranean. Porto Torres 18-20 September 1998, 177-185.

FAO (1976). A framework for land evaluation. FAO Soils Bulletin No. 32. FAO, Rome.

FAO (1994). FAO Yearbook Production 1993. FAO Statistic Series No. 117. FAO, Rome.

Idda L. (1978). Alcune considerazioni sullo sfruttamento in zootecnia delle aree estensive della Sardegna. Zootecnica e nutrizione animale, **5-6:** 291-300.

Idda L., Nuvoli F. (1981). Aspetti economici e organizzazione produttiva dell'allevamento ovino: il caso di un comprensorio della Sardegna settentrionale. Quaderni sardi di economia, **2-3:** 191-238.

ISTAT (1982). 3° Censimento generale dell'Agricoltura. Caratteristiche strutturali delle aziende agricole. Fascicolo regionale della Sardegna. Istituto Centrale di Statistica, Roma.

ISTAT (1992). 4° Censimento generale dell'Agricoltura. Caratteristiche strutturali delle aziende agricole. Fascicolo regionale della Sardegna. Istituto Centrale di Statistica, Roma.

THE IMPACT OF SUMMER FIRES ON VEGETATION IN SARDINIA

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Abstract. In Sardinia fire is an essential factor which designs and models various ecosystems. Fires in Sardinia generally occur during the summer and their effects are emphasised by the drought and the wind which characterise the climate of this Island. Causes of summer fires can be manifold but traditionally agropastoral activities are the main cause. Although a lot of species have high capability of regeneration, after fire the composition and the physiognomy of the forests radically change. Regeneration processes often become very difficult because of the joint action of repeated fires, tillage and overgrazing, and very long erosion processes occur, especially on slopes.

Key words: Fires, ecosystems evolution, regeneration

Introduction.

In the Mediterranean basin, and in Sardinia in particular, fire is an essential factor of development of various ecosystems. Man-influenced ecosystems, as we know them today, have been largely designed and modelled by fire. There are a lot of causes of summer fires and their effects are emphasised by both the particular Mediterranean climate conditions, especially by hot dry periods with high water deficit, and by the high flammability of the vegetation (Molina, 1996): we can think to property speculation along the coasts, revenges, carelessness, high jobless rate or, in the final analysis, natural causes, but the most of events, even though there aren't official statistics, are due to agropastoral activities. Not only in Sardinia, but also in all areas of the world where this type of activities are the main form of land economy, this phenomenon occurs with strong analogies (Camarda, 1991).
It is hard to summarise the effects produced by fire, because characteristics of soil and soil-water conditions, previous to fire, control the effects of forest fires on soil and because the fire has a different impact on different types of vegetation. The aim of this paper is to give a synthetic view of the effects of forest fires on vegetation in Sardinia with regard to the desertification issue.

Extent and causes of fires in Sardinia

The majority of fires in Sardinia generally occur during the summer, from the end of June until September, with the highest frequency in July and August that coincides with the driest period. From 1971 to 1998 the number of fires and burnt areas in Sardinia has been quite irregular (fig. 1), as the *"Corpo Forestale e di Vigilanza Ambientale della Sardegna"* measured (C.F.V.A., 1998), and this also because the dry period in Sardinia can sometimes begin in April and last until October or November.

The drought is due to the low rainfall rate, with a minimum in July and August, and to high summer temperature (Arrigoni, 1968). Furthermore the low air relative humidity during these same months and the effect of wind, particularly from South-East and North-West, cause, everywhere in the Island, a very high evapo-transpiration rate. This type of climate leads the soil moisture under the wilting point and causes the vegetation water content decrease, making the vegetation particularly vulnerable to fire (R.A.S., 1987a).

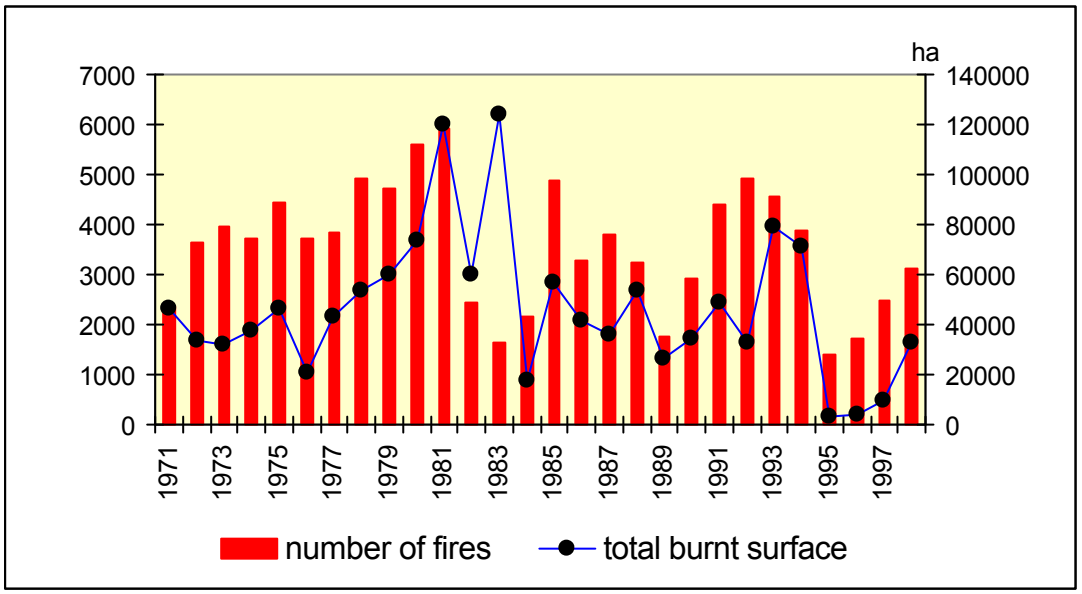


Fig. 1: Trend of fire events in Sardinia from 1971 to 1998.

In the last 30 years the highest number of fires occurred in 1981 when 5926 fire burnt 120137 ha, 14453 of which were woodland (fig.2). Instead the widest area (124215 ha) was burnt in 1983 by a relatively low number of fires. In the last 4 years we have been witnesses to a decreasing of the phenomenon, probably due to good prevention actions, and in the last four years the total burnt surface was consistent lower than the mean value.

Causes of summer fires are manifold and their effects are emphasised by both the peculiar Mediterranean climate conditions, hot dry summer with high water deficit, and the high flammability of the vegetation.

Traditionally agropastoral activities have been the main cause of fires. A detailed analysis of the forest fires shows that more than 90% of the total number of fires are historically and traditionally related to human activities (Enne et al., 1999). In 1998 in Sardinia 81% of fires are started deliberately (fig.3), this probably due to agropastoral activities. It is important to remember that in Sardinia, in the last 30 years, two types of events occur: on the one hand the strong increase in the number of sheep and goats due to the favourable situation of the market of milk and “Pecorino” cheese; on the other the progressive abandonment of the most marginal areas due to the prevalence of new economic activities. In both cases, even though for different reasons, a reduction of available grazing areas occurred and this resulted in a strong increase of the number of fires.

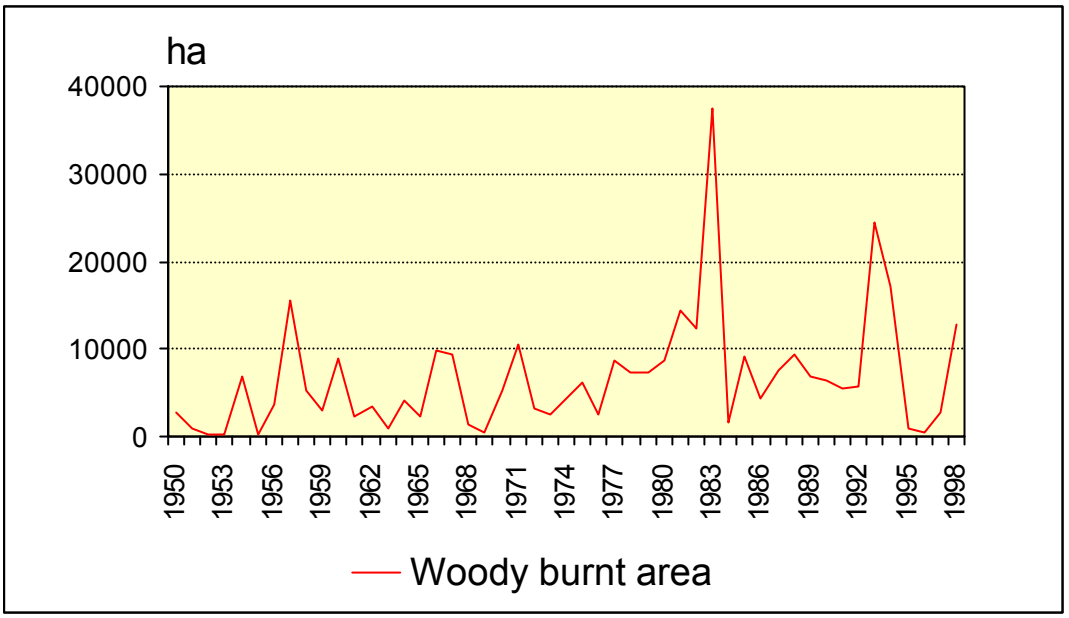


Fig. 2: Woody burnt area between 1950 and 1998 in Sardinia.

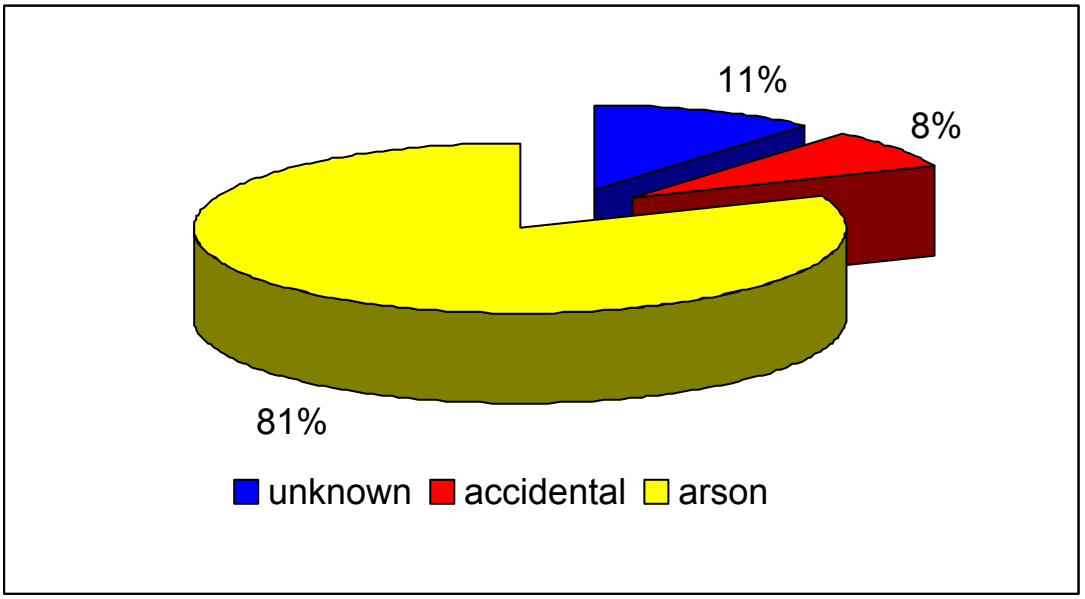


Fig. 3: Percentage subdivision of fire causes in 1998.

Indeed fire has been considered an important practical and economical tool for clearing lands for grazing, especially for sheep: this depends on the different feeding behaviours of grazing animals, because sheep prefer grass to shrub, whereas cattle and goats are very well adapted to graze on shrubland or woodland. In general, after fire annual plant species increase in number, and they constitute the main feeding source for sheep.

Evolution of ecosystems after fire.

Fire has a strong impact on Sardinian vegetation because it is able to, totally or partially, destroy the vegetation cover. Moreover the characteristic of sclerophylles are often related to a very easy wood and leaves combustion (presence of resinous substances, oils and other volatile substances) and, for this reason, the Sardinian vegetation is particularly easy to burn.
In the Island generally recur two types of fire: *crown fires,* which especially occur in conifer woods and that are driven and fed by the wind, and the *surface fires,* the most common types, that burn the litter, the shrub and the herbaceous vegetation (De Lillis,1995). In the most of cases they act at the same time. Wood destruction due to frequent fires, the fast mineralisation of the organic matter due to high temperatures during and after fire**,** the destruction of humic and clayey complexes by chemical and bio-chemical processes and the increased soil erosion rates, lead to a more and more intensive process of degradation of the vegetation and the soil (Susmel, 1977) which could result in desertification.
After fire the composition and the physiognomy of the forests change. First of all fire makes a strong selection of arboreal species: repeated fires affect more and more the arboreal vegetation until trees disappear. Other species take the place of trees: they are shrub and herbaceous species very well adapted to the particular environmental conditions. This way born *maquis* and *garrigues* that are the most frequent formations in Sardinia (R.A.S.,1987b). These are always temporary formations because the joint action of fires, tillage, overgrazing and atmospheric agents, progressively affect them, leading to *low maquis* and then, at the end, to *pre-desert lands* (in Sardinia is very common to find "deserts of asphodel" which represent an indicator of a very low productivity and of a long and strong degradation process). Fires affect *Quercus pubescens* and *Q. congesta* woods, leading to mesophyle maquis (whit *Erica spp., Arbutus unedo* and *Phillyrea* spp.) in areas above an altitude of 600 metres, and to termophyle maquis (with *Pistacia lentiscus, Olea oleaster, Calycotome* spp.) in areas below 600 metres (Camarda, 1991). Fire also causes the regression of holm oak *(Quercus ilex)* forest formations and leads to maquis with different species. The cork oak *(Quercus suber),* which is a fireproof plant with a good capability to resprout from stump, forms in Sardinia secondary origin woods because it originates from degraded (because of fire) holm oak woods or degraded mixed woods of *Q. ilex* and *Q. congesta.*
Obviously it is very difficult to halt degradation process especially when the involution processes are not only due to degradation of the vegetation cover, but particularly when they are due to a very low capability of re-evolution. In this sense the frequency of fire in a specific area is very important: frequent fires make the seed-bank decrease if the time that elapse between two fires isn't enough to allow plants to reproduce. Instead, as to concern species with agamic regeneration, they are able to resprout and to develop shoots only if they have enough reserves in roots. Generally if plants grow quickly they will accumulate reserves quickly but, if the new shoots are immediately and again and again grazed, plants won't have time to reaccumulate them and, as a consequence, they can't resprout anymore.

Regeneration strategies

Generally, after fire, it is possible to have of a new vegetation cover in few years. We can distinguish two regeneration mechanisms: the agamic one (plants produce suckers from roots that are still alive after fire**)** and the gamic one (when the plant is completely destroyed by fire**).** Sometimes seeds that germinate after fire were in the terrain before fire**,** but in some other cases plants release their seeds as a consequence of the fire or, seeds arrive from plants of the nearest areas (Mazzoleni, 1993).
A lot of species of the maquis of the Mediterranean basin, have high capability of agamic regeneration, especially the evergreen oaks *(Quercus suber, Q. ilex, Q. coccifera), Erica arborea,* the strawberry tree *(Arbutus unedo), Pistacia lentiscus, Myrtus communis, Phyllirea angustifolia, Olea europaea* and *Spartium junceum.*
This capability of regeneration depends on the resilience of species: indeed, only in certain cases fire completely destroys species, like in the case of *Pinus pinea,* but often species have the tools to survive: these species are the *pyrophytes* (De Lillis, 1995). Quercus suber, for example, survives the fire because the cork bark protects it. During a fire, the thick cork layer protects the most sensitive interior tissues of the plant, in such a way that the tree doesn't die and shoots out again later: it's an example of *passive pyrophyte*, whereas are *active pyrophytes* the species that, after fire, are able to gamic or agamic regeneration. For example *Pinus halepensis* is an active pyrophyte because the high temperature results in the opening of Aleppo pine cones, making easy the seed dispersion and, as a consequence, the natural regeneration: little seeds of Aleppo pine have a high degree of germination and the thin ash layer after fire with a little rain, are more than enough to have a high regeneration degree; holm oak (*Quercus ilex*) and *Erica arborea* regenerate resprouting and developing suckers from stump; on *Cistus* (*C. monspeliensis* and *C. incanus*) fire breaks seed integument increasing permeability, causing the seed imbibition and then making the germination easy.
Maquis represents the promptest and the most effective reaction system to contain erosion after fire: the frequent resprouting and the production of hundreds new seedlings protect the soil from torrential rains that usually follow the dry period.
Three or four years are generally needed to *Cistus* to cover the whole burnt surface (R.A.S., 1987c), but between the fire event and the total vegetation covering, a very critical stage occurs. During this period the soil can easy be affected, on the one hand, by atmospheric agents and, on the other, by the direct action of animals (grazing, often overgrazing, trampling) that shepherds immediately put on the burnt surface. In this critical phase the risk of land degradation is very high, but it is much higher when it happens on slopes.
In conclusion if the fire is followed by erosion processes and by organic matter lost, the regeneration processes will be very long and very difficult; indeed, in ecological terms, land degradation is due more to erosion processes than to fire. Erosion makes regeneration very difficult and often impossible.

References

Arrigoni P.V. (1968). Fitoclimatologia della Sardegna. Webbia, 23: 1-100.

Camarda I. (1991). Formazioni forestali, incendio, pascolamento e degradazione del suolo - Atti del Convegno ERSAT "La difesa del suolo in ambiente mediterraneo", Cala Gonone 12-14 giugno: 49-56.

Camarda I., Valsecchi F. (1982). Alberi e arbusti spontanei della Sardegna.

C.F.V.A. (1998). Campagna Anti Incendi Boschivi 1998 - Analisi Finale.

De Lillis M. (1995). Ecologia del fuoco - In Pignatti S. (ed), "Ecologia Vegetale", 17: 297-318. UTET.

Enne G., Pulina G., d'Angelo M., Previtali S., Madrau S., Caredda S., Francesconi A.H.D. (1999). Agropastoral activities and land degradation in Mediterranean areas: the case of study in Sardinia. In press on "Medalus book", Elsevier.

Mazzoleni S. (1993). Incendi e vegetazione mediterranea. In Mazzoleni e Aronne 1993. Introduzione all'ecologia degli incendi - Liguori Editore.

Molina M.J. (1996). Impact of forest fires on desertification processes: a review in relation to soil erodibility. In J.L. Rubio and A. Calvo, [Eds] "Soil Degradation and Desertification in Mediterranean Environments", Geoforma Ediciones, Logrono, Spain.

R.A.S. (1987a). La lotta contro il fuoco: fattori naturali che influenzano gli incendi. La programmazione in Sardegna, 109-111: 7-13.

R.A.S. (1987b). La lotta contro il fuoco: le conseguenze ecologiche degli incendi. La programmazione in Sardegna, 109-111: 68-77.

R.A.S. (1987c). La lotta contro il fuoco: economia pastorale e incendi. La programmazione in Sardegna, 109-111: 27-31.

Susmel L. (1977). Ecologia dei sistemi e difesa dal fuoco nell'area del mediterraneo italiano. International Symposium on "Environmental Consequences of Fire and Fuel Management in Mediterranean-climate Ecosystems (Forest and Scrublands)" - Palo Alto, California, August 1977.

CATION DYNAMICS IN SOILS UNDER DIFFERENT LAND MANAGEMENT

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Abstract. This study is focussing in order to determine if the clearance management in a *Quercus suber* forest is beneficial for the cation content of the soil and how it can affect in the development of this exploited specie. Thirty randomized samples were taken in two plots, one with shrubs and the other was cleared two years ago. We analised the plant avalaible content of the main cations: Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}. Basically, the results are higher in the *Quercus suber* with undergrowth plot than in the clean plot but, after the statistical test we can conclude that the shrub clearance management for to exploid the *Quercus suber* cork don't produce significant differences in the soil cation content.

Key words: Land management, *Quercus suber*, cation.

Introduction

The cork of the *Quercus suber* was extraordinarily exploted until the sixties. Until that moment the forest was clear of other species as *Erica arborea* and man controlled the growth of the shrubland. With the abandoned of the cork tree this shrubland growth immediately and the *Erica arborea* and the *Arbutus unedo* reached tree heights.
Nowadays, in some Mediterranean areas are taking place a new clearance of the forest in order to benefit the species which form the typical mediterranean forest as *Quercus suber*.

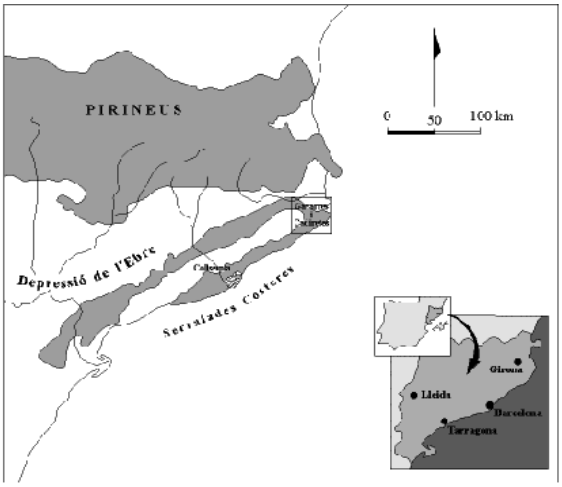
Objective

The objective of this study is to know how affect the land management in the cation content on the top soil.
To know the effect of the chemical soil fertility paramenters in two *Quercus suber* forest units, with and without shrub vegetation, in order to determine if the clearance management is beneficial for 1) the macronutrient content of the soil and 2) the development of the *Quercus suber*.

Study area

The study area is located in the Gavarres mountain, Girona province, Spain (map 1). The place selected is the Mas Bassets farm, dedicated to tradicional agriculture with crops to feed animals. Mas Bassets is 190 m.a.s.l. The lithology is granite with quaternary sediment accumulations in the depressions. Mean annual precipitation in the

area is around 718 mm, with a maximum rainfall in autumn, a season that also is characterized by storms and high rainfall intensities. The vegetation is a *Quercus suber* forest.



Map 1: Study area location

The soil can be classified as a Typic Xerochrept in the clean wood plot and as a Typic Xerorthent in the wood plot (USDA, 1988).

Methodology

Sampling:

The soil samples were taken in two plots (30x15 m each one). The first plot was cleared in 1996 and the second one has a high density of shrubs as *Arbutus unedo, Erica arborea, Erica scoparia, Smilax aspera*.

The sampling was done from the soil surface until 10 centimeters depth. Thirty random samples of each plot were collected (Khun, 1987). The chemical parameters analysed were: plant available Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} .

Analysed parameters:

- Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} using NH_4OAc, at pH 7 as extractor and valorated by AAS (Porta, 1986).
- C quantified by Elemental Analysator.
- pH 1/2.5

Data processing:

- Statistical Validation, Models Analysis of Variance: Multifactor ANOVA. It was done by Statgraphics, Statisticals Graphics System and SAS.
- Simple Statistics (average, maximum and minimum), and Correlation made by SAS.

Results

The results of the cation content (see table 1)are bigger in the woodland for Ca^{2+}, Mg^{2+} and K^{+} than in the clean woodland.

cations	MEAN ppm	MINIMUM ppm	MAXIMUM ppm	SUM ppm
Ca^{2+} (1)	2615	962	5868	78450
Mg^{2+} (1)	517	299	851	15535
Na^{+} (1)	220	67	376	6626
K^{+} (1)	336	0	854	10089
Ca^{2+} (2).	318	673	6620	65322
Mg^{2+} (2)	2177	158	804	9563
Na^{+} (2)	364	66	1314	10915
K^{+} (2)	234	28	409	7024

Table 1: simple statistics of the datas, (1) woodland, (2) clean woodland

The calcium content is more stable in the clean woodland than in the woodland, with the maximum of 6620 ppm and minimum of 673.2 ppm.
The magnesium is higher in the woodland, with maximum above 800 ppm. Generally the values are between 350 and 600 ppm in the two plots.
The values of sodium are higher in the clean woodland than in the plot of *Quercus suber* with undergrowth.
The values of potassium are also higher in the clean woodland with values reaching 854 ppm.
The Pearson's correlation results are only representative (R^2>0.5) in the case of Ca^{2+} and Mg^{2+} for each (see table 2).

	Ca^{2+} (1)	Mg^{2+} (1)	Ca^{2+} (2)	Mg^{2+} (2)
Ca^{2+} (1)	1	0.85998	-	-
	0.0	0.0001		
Mg^{2+} (1)	0.85998	1	-	-
	0.0001	0.0		
Ca^{2+} (2)	-	-	1	0.79274
			0.0	0.0001
Mg^{2+} (2)	-	-	0.79274	1
			0.0001	0.0

Table 2: Pearson Correlation coeffients and P values, (1) woodland, (2)clean woodland.

The statistical validation of the results shows that this kind of management has not significant differences (Colomer, 1997) in the soil in the soil cation content. For all parameter analysed the P value are bigger than 0.05, with values between 0.6 and 0.9.
Due the importance of pH and organic matter content in chemical soil fertility (Tisdale, S.L. et al. 1970, Porta et al. 1994) and to get some conclusions we analised these parameters. The results show that the organic matter content is higher in the woodland

(9-27%). The clean woodland has also high values (7%) for a Mediterranean soil (MOPT, 1992).
The pH in both areas is acid between 5.3 in the clean woodland and 5.9 in the woodland, where we have found a higher content in cations.

Conclusions

Shrubs clearance management in cork oak forest does not affect soil cation content.
To have a complete balance of the benefit of the clearing of the shrubland will be necessary analysis in more detail of micronutrients, quantity of nutrients in the leaves and the competence between species.

Acknowledgements

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References

Colomer, M.A. (1997): *Curs d’estadística*. Departament de Matemàtica, Universitat de Lleida. Lleida: 446

Duchaufour, P., Bonneau, M. & Souchier, B (1987): *Edafologia, Constituyentes y propiedades del suelo*. Vol. 2. Masson, Barcelona: 461.

Khuri, A.I., & Cornell, J.A. (1987): *Response Surfaces:Designs & Analyses*. New York.

MOPT (1992):*Guía para la elaboración de estudios del medio físico. contenido y metodologia*. Ministerio de Obras Públicas y Trasnportes. Madrid: 809.

Porta, J., López-Acevedo, M. & Roquero, C. (1994): *Edafologia para la agricultura y el medio ambiente*. Ediciones Mundi-Prensa, Madrid: 807.

Porta, J (1986): *Técnicas y experimentos en edafologia*. Col.legi oficial d’enginyers agronoms de Catalunya. Barcelona: 283.

Tisdale, S.L. & Nelson, W.L. (1970*): Fertilidad de los suelos y fertilizantes*. Montaner y Simon. Barcelona: 760.

USDA (1988): *Soil Taxonomy, A Basic System of Soil Classification for Making and Interpreting Soil surveys*. U.S. Department of Agriculture Soil Conservation Service. Florida: 393.

MEDCHANGE: SAMPLING DEIGN AND PHYSICAL-CHEMICAL ANALYSES IN DIFFERENT LAND USES AND LAND MANAGEMENTS

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Abstract. The aim of this paper is to introduce the european research project MEDCHANGE "Effects on land use and land management practices on land degradation under forest and grazing ecosystems". Which are its objectives and how is the work plan.
We explain how we made the experimental design depending on the objectives and the work planning. The study area is located in the Gavarres mountains in Girona province (Spain) where we have 24 experimental plots located according to lithology, land use and land management. Each plot has 10 sampling points, all the samples are going to be analyzed to determine the changes in the physical-chemical properties under different land uses and land management.

Key words: Medchange, Land use, Land management, Sampling design, Physical-Chemical analyses.

Introduction

This paper introduces the EU project: "Effects on land use and land management practices changes on land degradation under forest and grazing ecosystems" (ERB-IC18-CT97-0147), its objectives and the experimental design done by the research group GRAM as project partner.
The Medchange project is coordinated by the University of Aveiro (Portugal) and the rest of the partners are from: Universidad Politécnica de Madrid (Spain), University of Rabat (Morocco) and the University of Tunis (Tunisia).

Objectives

The objectives of the Medchange project are the following:

- To investigate the changes on land degradation, with the increasing forest and grazing activities in the Western Mediterranean region (North Africa-Morocco and Tunisia and the Iberian peninsula).
- To assess trends in land-use and land management policies, perceptions and response of socio-economic agents, occurring as a result of National/Regional soil-water conservation policies.
- To establish thresholds for sustainability and the degradation limits for the present status, and for mitigation measures.

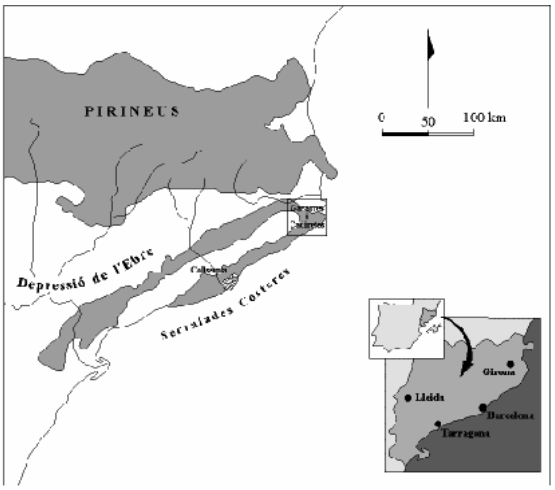
- To build scenarios for alternative land-uses/land management practices, under different socio-economic conditions.
- To develop a methodology based on GIS techniques, integrating physical, biological and socio-economic factors, in order to obtain a tool for regional planning.

Work Plan

Work Package 1: Assessment of aims and objectives of National/Regional Government policies in the study regions.
Work Package 2: Assessment of current land use and recent land use trends in the study regions, using national/regional statistics, and historical data.
Work Package 3: Perception of land users and of forestry, agricultural and local government administrators and officials about current/future forest land use and land management problems and the impacts of the national/regional policies.
Work Package 4: Intensive training course on monitoring (field and laboratory measurements).
Work Package 5: Measuring and modelling hydrological behaviour: Runoff and sediment yield at a basin and gully scales.
Work Package 6: Measuring and modelling hydrological and erosional behaviour at a plot scale.
Work Package 7:Vegetation structure and function.
In this paper we are going to talk about the experimental design included in the work packages number 2, 5 and 6.

Study area

The study area is located in The Gavarres Mountains. This massif is situated on the north-east of Catalonia, in the Catalan Coastal Ranges.



MAP 1: Location

The constituent materials of the Gavarres mountain are mainly of siliceous nature dating from the Palaeozoic.
In the half north of the massif, the slates are predominant. The slates gradually increase its metamorphic nature as they approach the granites area. This massif has the highest altitude around the 500 m a.s.l. and the climate is Mediterranean with a mean annual precipitation around the 720 mm with a maximum rainfall in autumn, a season which also is characterised by storms and high rainfall intensities.
We defined the present land uses in the Gavarres massif by photointerpretation and fieldwork. The result of this work is shown in the map 2. Finally, we selected the land uses were we located our experimental plots:

- *Quercus suber* without undergrowth
- *Quercus suber* with undergrowth
- Cropped pines
- Mixed pine forest
- Cropped eucalyptus

Sampling design

Due to the objectives, the working plan and the characteristics of the Gavarres massif we located the experimental plots depending on the lithology and the land use.
The experimental plots are organised in four areas depending on the lithology. We considered two lithologies: granites and slates. In every area we have plots in every land use and we introduced 4 plots of these land uses in urbanised zones.
The total number of experimental plots is 24.

Sampling

The sampling methodology has been always the same in all the plots under study. The plots were localised and named. In order to developed the study a grid of 35 meters long and 28 meters width was designed in every plot. Ten meters in the upper o lower part of the plot was destined to realise another kind of experiments.
There are 24 plots in total. In every plot there are 10 sampling points, and in every point we collect three samples of the top soil, one in a sample ring and two in a sample bag.
We made 4 field campaigns in order to collect samples. Therefore for every fieldwork campaign, 240 sample-rings and 480 samples in bags are produced for laboratory analysis.
To measure erosion rates, ten Gerlach traps were installed in the experimental plots of two areas, these traps are controlled once a week.

Physical-chemical analyses

To know the changes of the Physical-chemical properties in the soil under different land uses and land managements and according to the SSSA methods we are going to analyze the next parameters.

Physical parameters

Field capacity (gravimetric method)
Hydraulic conductivity
Total porosity and Effective porosity (gravimetric method)
Moisture content (gravimetric method).
Color (Munsell Soil Color Chart, wet and dry).
Texture (Coulter size analysis).

Chemical parameters

C and N (Elemental analisator).
Main cations: Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (extractor: N4HAc , valorated by AAS).
P_{total} (Olssen Bray method).

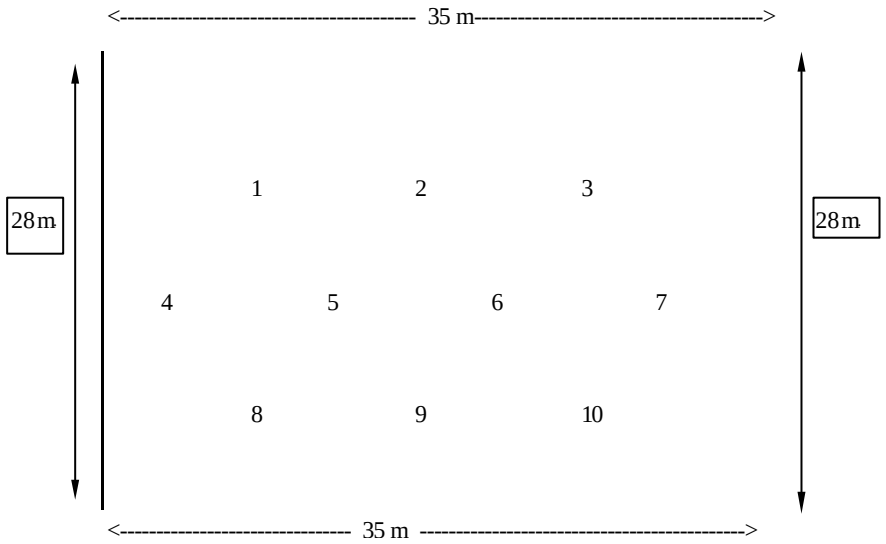


Figure 1: Sampling plot.

References

Porta, Jl, López-Acevedo, M. & Roquero, C. (1994): *Edafología para la agricultura y el medio ambiente*. Ediciones Mundi-Prensa, Madrid: 807.

Porta, J., (1986): *Técnicas y experimentos en edafología.* Col.legi oficial d'enginyers agrònoms de Catalunya. Barcelona: 283.

SSSA-ASA, (1986) *Methods in soil analysis: Part 1 Physical and Mineralogical Methods.* SSSA book series. USA

SSSA-ASA, (1984) *Methods in soil analysis: Part 3 Chemical methods.* SSSA book series. USA.

THE PERCEPTION OF DEGRADATION PROCESSES IN WESTERN MEDITERRANEAN

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Abstract. Land degradation and desertification phenomena affects vast areas of the planet, compromising the sustainability of natural ecosystems and the development of life of local communities. The policies and strategies defined to mitigate these processes have failed, as a result of: (1) the scarce participation of the populations/local agents; (2) the absence of knowledge on their perceptions and motivations. The main aim of this work is to discuss the importance of the perception studies in the definition of mitigation policies to combat desertification and to discuss some methodologies used for the definition of perception surveys to the key actors. Some preliminary results of the perception studies are analysed.

Key words: West Mediterranean, land degradation, desertification, perception studies.

Introduction

This research is being developed under a project funded by the European Commission: MEDCHANGE-Effects of land use and land management practices changes on land degradation under forest and grazing ecosystems (Contract ERBIC18-CT97-0147)[1].
The main objectives of this project are: i) to investigate the changes on land degradation, with increasing forest and grazing activities in the Western Mediterranean region (Iberian Peninsula and North Africa -Morocco and Tunisia); ii) to assess the current and likely future land-use and land management practice changes that socio-economic trends and national/regional policies may induce, in areas that are vulnerable to land degradation and desertification.
The research approach combines both societal and natural environmental dimensions. The social dimension involves the assessment of aims of the national/regional government policies and the assessment of current land-use and recent land-use trends in the study regions. The perceptions on land-use and land management problems and the impacts of the national/regional policies in the degradation processes are assessed through structured interviews and surveys, with local government administrators, officials and landowners/landusers. The natural dimension comprises the gathering of environmental data on hydrological, erosion, soil properties and vegetation characteristics for the different land-use/land management types. The data gathered in societal and natural dimensions is used for the identification of problematic areas and for the definition of

[1] The participants in this project are: Universidade de Aveiro, Portugal; Universitat de Barcelona, Spain; Universidad Politécnica de Madrid, Spain; Université Mohamed V, Morocco, Institute National de Agronomique de Tunisie,Tunisie.

strategies as well as the creation of scenarios to forecast environmental risks and socio-economic impact.
In this paper a special attention is given to the social dimension of the project, focusing on the perception studies and the methodologies used to implement it.

Socio-economic background

Within the Iberian Peninsula and Northern Africa, the Medchange project comprises nine study areas (Figure 1). These areas were selected since the combination of the changes on socio-economic, demographic and on natural conditions, are inducing serious problems in terms of land degradation and desertification. The selection of these areas allows a comparison between the two margins of the Mediterranean, both on relation to the socio-economic profiles and to land uses and land management techniques used at each site.

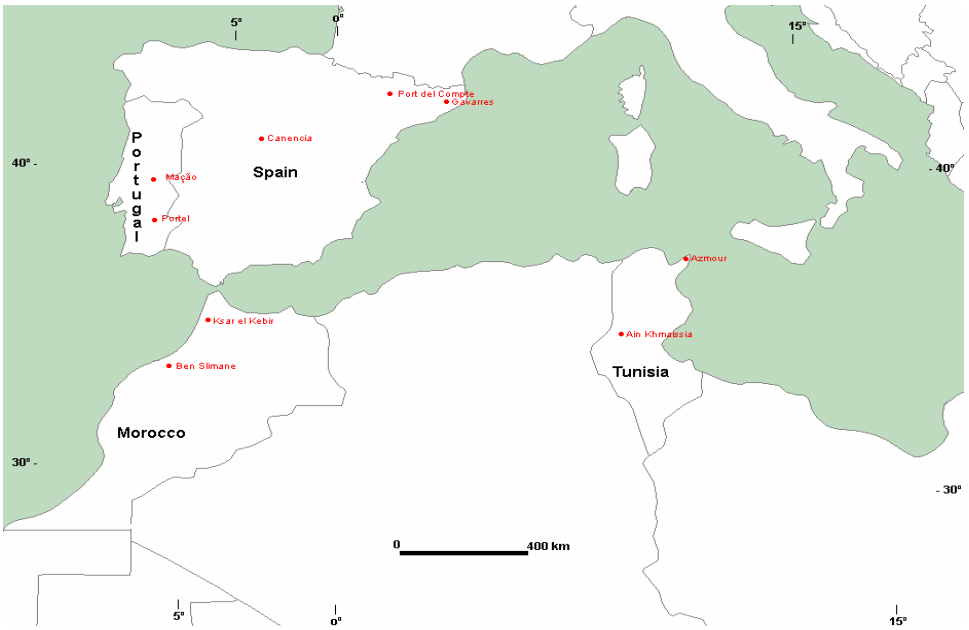


Figure 1 – Study areas location

Marginal areas of the Iberian Peninsula are suffering strong population losses towards the more developed areas, while in Northern Africa, rural population is still strongly increasing. In Iberian the depopulation process has as consequence the abandonment of agriculture, the increase of the lands under forest and the growth of understorey vegetation. This increases forest fire risk and leads to a spatial expansion of land degradation; also traditional agro-forestry systems became unregulated.
In the Moroccan and Tunisian study areas, the increasing population in the rural areas and the high human densities (173 hab/km2 in Azmour and 120 hab/km2 in Aim Khmaissia) are inducing serious land degradation, and consequently leading to socio-economic deterioration and poverty. The increase in population, making their living from

an agro-forest-grazing system, has induced strong pressures on natural resources, leading to the intensification of the agriculture and grazing and the use of non-traditional land management practices (Laouina, 1998). The original vegetation was progressively replaced by agriculture, mainly of wheat and barley and irrigated agriculture in the flat plains. In some areas of Tunisia, the communitarian lands for grazing were turned to private properties and replaced by intensive agriculture. Between 1948-1985 the matorral was completely extinguished or degraded, while the culture of cereals has strongly increased (Table I) (Hamza et *al.* 1998).

	1948		1985		Change 48-85	
Land Uses	ha	%	ha	%	ha	%
Dense Matorral	52	22	0	0	-22,03	-100
Degraded Matorral	9,68	4	8,5	4	-1,18	-12
High degraded Matorral	32,25	14	22,25	9	-10	-31
Cereals culture	135,6	57	195,5	83	+59,9	+44
Cereals culture with fences	5,65	2	0	0	-5,65	-100
Arboriculture	1,0	0	0,25	0	-0,75	-75
Irrigated agriculture	0	0	9,5	4	+9,5	+100

Table I – Evolution on land use from 1948 to 1985 in Azmour study area, Tunisia (adapted from Hamza et al. 1998).

The margins of the "oueds" in Azmour, Tunisia, did not suffer this substitution, but nowadays present a very degraded matorral. The regression of natural vegetation, specially dense *matorral* and degraded *matorral* occurred also in steep slopes and hill tops. The increasing pressure was aggravated by the replacement of traditional techniques by new non-conservative cultural techniques. Overgrazing, over-exploitation of wood and the increasing of agriculture on unsuitable lands, lead to an extreme soil erosion and a dangerous silting of the dams and reservoirs.

The importance of perception studies to mitigate desertification

The topic of degradation and desertification in Mediterranean environments has become the focus of a major concerted research effort. Nevertheless, the focus has been on the role of climate and subsequently on the role of the natural environment (i.e. soils and vegetation), while the role of man has not been researched with the same intensity (Van der Leeuw, 1995). Socio-economic studies on desertification have focused on two thematic groups: i) the assessment of the impact of human activities on the natural resources; ii) the definition and application of new technologies to resource management. However the lack of empowerment of local agents in the formulation and implementation of mitigation policies, the reduced use of "bottom-up" approaches and the absence of research on the perceptions of the phenomena are the more relevant gaps when studying environmental degradation (Pérez, 1996; Louro, 1998; Mourão, 1998; Van der Leeuw, 1998).

Most of the political and governmental actions to combat desertification failed, due to the low involvement of local agents and the lack of crossing all the socio-economic and environment sectors. The United Nations Convention to Combat Desertification specified

the need to define environmental and socio-economic policies to combat and mitigate desertification, giving a special emphasis to the involvement of all the participants in policy definition and implementation (UNEP, 1992; Louro, 1998; Mourão, 1998).

The definition and implementation of planning strategies interfere in the social, economical, political and environmental domain. Nevertheless, most of these strategies are not socially adapted, politically acceptable or perceived by the local communities as the most efficient. To promote local communities involvement is fundamental to understand their motivations and knowledge of the phenomena, since the perceptions, the concepts and the terms used by the technicians are not always coincident with the ones perceived by the local agents, the politicians or the mass media. This endangers the mitigation of the phenomena (Scoones and Thompson, 1993; Roxo & Mourão, 1998). Marginal rural areas are managed by farmers and absent land owners, who are not generally aware and informed about the consequences of their agricultural and forestry practices in terms of land degradation and desertification (Mourão, 1998). On the other hand, land users knowledge and understanding of physical and socioeconomic processes of land degradation is often dismissed by the technicians (Pérez, 1996). The integration of scientific and local people's knowledge, and consequently different criteria and methods of information and assessment is of utmost importance, when solutions based on local people's perceptions and understanding are required.

According to Van der Leeuw (1998) the dynamics involved in environmental change "... are at least in part due to choices made by people and therefore ultimately to people's perceptions of the environment. One of the most blatant lacunae in the research on environmental degradation is the absence of investigations of the human perception of the environment at different times, in different cultures and under different circumstances". This knowledge is needed to understand how a community perceive the potential risks, risk assessment and consequences of their land management practices. Risk knowledge is a pre condition for the acceptance of mitigation strategies (Carvalho & Coelho, 1998). Risk assessment can not be dissociated from people's values and attitudes, since most of the decisions are taken based on the personal perception rather than technicians risk assessment (Smith, 1992).

The implementation of rural development objectives must be made with cooperation with the people affected, unless the programme is condemned to failure. A very important way to assure this cooperation is to understand how the rural people perceives the problems of land degradation and desertification, and which are the solutions proposed (Laouina, 1998).

The perception studies may fulfil an important role in the public participation process, in terms of plan elaboration or other studies, integrating citizen opinions with the objective to minimise disagreement that emerge from the disparity between technocratic processes and public opinion (Pérez, 1996). The experience deriving from the land use planning process, which is intended to be participated by local populations, has demonstrated the importance of the public knowledge and their comprehension of the environmental values and characteristics. It is intended that people assume simultaneously the role of participants and receivers of the planned or voluntary actions that occurs into the landscape. Because environment is perceived and constructed according to points of view that reflect the viewer's cultural values, it is important to ascertain the views of the public, specially of the various social groups involved.

Perception survey: theoretical framework

Explanation of land degradation and desertification often emphasises land mismanagement, with the blame placed solely on land users irrationality, ignorance, conservatism, etc. No attempt is made to understand the reasons for these apparent attitudes and actions. Field visits by technicians are mainly to ascertain the natural environment rather than for participatory approaches (Pérez, 1996). Understanding land users practices, knowledge and their socio-economic circumstances and aspirations, can improve the success of mitigation policies, through the integration of their participation in planning process. Therefore, desertification studies besides biophysics and socio-economic characterisation should also include public preference models. These studies can provide an overview of the impacts of anthropic actions, as well as the careful examination of the relationship between the public and the environment.

Some of the most effective methods used in data collection for the explanation of desertification phenomena and the promotion of the communities involvement are the Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA). While RRA method extract information from respondents, PRA facilitate their involvement in the collection and analysis of the data, often with the purpose of facilitate their empowerment (Pérez, 1996). The origins of these methods are identified by Chambers (1994) as lying with three main groups of problems: dissatisfaction with the biases; disillusion with the normal process of questionnaire surveys and their results; and the need for more cost effective methods of learning.

RRA is often used in the initial stages of data gathering as a means of information extraction. It has limitations for the promotion of participation because respondents are excluded from the analysis of their data. PRA emerges from the deficiencies of RRA, the needs for refinement and the involvement of respondents, not only in providing the information, but also as actors in the research, as a result of researcher/respondent interaction. The usage of PRA methods by land users is a valuable form of data gathering if made to encourage a participatory and constructive response in planning. Two strong factors in this response are firstly, that their explanations or aspirations are taken seriously into account by planners from the very start in the data gathering process and secondly the possibility of being confronted with the analysis of their perceptions (Pérez, 1996).

One of the innovations of these methods is the promotion of a change from "top-down" to "bottom-up" approaches. RRA and PRA methods are highly applicable as innovative forms of data gathering for explanation of affected people in the planning process. They allow researchers not only to collect data, but also to learn with the local people's knowledge, providing valuable information for decision making (Pérez, 1996).

The application of a perception survey in Medchange study areas

Structured interviews and surveys, comprising both physical and socio-economic criteria are being done to landowners/landusers, local government administrators and officials, in order to define their socio-economic profiles and assess their perceptions towards the:

1. causes and effects of land degradation and desertification;

2. evolution of current land-use and recent land-use trends;
3. land management practices changes in agro-silvo-pastoral systems;
4. definition of measures to combat and mitigate degradation and desertification processes.

The promotion of empowerment of local agents, in all the stages of the work, was one of the most important goals of the survey. Besides gathering information, the survey constituted the first form of public participation, since respondents were integrated on the collection and discussion of data. In Morocco, to increase awareness towards runoff and soil loss risk some measurements were made, with the presence of the land users/land owners, regarding the soil's water reserve, soil's productivity, and soil characteristics. A long discussion on what local people's consider as effective processes of land degradation, causes of the degradation and effects or consequences of that causes were made. Afterwards, some practices for soil and water conservation and soil fertility improvement were discussed with the respondents.

In Morocco, the survey to landusers/landowners (LU/LO) developed by Laouina et *al.* (1998) has already finished.

1. LU/LO knowledge can give important information about the environment.

LU/LO have a good knowledge of soil characteristics. For example they know that clay soils are not suitable for olive trees plantation, while the grafting of olives on oleaster is successful and gives strong and productive trees.

2. LU/LO are conscious of the most visible land degradation problems.

The formation of gullies and soil erosion represents major problems for land production, since the effect of rills on the annual yield can be measured in term of surface lost. From one field to the other, the comparison is clear in relation with the spatial differentiation of the processes. The effect of soil loss and seeds washing downstream is clearly identified by LU/LO, as a result of their daily observations. The creation of rills and flood risk, due to intense rain is also well perceived by the respondents.

3. LU/LO don't realise that their self-sufficient and food security is menaced.

LU/LO do not perceive with the same accuracy the effects of land degradation that are not immediate, underestimating the seriousness of the problem in relation to their survival. The danger of pasture mismanagement and overgrazing is not well perceived. In order to feed an increasing population, carrying capacity for grazing was exceeded. The reduction of displacement of flocks and concentration of flocks in fields without rotation, lead to soil compaction and vegetation retreat.

4. Changes on land use and land management practices and their negative effects are well perceived by LU/LO, but many constraints prevent the adoption of positive behaviour.

LU/LO do not consider themselves as the main actors in land degradation processes. They are aware that demographic increase leads to more use of forest resources and more extension of cultivation, but they argue that land property system and the laws adopted are the main reasons of land degradation.

Property division due to heritage, favours the constitution of narrow fields along the slope. This leads to fields being ploughd accordingly to the slope and exaggerates the

effect of runoff and rill wash. LU/LO confirm that this plots distribution has a great effect on erosion and runoff, but they can't change it.
LU/LO knows that the vegetation cover is very degraded and natural vegetation is the best way to protect weak soils. But population does not have the capacity to take measures to prevent degradation, given that would represent a strong reduction of their income, since their social and economic level is very low. The need for fodder and fire wood leads to greater cutting. Reforestation is perceived first as a state appropriation of the land and then a reduction of the possibilities of breeding.

5. Population's and state's strategy is not coincident.
While the state is concerned with the promotion of some soil and water conservation measures, LLU/LO, especially in the plains are more concerned with profits and increasing the productions, avoiding any conservation measures.
For example, in relation to water strategy there is a wide gap between the two positions. While population wish to increase local water utilisation, the state wish to protect the mountain as a reservoir, in order to guarantee water downstream.

6. Some protection measures have failed due to the lack of population engagement.
In the future, population need to be committed in the mitigation of erosion. The actions that were taken without the support of the population have been failed.
The results shown here refer to Morocco study areas. In Tunisia the survey is being implemented. In Portugal, a pilot survey was carried out to a set of potential institutional key-actors: (i) institutions related to territorial planning and management; (ii) technical and administrative services of the ministry of agriculture; (iii) representatives of socio-economical groups; (iv) development associations; (v) political representatives; (vi) tourism organisations. This survey aimed to assess their profiles and inter-connections. The survey to land users/land owners is starting to be implemented.

Conclusions

The results of the survey developed by the Moroccan team show that the most visible effects of land degradation (formation of gullies and rills and soil wash), generally associated to extreme rainfall events, are well perceived by the respondents. While the effects of land degradation that are not immediate are not perceived with the same accuracy. These effects generally result from incorrect land management practices, such as overgrazing, overexploitation of timber or intensive agriculture. However, land users/land owners do not perceived themselves as principal actors in land degradation or that their survival is menaced. On the other hand, this survey also shows that the involvement of respondents in data gathering and analysis and the integration of their points of view is determinate to increase their knowledge as well as for their participation and acceptance of the solutions proposed.
A discussion on LU/LO perception is important, in order to correct their wrong ideas and adopt their good proposals. This strategy promotes mutual trust, by determining what the peasants consider positive and easily adoptable. The integration of their points of view is determinate for participation and acceptance of the actions proposed, since

they realise that the proposed solutions are based partly on a knowledge in which they have participated.

Most of the strategies defined to mitigate these processes have failed due to: (i) lack of populations/local agents empowerment; (ii) lack of interconnection between land users knowledge and scientific knowledge; (iii) reduced use of "bottom-up" approaches. As a way to promote public participation/public commitment and the success of mitigation policies it is fundamental to:

1. understand land users perceptions and knowledge of the phenomena;
2. promote local communities involvement in policy definition and implementation;
3. integrate local people's knowledge in mitigation strategies.

Acknowledgements

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References

Burke, S. & Thornes, J. (1998). *Actions taken by national governmental and non-governmental organisations to mitigate desertification in the Mediterranean*. European Commission EUR 18490 EN. Brussels, pp. 349

Carvalho, T.M.M. & Coelho, C.O.A. (1998). Coastal risk perception: a case study in Aveiro district, Portugal. *Journal of Hazardous Materials*, 61, p.263-270.

Chambers, R., 1994. The origins and practice of Participatory Rural Appraisal. *World Development*, 22 (7), p. 953-969.

Clark, N. & Perez-Trejo, F. (1995). The interaction between research and policy in the management of desertification. In *Desertification in an European context*. European Commission, EUR 15415 EN. Brussels, p. 341-355.

Coelho, C., Sala, M., del Tanágo, M., Laouina, A., Hamza, A. (1998). *Effects of land use and land management practices changes on land degradation under forest and grazing ecosystems*. European Commission - INCO DC First Year Report. ERBIC18-CT97-0147.

Conacher, A. and Sala, M. (1998). *Land degradation in mediterranean environments of the world: nature and extent, causes and solutions.*, John Wiley and Sons, England.

Direcção Geral das Florestas & Ministério Agricultura Desenvolvimento Rural e Pescas. (1997). Convenção das Nações Unidas de Combate à Desertificação: Programa de Acção Nacional.

Fresco, L. et al. (1994). *The future of the land: mobilising and integrating knowledge for land use options*. John Willey and Sons, England.

Garcia-Perez, J., 1996. Socioeconomic processes of land degradation in Gualajara province (Spain). Unpublished *PhD thesis*. University of Plymouth. UK. pp.335.

Hamza, A. (1998). *Effects of land use and land management practices changes on land degradation under forest and grazing ecosystems*. European Commission - INCO DC First Year Progress Report. ERBIC18-CT97-0147.

Laouina, A. (1988). The participation of the rural population, condition for the success of interventions in mountains. The case of the rif and prerif slopes, Morocco. In Proceedings of the *International Seminar on Land Degradation and Desertification*, 24th-30th August, Évora.

Louro, V. (1998). O Programa de Acção Nacional de Combate à Desertificação. In *Revista Florestal*, vol.XI, nº1. p. 9-12.

Mourão, J.M. (1998). Governmental action to combat desertification in Portugal. In *Actions taken by national governmental and non-governmental organisations to mitigate desertification in the Mediterranean*. European Commission. EUR 18490 EN. Brussels. P. 177-205

Roxo, M.J., Mourão, J.M. (1998). Desertificação: a percepção pública do fenómeno. In *Revista Florestal*, vol.XI, nº1, p.30-34.

Sequeira, E. (1998). Desertificação, Conservação da Natureza e ONG's. In *Revista Florestal*, vol.XI, nº1. p.22-26.

Smith, K. (1992). *Environmental hazards: assessing risk and reducing disaster*. Routledge, London. pp.324.

Van der Leeuw, S.E. (1995). Social and natural aspects of degradation. In *Desertification in an European context*. European Commission, EUR 15415 EN. Brussels. P. 57-76.

Van der Leeuw, S.E. (1998). *The Archaeomedes project: understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean basin*. European Commission, EUR 18181 EN. Brussels.

UNEP (1992). *United Nations Convention to Combat Desertification*.

PORTUGUESE NATIONAL ACTION PROGRAMME TO COMBAT DESERTIFICATION

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Abstract. Desertification and drought are two of the most serious problems, affecting 1/6 of the world population and compromising a surface equal to 3,6 millions of hectares, i.e., almost 30% of the terrestrial areas of the planet. Desertification has strong implications in both natural ecosystems and human communities. The main aim of this paper is to present the National Action Programme to Combat Desertification in Portugal and to discuss some of the strategic measures proposed.

Key words: Desertification, National Action Programme, Portugal.

Framework

Since Nairobi's Conference in 1972, that UN is delivering some efforts to combat desertification. In 1987 was established an Action Plan to combat desertification, but without success, since soil degradation and desertification was still expanded. One of the major causes was the lack of local population involvement.
Along with the period of drought of 1991 and especially after the UNCED, Rio de Janeiro 1992, desertification became an increasing important subject at both political and scientific levels. This conference concluded on the importance of the constitution of a Convention to Combat Desertification (CCD). The formal negotiation involving expertise's and politicians has occurred between May 1993 and June 1994. The final text of the Convention, approved in Paris on the 17th June 1994 by 103 countries, including Portugal, considers desertification as a global and complex problem, that concerns the international community, and results from complex interactions between natural environment and anthropic actions. Portugal was one of the first countries to subscribe the convention in October 1994. Ratification of this same Convention occurred on the 1st April 1996.
Two of the most important reasons for the establishment of this convention were: i) the creation of a international legal tool (binding for all the signatory countries) to combat desertification in countries affected by serious drought and/or desertification; and ii) the promotion of local empowerment as a way to assure local populations involvement in the mitigation of desertification. The first step of CCD was the elaboration of the Convention principles and the definition of four regional annexes: Africa; Asia; Latin America and Caribbean; and Northern Mediterranean, where Portugal is included.
The objectives of the Convention to Combat Desertification are:
1. the commitment of all affected countries to pursue their obligations under the framework of the convention;
2. to prepare and implement national, regional and sub-regional actions programmes in the countries included in the annexes;

3. to adopt "bottom-up" approaches to stimulate public empowerment;
4. international co-operation and joint actions at the scientific, social and political levels, namely with Agenda 2000, Climate Change Convention and Biologic Diversity Convention.

The convention stresses the role played by national governments and non-governmental organisations in combating desertification, through the implementation of National Action Programmes, as well as, through scientific and technical co-operation and by means of consistent support measures and public awareness of the desertification problem.

Portugal has participated in all the meetings and negotiation sessions to prepare the Convention, including the Annex IV of the Regional Implementation for the North Mediterranean, which was forstered by Portugal and Spain, and it is thought to be of crucial importance to all southern Iberian regions. Portugal, as a State Party of the Convention and affected by desertification processes, has as main duties:

1. to adopt CCD policies to combat the desertification problem and minimise the effects of long drought periods, through the preparation, elaboration and implementation of the National Action Programme to Combat Desertification (NAP);
2. to articulate the NAP with the other countries of the Regional Annex for the North Mediterranean such as Spain, Italy and Greece;
3. to establish bilateral and multilateral co-operation with the south margin of the Mediterranean (MAGREB) and African countries with official Portuguese language, such as Angola, Mozambique and Cape Verde (PALOP).

According to articles 4º and 5º of the Annex IV of CCD, in the elaboration and implementation of the NAP, Portugal should also:

1. define the entities responsible for NAP elaboration, coordination and implementation;
2. involve local authorities and NGO's in all the phases of NAP;
3. assess the causes and effects of desertification processes;
4. define a strategy to combat desertification in collaboration with the affected communities;
5. prepare technical and financial programmes;
6. assess and follow up the development of the NAP.

Physical and social constrains

Northern Mediterranean systems have specific, socio-economic and natural characteristics that make ecosystems highly vulnerable to human impact and to natural processes, which may induce environmental problems, such as land degradation and desertification. Mediterranean rural communities have also social and economic problems, due to the low income of agricultural activities, and depopulation processes, which can also influence desertification process. In Portugal the Southeast region of Alentejo, the Algarve, the inland regions of Central east (Beira Alta and Beira Baixa) and Northeast (Trás os Montes) are the most affected areas by desertification. In those regions the basic natural resources, such as soil, water and vegetation became scarce and degraded, due to human impact and to high climatic variability. The worst affected areas are where intensive conventional agricultural practices, overgrazing, deforestation, together with specific geological and climatic conditions appear at one place. These circumstances favour land degradation, soil erosion, pollution and fertility loss, hydric

stress for vegetation, lowering of underground water tables and forest fires among others (Mourão, 1998).
Portugal, being in the transition between the Mediterranean and the Atlantic climate types, presents severe constraints in terms of water availability. Rainfall varies sharply, both in amount, intensity and yearly distribution. The wettest years present more than three times the amount that falls during dry years. In addition, there is a gradient of rainfall distribution, with more rainfall in the Northwest part of the country (average annual rainfall is 2500mm), which then decreases to the south and to the interior. In the Southeast region evapotranspiration is frequently far above average rainfall values, which vary roughly between 200 and 300 mm in dry years, and between 500 and 600 mm in normal climatic years. Droughts or heavy rainstorms are frequent. Summer high temperature are also frequent in the more continental areas of Portugal, and when combined with low moisture content, can increase forest fire risk.
In the mountain areas at north of the Tejo River and in the drier areas of the south, soils are thin, stony and with low fertility. These soil characteristics result from natural conditions and the introduction of new agricultural and forestry management practices as well as overgrazing. A high amount of the soils are threatened by erosion: 30% of the soils have high erosion risk, 54% moderate risk, and 15% low erosion risk. Future perspectives anticipate that 68% of the soils will have high potential erosion risk, 25% moderate potential risk and only 6% low potential risk (Corine, 1992).
In the 60's and 70's Portugal suffered internal migration and emigration towards Europe, with serious consequences on the spatial distribution of the population. While rural became depopulated (in some areas human density is less than 10 hab/km^2) and characterised by elderly populations, the littoral urban areas became overpopulated. This spatial distribution has created strong contrast between littoral and interior regions, compromising the sustainability of natural ecosystems and the economical development of the more rural areas, emphasising even more the depopulation process.

Effects of anthropic action in land degradation in Portugal

Land degradation processes are the result of natural phenomena and human activities. Some of these human activities, which may act separately or combined, are inducers of desertification processes.

1. Agriculture
Intensive agriculture in poor soils among with inappropriate agricultural practices, such as deep ploughing or ploughing in sloppy soils, lead to extensive soil degradation. Contemporary innapropriate agricultural policies, are inducing serious environmental problems related to desertification and biodiversity lost, due to conventional agricultural and forestry practices.

2. Cattle Breeding
Extensive grazing is an important economic activity in rural areas. Due to soil compaction and land cover destruction, this activity can increase land degradation and desertification. The absence of carrying capacity control induces overgrazing, with serious consequences on the degradation of the vegetation, especially in dry years.

3. Silviculture
Deforestation and some forest management techniques, such as clear cutting or intensive ploughing, can also promote land degradation especially in steep slope areas, since a large amount of soil is washed or exposed to erosive agents.

4. Forest Fires
The extensive and continuos burning in areas affected, sometimes more than once in a year, contribute enormously to increase land degradation and desertification, since they are the main responsible for land cover destruction. The problem assumes an intolerable magnitude every year, with thousands of hectares of forestry and *'mato'* burned, with drastic consequences in terms of soil erosion rates and biodiversity losses. Summer 1991 was one of the worse times ever recorded: 182 486ha of forest and woodlands burned (Mourão, 1998).

5. Tourism
The development of tourism and the consequent pressure over natural resources are inducing significant land use changes, aggravated by overuse of aquifer reserves.

6. Socio-economic degradation
The strong population losses that affected Portuguese rural areas after the 50's have as consequence the abandonment of agriculture, the increase of the lands under forest, due to the good natural regeneration of some species, such as *Pinus*, and the growth of understorey vegetation, augmenting thereby forest fire risk and leading to an increasing land degradation. Traditional systems became unregulated, since man is an important factor on the regulation of the ecosystem.

Methodology to define areas susceptible to desertification

The combination of the different factors that may induce soil degradation (climatic conditions, soil characteristics, land cover and slope) is an indicator for the definition of the susceptibly of an area to desertification. The methodology used for the characterisation of desertification in Portugal includes three main indexes: climatic, soil loss and drought.

1. Climatic index: is defined by the relation between average annual precipitation and potential average annual evapotranspiration (P/EVT), calculated by Penman method, as is defined by the United Nations Environment Program (UNEP).
To determine the climatic index 87 climatological stations were analysed. According to Penman Method three climatic zones are defined to Portugal (Table I).

P/EVP	Climatic Zones	Climatic Index
> 0,65	Humid	1
0,5 - 0,65	Dry sub-humid	2
< 0,5	Arid and semi-arid	3

Table 1 - Climatic index

2. Soil loss index: combines four determinant elements in the erosive process: erosivity of rainfall, land cover, type of soil and slope.
Each of these elements are divided in classes according to their susceptibility to soil loss (Table II).

Values of Soil loss	Soil loss index
1-4	Low
4-17	Moderate
17-72	High

Table 2 - Soil loss index

3. Drought index: introduces drought element from the number of years in which the value of precipitation is lower than the value represented by the quantil 0,01 of the log-normal distribution.
The spatial distribution of drought is made according to Thiessen method. The time scale of the analysis was between 1934/44 and 1994/95 and has comprised the analysis of rainfall measurements in 321 stations.
The combination of the three indexes results in the definition of the susceptibility desertification index. Through GIS is possible to map areas with different levels of desertification susceptibility. This methodology resulted on the spatial distribution of the phenomena in Portugal. The most susceptible areas to desertification are located in Alentejo and in some areas of northern Portugal in almost 11% of the continental surface. However, 60% of the national surface is included in moderate risk of desertification.

The National Action Programme in Portugal

From February 1993 to June 1995, a national work group involving different governmental departments, followed and participated in all the negotiation meetings to prepare the Convention and establish the Annex IV - Regional Implementation for Northern Mediterranean. This same group ensured the national participation in all the post approval meetings.
In order to assure the complete implementation of the Convention and the participation of Portugal both in Annex IV-Regional Implementation for Northern Mediterranean, and in multilateral co-operation with affected African countries, two workgroups were established:

1. An external workgroup co-ordinated by the Ministry of Foreign Affairs, including representatives from other governmental departments.
2. An internal workgroup, co-ordinated by the Ministry of Agriculture, Rural Development and Fishery (General Directorate of Forestry), in charge of the scientific and technical aspects of the Convention implementation.

Until the Eight Meeting of the Intergovernmental Negotiating Committee, Geneva, February 1996, the Ministry of Foreign Affairs (MNE) has demonstrated little interest in the subject. It should be mentioned that no representatives from MNE were in this

meeting and Portugal was represented by a single person, from the General Directorate of Forestry (DGF) (Mourão, 1998). Between 1996-1997 a draft document of the National Action Programme was elaborate by the internal workgroup, co-ordinated by DGF, (national Focal Point) and in co-operation with representatives from the scientific and political institutions. This first plan proposal review was based on discussion with scientific community, concerning the deep knowledge of the physical and human causes of land degradation and desertification and the effective measures, policies and mitigation schemes to reverse the problem.

The draft document of NAP was presented on the January 1998 and it was the starting point for a national debate among research institutions, NGO's and local communities, following a methodology based on two basic principles: 1) to organise public participation in order to obtain results agreeing with CCD objectives; and 2) focus public discussion in thematics directly related with desertification and drought. The first principle aimed the gathering of different types of knowledge's on the phenomena from the different local/regional organisations and to generate public awareness of soil erosion, climate change and socio-economic dimension of the problem. While the second one performed a main role in the elaboration and dissemination of a synthesis document about the causes and effects of desertification in Portugal. It also provided some essential information on the aims and concepts of CCD, as well as the most important processes, which may induce desertification phenomena. A total of 2200 people from scientific communities and expertise's, economical agents, local populations and farmers, were involved in this process. A truly recognition of the desertification and drought phenomena, as well as, the need of their mitigation was achieved.

These actions resulted in the production : 1) by the National and Regional Focal Points among with research institutions, NGO's and affected municipalities, of a large data base which includes nearly all projects, actions, initiatives developed by universities, public governmental departments and NGO, concerning scientific research and measures to combat desertification; and 2) a working document with the main reflections, proposals and recommendations for the elaboration of the final version of NAP. Pretending to reflect public participation in all the levels of knowledge, this working proposal of the NAP[1] only includes suggestions derived directly from that process.

The proposal for the National Action Programme defines as strategic objectives**:**

1. Settlement of the population in marginal rural areas;
2. Soil and water conservation;
3. Recovery of degraded areas;
4. Consciousness of the population for desertification phenomena,

Strategic measures to combat desertification

The proposal of the National Action Programme defines some strategic measures to combat and mitigate desertification. These suggestions include the priority guidelines to develop, the entities responsible for the execution and the expected results. In general they do not reflect new initiatives to mitigate the phenomena, but they attempt to

[1] This proposal will be discussed in the Ministry Council in 10th June 1999 and presented to the community on the 17th June 1999, the international day of Desertification.

improve the existent governmental and non-governmental projects and programmes, which are already in progress to combat land degradation and desertification. Besides the definition of the strategic measures, at this moment there is a proposal to create a National Co-ordination Commission to Combat Desertification, CONDENSER. This Commission comprises all the entities which integrate the internal workgroup and representatives of NGO's and the municipalities, and seeks to dynamize and follow up the several entities responsible for the application of NAP, as well as, to assess the results achieved. The constitution of commissions with the same aims as CONDENSER will be recommended at regional level.

Trying to achieve the execution of the strategic objectives (population settlement in rural areas; soil and water conservation; recovery of degraded areas; population consciousness), the Strategic Measures to combat desertification are divided in four main groups: rural development, soil and water conservation, research, information and sensitisation and co-ordination. In this paper some of the more relevant measures are presented.

1. Rural Development

This strategic measure aims to reduce the strong regional asymmetries, trough the settlement of the population in marginal rural areas and the improvement of their quality of life in accordance with sustainable parameters, as well to decrease human pressure in the territory. Within this measure a special attention is given to territorial and spatial planning, through the revision of master plans and other tools of physical planning and the inclusion of desertification issues on national/regional plans and programmes, in order to combat/mitigate desertification as well as to reduce depopulation process. Some of these measures are: i) to define criteria for urban occupation, in order to avoid edification in sloppy and infiltration areas; ii) to protect soils suitable for agriculture; iii) to protect natural ecosystems; iii) to elaborate sustainable local developments plans; iv) to improve accessibility in isolated rural areas; v) to reinforce infrastructure, social equipment and sub-regional teaching poles; vi) to support rural investments

2. Soil and Water Conservation

This measure is divided in three sub-measures: agriculture, forestry and water.

Regarding agriculture, the actions which are defined emphasise the maintenance, improvement and recovery of traditionally agro-systems, such as *montado*, as well as, dissemination of a code of good agriculture and grazing practices and rural extension, in order to increase public awareness to land degradation processes. The actions for forestry are also devoted to the dissemination of a code for good forest management practices, in order to reinforce forest role in soil and water conservation. Is also emphasised the need to combat forest fires through the increase of native species and application of fire prevention techniques, as well as by developing forest multi-uses and silvo-pastoral systems. Water strategy is also based in the elaboration of a code good practices for the protection of surface and ground waters; the elaboration of emergency plans in drought situations and the integration of water resources management.

For all the three components it is recommended that criteria to combat/mitigate desertification should be included in Regional Agriculture Plans, Forest Management Plans and Watercatchment Basin Plans.

3. Research, Information and Dissemination
A special attention is given to the: i) identification of affected areas and prioritisation of means for their recovery; ii) integrated research on the causes and application of mitigation measures to combat desertification processes; iii) creation of demonstration centres, where techniques for soil and water conservation are shown; iv) creation of pilot projects for the protection and valuation of *montados*; v) improvement of soil maps and their harmonisation with national/european soil maps.
Two other main tasks are: continuous information and sensitisation of decision makers and populations and the dissemination of the National Action Programme in the whole community.

4. Coordination of the National Action Programme
The development of indexes for assessment and application of the NAP and the revision of the NAP.

Conclusions

A list of 220 on going national and European funded projects, directly or indirectly related, with this thematic is included in the annexes of the NAP working paper. These projects are co-ordinated mostly by universities or governmental institutions, and are mainly related with six issues: soils, water resources, forest fires, environmental management, land use change and crops, rainfed agriculture and silviculture. In spite of research original thematic, these projects are based on pluri-sectoral strategies, rather than on integrative ones. On the other hand, human dimension of desertification and the role human perception has not been researched with the same accuracy as natural phenomena.
Understanding land users practices, knowledge and their socio-economic circumstances and aspirations, can improve the success of mitigation policies, through the integration of their participation in planning process (Pérez, 1996).
Therefore, besides the tasks performed by CONDENSER it would be also important that this a institution would be able to provide:

1. Research on the thematic of desertification, integrating the complexity between natural and human dimension;
2. Training and capacity building;
3. Local communities involvement in policy definition and implementation, by the integration of local people's knowledge in mitigation strategies;
4. Integration of scientific knowledge and decision maker knowledge in mitigation policies;
5. Concerted actions between governmental and non-governmental entities;
6. Monitorization of the results achieved and developing long term integrated strategies, as well as, the promoting of sustainable development;
7. Integration of sectorial policies, in order to combat and mitigate the effects of land degradation and desertification.

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References

Burke, S. & Thornes, J. (1998). *Actions taken by national governmental and non-governmental organisations to mitigate desertification in the Mediterranean*. European Commission EUR 18490 EN. Brussels. 349 p.

Conacher, A. and Sala, M. (1998). *Land degradation in mediterranean environments of the world: nature and extent, causes and solutions.*, John Wiley and Sons, England.

Corine (1992). Soil erosion risk and important land resources in the southern regions of European Community. Commission of the European Communities. 97p.

Direcção Geral das Florestas & Ministério Agricultura Desenvolvimento Rural e Pescas. (1997). Convenção das Nações Unidas de Combate à Desertificação: Programa de Acção Nacional.

Garcia-Perez, J., 1996. Socioeconomic processes of land degradation in Gualajara province (Spain). Unpublished *PhD thesis*. University of Plymouth. UK. 335 p.

Louro, V. (1998). O Programa de Acção Nacional de Combate à Desertificação. In *Revista Florestal*, vol.XI, nº1. p. 9-12.

Mourão, J.M. (1998). Governmental action to combat desertification in Portugal. In *Actions taken by national governmental and non-governmental organisations to mitigate desertification in the Mediterranean*. European Commission. EUR 18490 EN. Brussels. p. 177-205

Roxo, M.J., Mourão, J.M. (1998). Desertificação: a percepção pública do fenómeno. In *Revista Florestal*, vol.XI, nº1, p.30-34.

Van der Leeuw, S.E. (1998). *The Archaeomedes project: understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean basin*. European Commission, EUR 18181 EN. Brussels.

UNEP (1992). *United Nations Convention to Combat Desertification*.

GEOMORPHOLOGICAL HAZARD MAPPING IN THE WADI MUJIB CANYON (JORDAN) BASED ON RUSSIAN STEREOSCOPIC TK-350 SATELLITE IMAGES.

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Abstract. The spectacular Wadi Mujib canyon is draining on the Jordanian plateau from the east to the west into the Dead Sea and is characterized by high dynamical slope processes. As the government in Jordan has planned the construction of a dam through the wadi to gain fresh water for irrigation and to fill up the groundwater (Loy, 1994), estimated higher landslide occurrence will endanger the future dam and reservoir and at the other hand, the reservoir will strongly enhance the instability of the adjacent slopes. To estimate possible future geomorphological hazards it was aimed to set up a slope (in)stability model based on various environmental triggering factors. Relief inventory demands several information sources. Topographical and lithological maps were available, so that a DEM and a digital lithological map could easily be prepared and put into a GIS (Geographical Information System). To collect information of the relief forms *in se* a geomorphographical map has been made using the information given by high resolution and stereoscopic Russian TK-350 images. These images seem very competitive in comparison with stereoscopic aerial photographs on 1 :50,000 (or smaller) due to their high quality, their easy image processing, the large covered area and the high degree of availability.

Key words: slope degradation, triggering factors, remote sensing, risk modelling

Environmental settings

The geology of the Dead Sea Rift Valley has been the subject of much debate and many theories have been published over the past decades in order to explain the Cenozoic structural development in the area. The Jordan-Dead Sea Rift divides the eastern Jordanian block and the western Palestine block and forms the deepest continental valley (presently at -408 m below sea level) in the world. She is part of the great Syrian-Red Sea-African Rift which has an overall length of about 6000 kms (Bender, 1968; Bender, 1975; Burdon, 1959; Neev et Emery, 1995). The development of the Dead Sea graben caused by the sinistral strike-slip fault movement started since Miocene times, and it is clear that the Rift is still active and that subsidence has not finished yet. The spectacular Wadi Mujib canyon has a mean depth of 600 m and is one of the valleys developed during Quaternary times along the Rift. It is draining from the east on the Jordanian plateau to the west into the Dead Sea. Important archaeological excavations have been executed by the 'Belgian Committee for Excavations in Jordan' at the site of Lehun situated on the Jordanian plateau close to the northern rim of the Wadi Mujib canyon, at an altitude of ±700 m above sea level (figure 1). The dislevelment of ±1,100

m over a distance of only some tens of kilometers produces a strong relief energy and results in a very dynamic landscape with extreme contrasts, illustrated in figure 1 by the shadow map derived from the DEM.
Late Tertiary to Early Pleistocene local basalt coverage on the western part of the plateau and clearly visible at the upper canyon rim proves the very young development of the canyon system, since the canyon walls are free of basalt coverage. The high tectonic activity of the last million years has created a network of faults, fractures and flexures causing slope instability on the canyon walls. However, slope instability is not exclusively the result of tectonism as the lithological, topographical and climatic conditions even favour landsliding in the area. Apart from these natural triggers, human activity such as irrigation and trampling by cattle grazing are triggers just as much. The wadis of the Wadi Mujib Basin have incised the plateau built up by thick subhorizontally bedded marine layers of marls, chalks, limestones and cherts (Khalil, 1992) which are very susceptible to mass movements. As these sediments consist of an alternation of hard and soft layers a canyon system could develop by differential headcutting erosion.

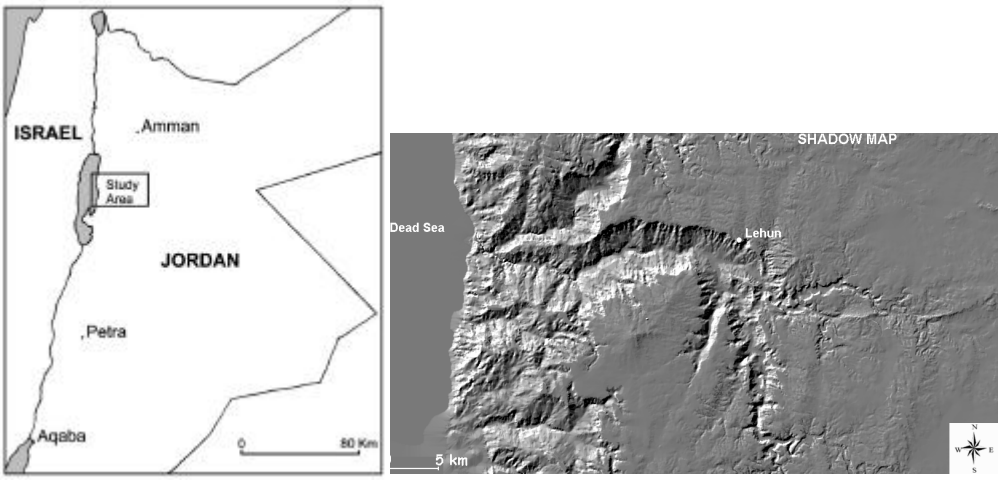


Figure 1: Localisation of the study area: The Wadi Mujib canyon in Jordan

Due to the high CaCO3-percentage karstic processes (as dolinas and travertine deposits) occur and create local subterranean water transport. The canyon walls of the Wadi Mujib once were afforested. Since the "Neolithic Revolution" some 10,000 years ago, Man tried to get hold of nature and started deforestation. Because the protecting vegetation disappeared the thin soil layer washed away, so that the canyon walls now appear bare. The high variability together with the high intensity of scarse winter rainfall in this semi-arid region form another trigger for destabilization of the naked slopes. Floods occur frequently after heavy rainfall and change the landscape rapidly. Then rising groundwater tables and accelerated fluvial erosion again have their negative influence on the slope stability. Steep slopes are always sensitive to degradation due to the gravity forces. The higher and steeper parts of the canyon walls show unloading processes and rock fall. Downwards, the slopes become less steep, water can penetrate more easily, alteration is higher hence landsliding (translational and rotational) is very common. Some terrace remnants are buried by landslide masses, others have developed

upon older landslide masses themselves. Finally Man, in the past and now, uses those parts on the valley walls showing a relatively low slope degree (terrace remnants, the upper side of a landslide mass…) for cultivation of crops. By means of artificial irrigation and natural higher infiltration of water quantities, landsliding is favoured again (De Dapper et al., 1997).

TK-350 imagery : technical aspects and processing

Average characteristics of the topographical camera (COSMOS series spacecraft):

Focus	350 mm
Average flying height	231 km (in this case: 225.7 km)
Ground resolution	10 m
Average scale	1:660,000 (in this case: 1:645,000)
Picture size	30*45 cm
Covered area	200*300 km
Stereoscopic overlap	60%, 80%

The B/H ratio of the used stereopair of 60% overlap (20 May 1992):
B/H = (40%*300 km)/225.7 km= 120/225.7 = 0.53
With: B = air base
H = flying height

Image processing

The enlargement of the TK-350 negatives has been executed on photo paper to obtain a stereopair of positives on a scale of 1:50,000 or the maximum enlargement without loss of information, factor 12.9. (used photo paper: AGFA 50.8*61 cm; Brovira Speed BW 310 RC; soft (1); neutral tone; glossy). In figure 2 the digital format of the result is draped over the DEM after georeference.
Threshold for stereoscopic view h:
h = (p/(b+p))*H=(0.05/(40%*450*12.9+0.05))*225700000 (mm)
= 4860 (mm) = 4.86 (m)
With p = lowest parallax difference on the stereo-micrometer = 0.05 mm
b = air base on the picture, and H = flying height

Model setup for landslide risk mapping

Introduction:

Jordan plans the construction of a dam in the Wadi Mujib (Loy, 1994). Mass movements as landslides could create giant waves in the storage lake, slowdown the reservoir capacity and damage the dam.
In order to implement the model for 'slope (in)stability mapping' or in this case, for 'landslide risk mapping', the geomorphological interpretation of the TK-350 photo stereopair (1:50,000) has been executed allowing the inventory of past landslides along the canyon walls.

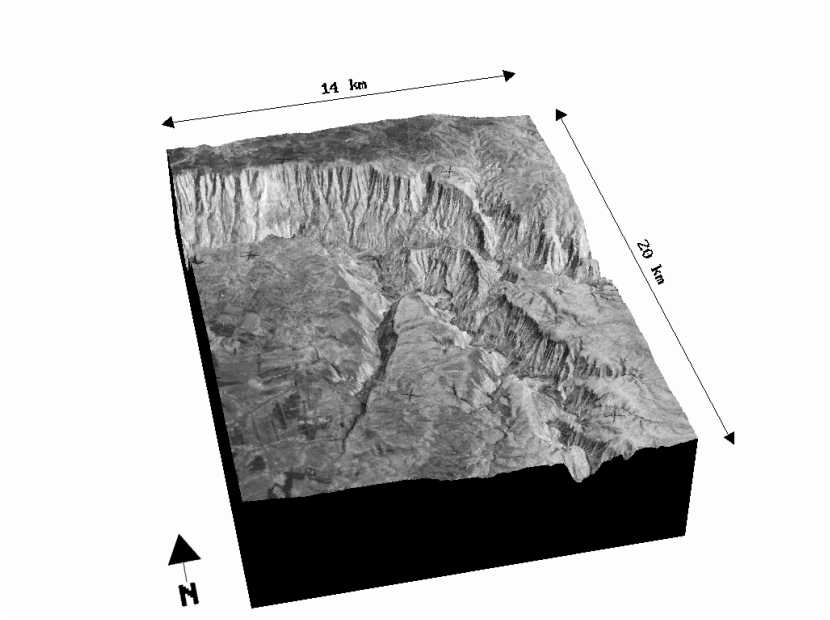


Figure 2: 3D-view on the study area (DEM) with overlay of the georeferenced TK-350 photo image

Once the geomorphological map was put into a GIS[1] (containing a DEM, lithological layer and tectonical layer) by scanning and georeferencing (according to the DEM) the 44 landslides were digitally identified as single point objects because their exact borders could not be mapped clearly. The point given is positioned at the estimated centre. Because of the relatively limited number of identified landslides, the different types (rotational or translational) have not been distinguised in the followed statistical procedure.

The next step was to list the possible factors that likely might cause landslides. Field observations and study of literature helped to understand the relationship between the landslide occurrence and the environmental context (Carrara et al., visited on 08/12/98; Floras et al., visited on: 14/08/98; Hansen, 1984; Napolitano et Budde, visited on: 08/12/98; Pisot et al., visited on: 30/07/98; Tutton et al., visited on: 14/08/98; Van Westen, 1994).

Four main triggering factors were selected: slope degree, lithology, distance to fault / lineament, and distance to thalweg.

Criteria for the selection of the influencing factors

Factor 1 : Slope degree : 'Slope degree' usually is a very critical triggering factor for slope instability. Selby (1993) and Kirkby et al. (1993) have proposed a value of 8 degrees below which landslides normally do not occur, and another level (30°-35°) above which the event can no longer be considered as 'landslide', but rather as 'rock-fall'. The layer concerning slope degree was obtained using the numerical model of the

[1] Data processing was performed using three different kinds of software to produce layer imagery for the GIS: ILWIS, ARC/INFO and ERDAS Imagine. A fourth software has been used for the cartography : ArcView.

digitalized isolines on the topographical map on 1:50,000 (DEM). The algorithm for calculating the slope used the eight nearest pixels and the slope degree was classified by classes of 5°.

Factor 2 : Lithology : According to the literature and field observation the lithology is a second important trigger factor. Materials will respond differently due to their own characteristics of deformation, rupture or permeability. This information layer was obtained by digitalization and polygonalization of the lithological map on 1:50,000.

Factor 3 : Distance to fault / lineament : Fault proximity is of great importance to the instability of slopes, certainly in this study area close to the active Dead Sea Rift. Fault zones are areas of likely weakness where the lesser cohesion of the rock due to fractures would allow water infiltration. As a result, areas where there had been movement would move more easily in the event of seismic activity or further readjustment.

The Euclidean distance to fault / lineament was calculated for the digitized faults of the geological map 'Dhiban (Wadi Al Mujib)' (1:50,000), as well as for the lineaments derived from the Russian TK-350 satellite images (on 1:50,000) completed with field work data.

Factor 4: Distance to wadi : The horizontal distance to wadis or thalwegs can influence landslides in two ways. Firstly, proximity will cause a higher degree of humid conditions. Secondly, lateral erosion caused by the thalweg will undermine the sides (concave banks). This weakening and destabilizing may start a landslide in order to restore equilibrium. Computation of the thalweg network was undertaken using a DEM that was hydrologically correct, in other words, whose sinks (occasional depressions) have been filled up. In this way a continuous thalweg network is obtained. The Euclidean distance between thalwegs within the network has been calculated.

Other factors that influence the occurrence of landslides are deforestation, anthropic interference and agricultural practices. In this particular case, it is an encased valley that has been deforested long time ago and is very sparsely populated. Heavy rainfall during winter in this semi-arid region can be another trigger for landslides. Cattle grazing on the hillslopes can stimulate movement by trampling, and water infiltration due to artificial irrigation just as much. But these factors are estimated here as secondary factors and are not easy to integrate into the model due to the absence of necessary spatial and temporal data.

Weights:

By introducing the layers into the GIS, for each layer, it has been possible to extract automatically the parameter information corresponding to the location of each detected landslide.

The data for each information layer have been put in a table with indications of the classes, the according number of landslides and surface area affected. From these values the landslide density (number of landslides/surface area) has been calculated. The density value has been normalized and expressed as a percentage (‘N.D.*100’) representing the significance of each class of each layer in the model. The variance between the densities (‘Density all’) of these classes has then been calculated, and gives the weighted factor for each layer used in the model (Table 2-5): before fusing the different factor layers a weight has been given to each *class* corresponding to the attributed percentage of the normalized density or ‘N.D.*100’ of each factor class. The weight for each *factor* is equal to the variance of the ‘Density’. A greater variance signifies that the *factor* plays a more important role in the occurrence of landslides. On the other hand a smaller variance indicates that the density is quite similar to each *class*

of a factor and the *factor* plays a less significant role in the spatial distribution of landslides.

N°	Slope (°)	Lithology (class)	Fault distance (m)	Wadi distance (m)	N°	Slope (°)	Lithology (class)°	Fault distance (m)°	Wadi distance (m)°
1	10-15	10	200	23	**23**	10-15	10	584	620
2	10-15	11	860	87	**24**	0-5	12	119	115
3	10-15	10	30	234	**25**	10-15	12	258	20
4	10-15	12	758	142	**26**	15-20	11	93	115
5	15-20	11	178	27	**27**	15-20	11	18	230
6	10-15	10	118	900	**28**	10-15	11	22	640
7	20-25	3	355	1583	**29**	10-15	10	56	436
8	15-20	10	143	535	**30**	5-10	11	108	260
9	10-15	12	552	440	**31**	15-20	3	92	500
10	5-10	10	336	1020	**32**	30-35	6	35	160
11	10-15	10	490	850	**33**	15-20	10	741	185
12	10-15	10	511	55	**34**	5-10	5	1174	325
13	15-20	10	113	390	**35**	10-15	10	463	150
14	10-15	10	96	555	**36**	10-15	10	369	146
15	10-15	10	115	570	**37**	20-25	10	160	320
16	15-20	10	231	845	**38**	10-15	10	633	595
17	10-15	10	321	310	**39**	0-5	10	57	45
18	5-10	10	392	558	**40**	15-20	3	432	270
19	35-40	10	563	816	**41**	10-15	11	145	200
20	10-15	3	144	270	**42**	20-25	11	113	280
21	10-15	10	552	300	**43**	25-30	10	358	500
22	20-25	11	338	295	**44**	15-20	6	36	615

Table 1: The 4 parameters for each landslide detected on the TK-350 images (remark: the classes of lithology are given in table 3)

Class (°)	numb.	Surface (km²)	Density	Density all	Norm. Dens.	N D * 100
0-5	2	107,376	0,018626136	0,018626136	0,009830133	0,983013258
5-10	4	36,48	0,109649123	0,109649123	0,057868438	5,786843838
10-15	21	32,3328	0,649495249	0,649495249	0,342777715	34,27777155
15-20	10	25,7024	0,389068725	0,389068725	0,205334972	20,53349718
20-25	4	18,7904	0,212874659	0,212874659	0,112346764	11,23467639
25-30	1	13,5936	0,07356403	0,07356403	0,038824164	3,882416417
30-35	1	5,6576	0,176753394	0,176753394	0,093283399	9,328339897

(Continued on the following page)

*Table 2: Statistical approach of defining the weight factor for each slope degree class ('N.D.*100') and for the total layer ('Var')*

(Continuation)

35-40	1	4,7872	0,208890374		0,208890374	0,110244017	11,0244017
40-45	0	0,6144	0		0,018626136	0,009830133	0,983013258
45-50	0	1,152	0		0,018626136	0,009830133	0,983013258
>50	0	37,376	0		0,018626136	0,009830133	0,983013258
sum	44	283,8624	1,838921691	Sum	1,8948001		
				Var	0,03858455		

*Table 2: Statistical approach of defining the weight factor for each slope degree class ('N.D.*100') and for the total layer ('Var')*

class	numb.	Surface (km²)	Density		Density all	Norm. Dens.	N D * 100
1.Soil	0	97,6128	0		0,03591954	0,01615817	1,615817005
2.Alluvium	0	2,048	0		0,03591954	0,01615817	1,615817005
3.Coquina-chalk	4	22,8096	0,175364759		0,175364759	0,078886689	7,888668879
4.Cemented fluvial / lacustrine gravels	0	0,9472	0		0,03591954	0,01615817	1,615817005
5.Chalk-marl	1	8,4224	0,118731003		0,118731003	0,053410365	5,341036452
6.Coquina-phosphorite	2	55,68	0,03591954		0,03591954	0,01615817	1,615817005
7.Sandstone	0	0,0512	0		0,03591954	0,01615817	1,615817005
8.Coquina-Silicified limestone	0	19,3536	0		0,03591954	0,01615817	1,615817005
9.Calcrete	0	2,1504	0		0,03591954	0,01615817	1,615817005
10.Landslip	24	28,8	0,798611111		0,798611111	0,359249981	35,92499808
11.Limestone	9	22,5536	0,399049376		0,399049376	0,17950975	17,95097496
12.Undifferentiated limestone	4	9,8048	0,407963446		0,407963446	0,183519686	18,35196859
13.Travertine	0	0,1024	0		0,03591954	0,01615817	1,615817005
14.Basalt	0	13,6448	0		0,03591954	0,01615817	1,615817005
	Sum	283,9808	1,935639235	Sum	2,222995557		
				Var	0,018839112		

*Table 3: Statistical approach of defining the weight factor for each lithological class ('N.D.*100') and for the total layer ('Var')*

Class (m)	numb.	Surface (km²)	Density	N. D	N. D * 100
0-200	21	111,3088	0,188664328	0,23972224	23,97222402
200-400	10	64,2304	0,155689518	0,197823512	19,78235117
400-600	8	36,3776	0,219915552	0,279430931	27,94309308
600-800	3	23,3728	0,128354326	0,163090643	16,30906432
800-1000	1	15,616	0,064036885	0,08136708	8,136708045
+ 1000	1	32,9472	0,030351593	0,038565594	3,856559369

(Continued on the following page)

*Table 4: Statistical approach of defining the weight factor for each fault proximity class ('N.D.*100') and for the total layer ('Var')*

(Continuation)

	44	Sum	0,787012203		
		Var	0,005292342		

*Table 4: Statistical approach of defining the weight factor for each fault proximity class ('N.D.*100') and for the total layer ('Var')*

Class (m)	numb.	Surface (km^2)	Density	N. D	N. D * 100
0-200	13	56,1664	0,231455105	0,246092343	24,60923432
200-400	13	50,5344	0,257250507	0,273519048	27,35190481
400-600	9	43,6224	0,206316021	0,219363462	21,93634619
600-800	3	36,2752	0,082701129	0,087931155	8,793115481
800-1000	4	30,1056	0,132865646	0,14126808	14,12680798
+ 1000	2	66,816	0,02993295	0,031825912	3,182591223
	44	Sum	0,940521358		
		Var	0,008054851		

*Table 5: Statistical approach of defining the weight factor for each thalweg proximity class ('N.D.*100') and for the total layer ('Var')*

Fusion of the layers

The final image overlay of the different weighted factors reveals areas of relative risk for landslides. An addition of the weighted values of all factors provides information that can give a rough indication of potential risk by comparing the values of pixels in the same image. The greater values indicate the pixels where landslides are most likely to appear. For ameliorating the presentation of this kind of information it was advisable to classify the image into a few major groupings by thresholding the values in the analysis of the histogram (figure 3). For the final presentation of the risk map the number of classes has been restricted to 4 by fusing the two lowest ones.

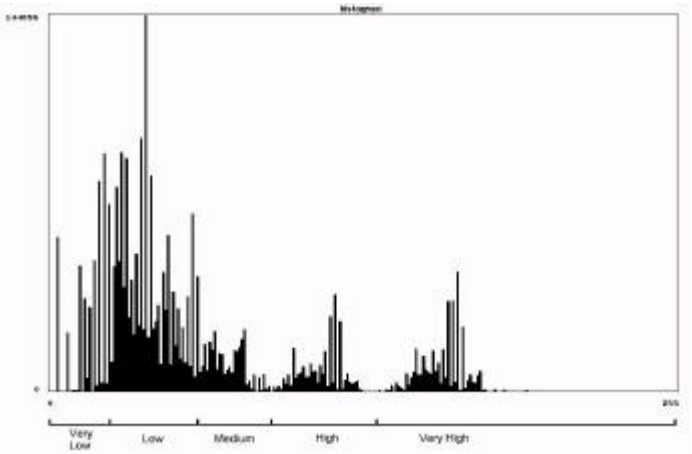


Figure 3: Histogram and limits of classes for the landslide risk map

Application on the model

Figure 4 shows a part of the landslide risk map in overlay with the extension of the future reservoir depending on different possible heights (10m, 20m, 30m, 40m, 50m) of the dam. The higher the dam, the larger the reservoir and the higher the danger for landslides, diminishing the reservoir capacity and damaging the dam.

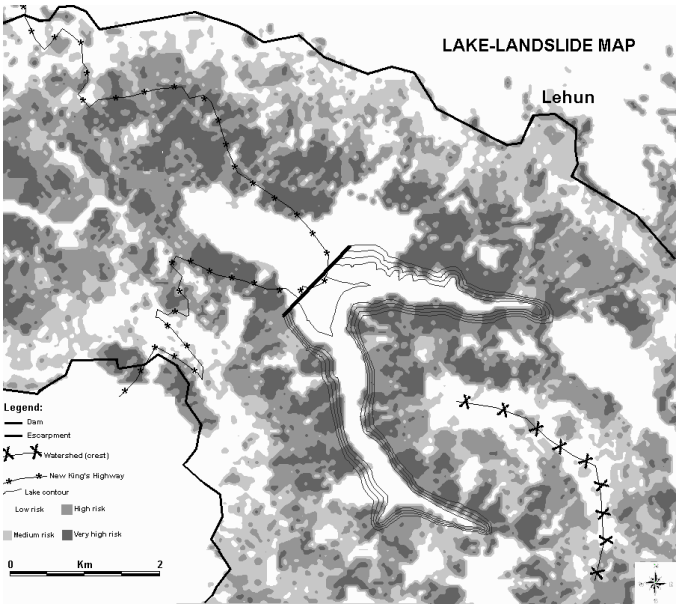


Figure 4: The extension of the future reservoir (resp. dam height of 10m, 20m, 30m, 40m, 50m) showing the endangered zones

Conclusions

The model for slope (in)stability mapping results in a map with a lot of necessary basic information for computations and simulations in the frame of future infrastructure management. The landslide risk map obtained by the use of TK-350 images can help in the decision for the best site and height of the future dam. The simulation in figure 4 shows that the higher the dam, the larger the lake and, consequently, the higher the contact with high risk zones (especially if the dam height >20m). The combination of the geomorphological interpretation of TK-350 images with a short controlling field survey to obtain a landslide inventory map gives the necessary, qualitative basic information of the model for landslide risk mapping. Even if time or money prevents the execution of field survey, the quality of the basic information gained by the use of TK-350 products should be satisfying: in the case study of the Wadi Mujib canyon the geomorphological map (with indications of landslide presence) corresponded well with the field observations afterwards. However, the statistical approach of the model based upon the point indications at the supposed centre of detected landslides involves some limitations: the knowledge of the real dimension of the moved masses, their relative age and an estimation of the distance of movement requires detailed field work or, at least, stereoscopic photo images on a higher scale (>1:50,000).

A chief advantage of using the TK-350 images and integrating them into a GIS is the easy image processing and photogrammetric restitution and related time-saving due to the large covered area (200*300 km) and the presence of reference cross marks upon the negatives. Another key advantage is the high security that recent TK-350 images can be obtained for almost every region in the world, even for deserted areas or for military 'security' zones, within a month after ordering. Finally, apart from the possibility to interpret the geomorphology due to the stereoscopic view on the overlapped area, the TK-350 images allow to detect basic features of local geology as macroscopic deformation and the identification of lineaments / faults. A disadvantage, however, seems to be the limited scale of enlargement (1:50,000), which probably does not turn out to be satisfactory in some study cases.

References

Bender F. (1968). *Geologie von Jordanien: Beiträge zur Regionalen Geologie der Erde*, Gebrüder Borntraeger, Stuttgart: 230 p.

Bender F. (1975). Geology of the Arabian Peninsula: Jordan, in: *Geological Survey Professional Paper*, US Government Printing Office, Washington, 560 (1): 36 p.

Burdon D.J. (1959). *Handbook of the Geology of Jordan*, Benham and Company Limited, Colchester: 82 p.

Carrara A., Cardinali M., Guzzetti F., Reichenbach P. GIS-based techniques for mapping landslide hazard. [http://deis158.unibo.it/gis/chapt1.h] up to [http://deis158.unibo.it/gis/chapt8.h]. In: *GIS technology in mapping landslide hazard* [http://deis158.unibo.it/gis]. Visited on: 08/12/98.

De Dapper M., De Jaeger C., De Vliegher B.-M., Mertens J. (1997). La recherche geo-archeologique / Geo-archeologisch onderzoek, in: Homès-Frédéricq D., *Lehun et la Voie Royale – Les fouilles belges en Jordanie / Lehun en de Koningsweg – De Belgische opgravingen in Jordanië*, Belgisch Comité voor Opgravingen in Jordanië / Comité Belge de Fouilles en Jordanie, Bruxelles / Brussel, Drukkerij Cultura Wetteren: 129-135.

De Dapper M., De Vliegher B.-M. (1995). Geomorphological survey of the Lehun area, in: Homès-Frédéricq D., *Lehun (District Madaba) Preliminary report of the thirteenth season of the Belgian excavations in Jordan (Fall 1995)*, Lehun, Jordan: 120-126.

Floras S., Pateras D., Raptis S. Assessment of the environmental impact from the construction of a dam and a reservoir. Demonstration Case Study (Ref: 639620). [http://ewse.ceo.org/anonymous/construct/build.pl/639911]. In: EWSE: *Assessment of the environmental impact from the construction of a dam and a reservoir* [http://ewse.ceo.org/anonymous/construct/build.pl]. Visited on: 14/08/98.

Hansen A. (1984). Landslide hazard analysis, in: Brunsden D., Prior D.B. (eds.), *Slope Instability*, John Wiley & Sons: 544-595.

Homès-Frédéricq D., De Dapper M., De Vliegher B.-M. (1997). Al-Lahun: A Geo-Archaeological Approach of the Belgian Excavations in Jordan, in*: Studies in the history and archaeology of Jordan VI*, Amman: 57-65.

Khalil B. (1992). *The geology of the Ar Rabba area – Map sheet NO.3152 IV*, Geology Directorate, Geological Mapping Division, Amman, Bulletin 22: 106p.

Kirkby M.J., Naden P.S., Burt T.P., Butcher D.P. (1993). *Computer Simulation in Physical Geography*, Second Edition, John Wiley & Sons, Chichester: 180 p.

Loy W. (1994). Waterconflicten, in: *Meded. Zitt. K. Acad. Overzeese Wet.*, Brussel, 39: 281-290.

Napolitano P., Budde P. Ilwis (landslide index method). [http://www.itc.nl/ilwis/applic/app05.h]. In: *ILWIS Application 5: Statistical hazard analysis* [http://www.itc.nl/ilwis/applic]. Visited on: 08/12/98.

Neev D., Emery K.O. (1995*). The Destruction of Sodom, Gomorrah, and Jericho: Geological, Climatological, and Archaeological Background*, Oxford University Press, Inc., New York: 155 p.

Peña Monne J.L. (ed.) (1997). *Cartografía geomorfológica básica y aplicada*, Geomorfa Ediciones, Longroño: 227 p.

Pisot N., Schittekat J. Dam construction : feasibility study. Demonstration Case Study (Ref: 620979). [http://ewse.ceo.org/registered/construct/build.pl/637813]. In: EWSE: *Dam construction : feasibility study* [http://ewse.ceo.org/registered/construct/build.pl]. Visited on: 30/07/98.

Selby M.J. (1993). *Hillslope materials and processes*, Second Edition, Oxford University Press, Oxford: 451 p.

Tutton M., Rao B., Greenbaum D., Hodges J. Rapid methods of landslide hazard mapping. Demonstration Case Study (Ref: 617942). [http://ewse.ceo.org/anonymous/construct/build.pl/618417]. In: EWSE: *Rapid methods of landslide hazard mapping* [http://ewse.ceo.org/anonymous/construct/build.pl]. Visited on: 14/08/98.

Van Westen C.J. (1994). GIS in landslide hazard zonation: a review, with examples from the Andes of Colombia, in: Price M.F., Heywood D.I. (eds.), *Mountain Environments and Geographic Information Systems*, Taylor & Francis, London: 135-165.

SEARCHING FOR BIOINDICATORS OF DESERTIFICATION: A COMMUNITY LEVEL APPROACH TO EPHEMERAL RUNNING WATERS.

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Abstract. The aim of this work was to investigate land degradation by means of fresh water macrozoobenthos like bioindicators of environmental health. Samplings were performed in 16 sites out of 14 streams in the Baronie Region (Eastern Sardinia). Target biotopes have been choosed in relation to canopy vegetation, altitude and land use. In spite of macrozoobenthec communities seem to be well stuctured with regard to taxa richness, the functional feeding groups analysis appeared unbalanced with dominance of predators and collectors and scarcity of shredders . These results seem to be related both with local land use and climatic conditions, in accordance with the functional structure of lotic benthos from different geographic areas characterized by a more arid climate and similar environmental condition.

Key words: macroinvertebrates, biodiversity, trophic structure, desertification

Introduction

Man has changed his environment along the centuries with progressive power, in such manner that all living beings had been influenced by him, directly being the objective of that change or indirectly modifying its habitat. Land use by man has involved deforestation since long ago, as a premise for cattle-raising and farming. These effects are mainly erosion that cause a large modification in the chemistry of drainage water and an increase of stream flow (Garcia de Jalòn, 1986). As results aquatic macroinvertebrate communities have been certainly affected. The riparian zones are those of direct interaction between terrestrial and aquatic environments, in natural conditions the riparian zones is covered by a dense vegetation usually dominated by trees. Riparian vegetation controls the energetic budget of aquatic ecosystems by shading and supplying allocthonous detritus, specially in streams. In Sardinia overexploitation of natural resources associated with climatic condition of the island, contribute to cause environmental degradation with consequent decrease of biodiversity. The purpose of this study was to investigate land degradation processes due to agropastoral activities by means of biological indicators of environmental health. The approach was to evaluate the biodiversity of benthic communities of water course and to analyze their trophic-functional structure in a range of habitat typologies along a cline of degradation related to the decrease of riparian canopy and wooded areas.

Study area and methods

The study area is located in Baronie Region, middle-eastern Sardinia, along the Tyrrhenian coast. Twentyseven samplings have been performed in fourteen ephemeral streams. Local climate ranges from dry, sub-damp to half-dry climate. Average annual temperature is 17°C with rainfalls from 500 to 700 mm, most in autumn and winter. Sites were choosed in relation to altitude, environmental typologies and canopy. In each site samplings were carried out using a modified Surber sampler (Ghetti, 1986). The following biological indices based on macroinvertebrate communities, were used in order to obtain a water quality evaluation: E.B.I. (Extended Biotic Index, Ghetti 1986), I.B.E. (Indice Biotico Esteso, Ghetti 1995)), BMWP' (Biological Monitoring Working Party, Alba-Tercedor et Sanchez-Ortega, 1988), ASPT (Average Score Per Taxon, to correct index values in environment with scarcity of fauna due to oligotrophic water and don't caused by pollution, Rico et al., 1992). Samples were sorted out on the field and a preliminary identification of taxa, at the family and genus level, was performed *in vivo* and then confirmed in laboratory. Macroinvertebrates were also related to Functional Feeding Groups (Cummins et Wilzbach, 1985).

Results

The very scarce water flow observed since from the beginning of spring in the streams, highlighted a precocious dry season in the studied area. A high percentage of surveyed sites were dry since spring. A total of 83 taxa belonging to 38 families and 33 genera were collected in the 16 studied sites. Insecta represented 73% of total taxa and in remaining 27% were dominant Crustacea, Mollusca and Oligochaeta. Results of biotic indeces and denote a good environmental conditions along most of the streams. (Tab. I).

SITES	EBI	C.Q	IBE	C.Q	BMWE	C.Q	ASPT
1	11	I	11	I	126	I	5,2
1 bis	10	I	11	I	143	I	4,93
3	8	II	8	II	78	II	4,6
5	10	I	10	I	114	I	5
6	10	I	10	I	123	I	5,6
6 bis	10	II	10	I	158	I	4,4
9	10	I	10	I	133	I	4,9
16	12	I	12	I	180	I	4,6
17	11	I	11	I	167	I	5,2
19	11	I	11	I	130	I	5,4
20	11	I	11	I	197	I	4,9
21	11	I	11	I	188	I	4,9
22	12	I	12	I	162	I	4,9
22 bis	11	I	11	I	129	I	4,8
23	9	II	9	II	106	I	5
24	10	I	10	I	124	I	4,4
24 bis	12	I	12	I	184	I	5,1
25	9	II	9	II	89	II	5,2
25 bis	11	I	11	I	130	I	5,2
26	7	III	7	III	64	II	4,3
27	9	II	9	II	101	I	4,4

Table I: biotic indeces and corrispondent classes of quality

In spite of the taxonomic composition of communities seems apparently not affected by environmental alteration, excepted the natural stress linked to the partial or total dessication of the stream bed, the trophic-functional analysis of communities highlighted a substantial influence related to land use. Predators and collectors are the most cospicuous groups, this fact denote an high carrying capacity of the running water sistem and a notable availability of particulate organic matter. Shredders are scarcely represented, they reached the highest values in those sites, rare in the studied area, with dense riparian deciduous canopy and structured vegetation in the surrounding areas; their abundance is low in those sites with herbaceus vegetation (Fig. 1). On the other hand these last land typologies supported the highest abundance of scrapers that prefer open sites and feed on periphyton.

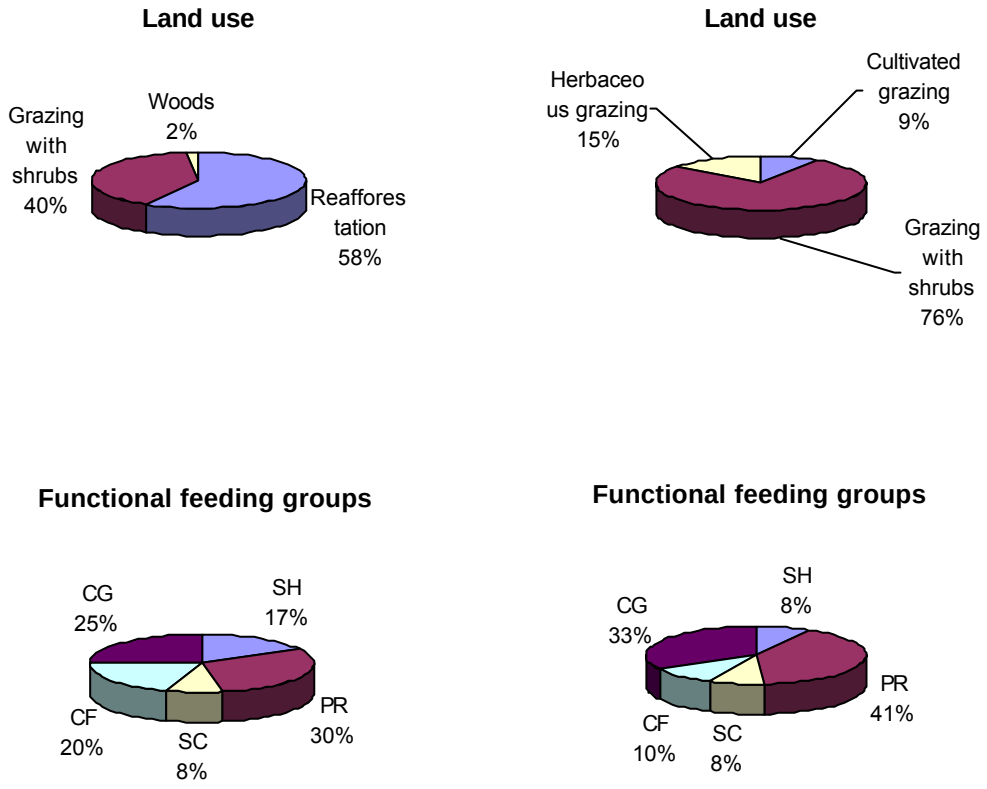


Fig. 1: Trophic functional composition of benthic communities in two water course with different vegetation cover.
Legend: SH= shredders; PR= predators; SC= scrapers; CG= collectors of particulate organic matter; CF= collectors of fine particulate organic matter.

Conclusions

The high capacity of adaptation of benthic communities to the ephemeral running water don't make possible to evidence, using biotic indexes, environmental degradation due to the synergetic effects of cattle-raising and farmer activity with peculiar climate of examined area. In fact, water quality varied from first to second class. The evaluation of

biotic indexes is essential to define water quality but it is not exhaustive to characterize habitats impacted by an impoverishment of vegetal cover. Alteration due to this kind of impact become evident with analyses of trophic structure of communities, like proved in letteratures (Hawkins et al., 1982; Boulton et Lake, 1992; Puig, 1993; Mihuc et Minshall, 1995; Death et Winterbourn, 1995; Anderson et Anderson, 1995; Hannaford et Resh, 1995). Nevertheless further studies are necessary on trophic-functional structure of benthic communities in Mediterranean countries with similar climatic condition and land use. It is necessary to compare a large spectrum of biotypologies in countries where desertification processes are in progress, to make possible identify a range of key benthic communities with a peculiar trophic functional structure that could be used as models in the defining of bioindicators of desertification.

References

Alba-Tercedor J. Et Sanchez-Ortega A. (1988). Un metodo rapido y simple para evaluar la calidad biologica de las aguas corrientes basado en el de Hellawell (1978). *Limnetica*, **4**: 51-56.

Anderson T.M. et Anderson N.H. (1995). The insect fauna of springs habitats in semiarid rangelands in central Oregon. *Journal of the Kansas Entomological Society*, **68**: 65-76.

Boulton A.J. et Lake P.S. (1992). The ecology of two intermittent streams in Victoria, Australia. III. Temporal changes in faunal composition. *Freshwater Biology*, **27**: 123-138.

Cummins K. et Wilzbach M.A. (1985). Field procedures for analysis of functional feeding groups of stream macroinvertebrates. University of Maryland, Frostburg, Maryland 21532, U.S.A.

Death R.G. et Winterbourn M.J. (1995). Diversity patterns in stream benthic invertebrate communities: the influence of habitats stability. *Ecology*, **76**: 1446-1460.

Garcia de Jalon D. (1986). Human impact on aquatic insect communities. In Proceedings of the 3rd European Congress of Entomology, August 24-29, 1986 Amsterdam. Eds. Nederlandse Entomologische Vereniging, Plantage Middenlaan 64, 1018 DH Amsterdam.

Ghetti P.F. (1986). I macroinvertebrati nella analisi di qualità dei corsi d'acqua. Indice Biotico: E.B.I., modificato Ghetti, 1986. Provincia Autonoma di Trento, Stazione Sperimentale Agraria Forestale, Servizio Protezione Ambiente.

Ghetti P.F. (1995). Manuale di applicazione: Indice Biotico Esteso (I.B.E.). I macroinvertebrati nel controllo della qualità degli ambienti di acque correnti. Provincia Autonoma di Trento, Servizio Protezione Ambiente.

Hannaford M.J. et Resh V.H. (1995). Variability in macroinvertebrate rapid-bioassessment surveys and habitat assessments in a Northern California stream. *J. N. Am. Benthol. Soc*., **14**: 430-439.

Hawkins C.P., Murphy M.L., Anderson N.H. (1982). Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in cascade range streams of Oregon. *Ecology*, **63**: 1840-1856.

Mihuc T.B. et Minshall G.W. (1995).Trophic generalists vs. trophic specialists: implications for food web dynamics in post-fire streams. *Ecology*, **76**: 2361-2372.

Puig M.A. (1993). Relaciones troficas de la comunidad de macroinvertebrados en el Rio Matarrana (Cuenca del Ebro). *Actas VI Congreso Espanol de Limnologia*, Granada, Mayo de 1993: 355-362.

Rico E., Rallo A., Sevillano M.A., Arretxe M.L. (1992). Comparison of several biological indices based on river macroinvertebrate benthic community for assesment of running quality water. *Annals Limnol*., **28**: 147-156.

UTILIZATION OF REMOTE SENSING IN FLOODING MANAGEMENT

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Abstract. The aim of this study is to demonstrate the possibilities of satellite remote sensing utilization in the obtaining hydrological data of a river basin. The selected area is the Tordino River Basin (Abruzzo, Italy), where flooding events are very frequent.
This paper describes the results of the top soil moisture monitoring with ERS SAR interferometric data. Bare and sparsely vegetated fields with constant surface roughness were identified based on their high interferometric correlation. Under the assumption of limited vegetation scattering and constant surface roughness, microwave backscattering depends mainly on the top soil moisture content.
The relative top soil moisture change is derived from relative backscattering change, while the absolute value can be estimated if the top soil moisture is known for one reference data set.

Key words: Flood management, ERS, SAR interferometry, soil moisture

Introduction

Satellite Remote Sensing data is a powerful tool for the provision of information for flood control purposes.
Their application to flood prevention relates mainly to the estimation of hydrological parameters and variables; those are given with an adequate spatial resolution and so can be used to build up distributed hydrological models.
This paper describes how Remote Sensing data can be used to estimate the water content of the upper soil layer for use as input in flash-flood event simulation.
In fact soil moisture content of the upper soil layer is considered a key element in runoff generation process. Facilitation and improvements of the computation of runoff, especially during flood events, can be obtained if the moisture of the top soil layer are known for the whole catchment or at least for representative sub-areas (Mendel et Portmann, 1997). Direct measurements on the ground at all sites are impossible, because they are very expensive and the data processing time is very long.
Remote Sensing from satellites, especially form Radar satellites like ERS, which can operate even during cloudy skies condition, can give an alternative.
In fact the scattering proprieties of the soil depend on its geometry and its dielectric constant. The value of the its dielectric constant is dominated by the water content of the soil, because the dielectric constant of the water has approx. 20-30 times the value of the soil matrix (Rombach et Mauser, 1997).
Therefore the approach is to relate the backscattering coefficient directly to the moisture of the upper soil layer.
In order to obtain quite reliable soil moisture estimates, it's necessary eliminate the effect of the vegetation and of the roughness change. For this reason, in this study, soil

moisture measurements based on microwave backscattering are restricted on bare and sparsely vegetated fields. Furthermore, using repeat-pass SAR interferometry from ERS satellites, areas with constant surface roughness have been identify (Wegmüller, 1997). Then the change of the backscattering coefficient can be used to monitoring the relative change of the moisture of the top soil layer in the sample areas.

Test site and data

The Tordino River Basin was selected as test site because it's often subject to floods events.
In order to get quite reliable soil moisture estimates, a couple of interferometric SAR images was used. The images were acquired on 18 April 1992 and on 5 September 1992; the first was selected because in the 10 April 1992 the low part of the Tordino River Basin was flooded and so in the 18 April the soil probably had an high moisture content, while the second one was selected in order to have a reference data for which the soil moisture content is known.
The moisture content of the top soil was obtained from microwave backscattering only for 10 test-field (see Figure below); such fields were selected for their high interferometric correlation. Quite reliable soil moisture estimates are obtained for the test-fields without roughness change.



Soil Moisture

In this study the relation found by Wegmüller (1997) was used. He found a linear regression between the backscattering coefficient and the volumetric moisture content of the top soil (%) for some fields. Furthermore he found a relation between the slope and the intercept of the regression curves.
The last relation (see Figure 2), was then used to find the linear regression between the backscattering coefficient and the volumetric moisture content of the top soil (%) for each of the 10 test-fields. For each field the soil moisture change was estimated from the relative backscattering change (see Table 1). Furthermore it's possible to estimate the value of the top soil moisture content for the 18 April, under the assumption that in the 5 September 1992 the top soil was very dry, and so the areas A, B, C, D, E, which belong to medium texture class had a volumetric top soil moisture content about 15.2%, while the areas F, G, H , I, L, which belong to the medium-fine texture class, had a value about 28%.
The values represent respective moisture content of the top soil for the two texture class at pressure head of 1.5 MP.

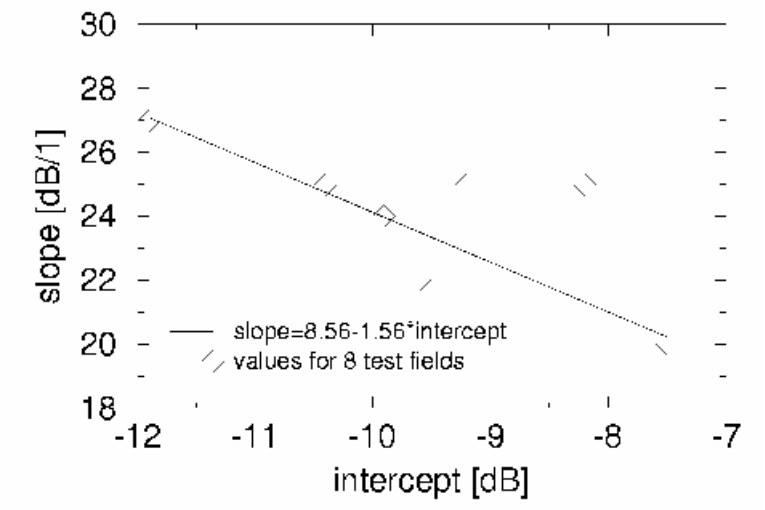


Figure 2: Slope of the regression curves for the different test fields versus the intercept. Ignoring the point located far away from the regression curve leads to the correlation coefficient of 0.89 (Wegmüller, 1997).

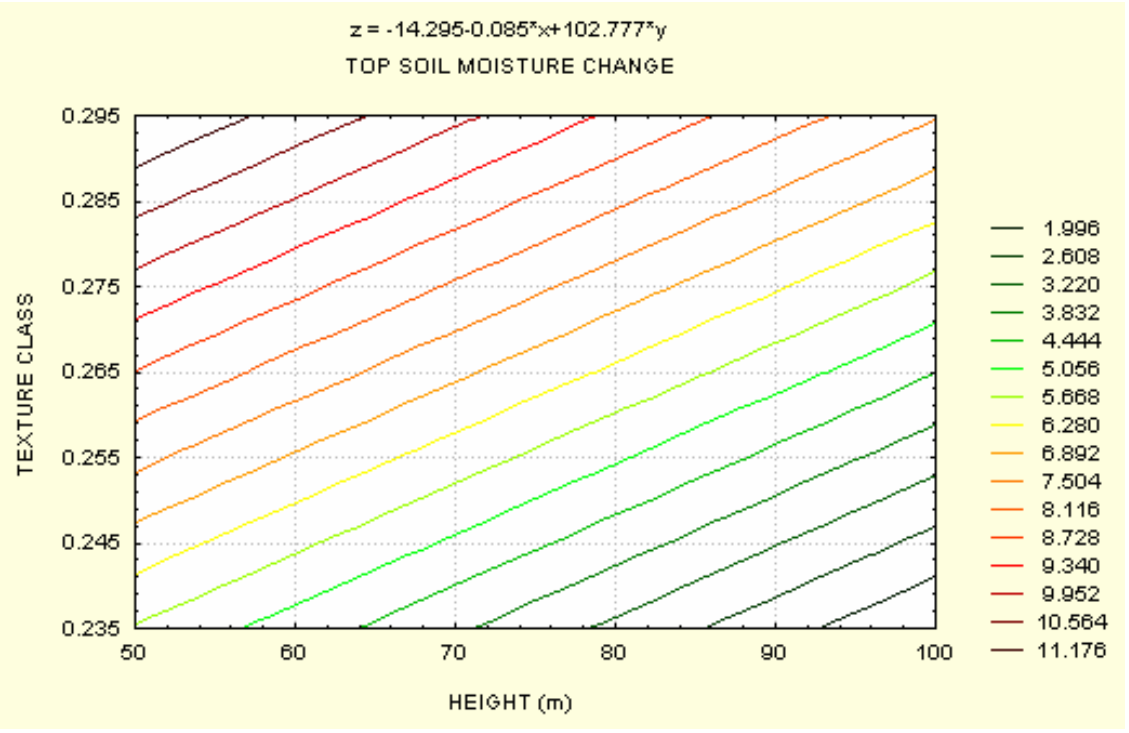
Results

From results obtained for the 10 test fields, it's possible to see how radar remote sensing can give improvements in the estimation of the top soil moisture change. In order to obtain quite reliable soil moisture estimates, it's necessary to use large enough averaging/filtering windows to determinate average backscattering coefficients.
The results show a greater soil moisture change for the areas A, B, C, D, E. The difference depends either on the altitude or on the different texture class. A linear relation, with a correlation coefficient of 0.81, was found between the moisture change, the altitude and the texture class, which was expressed as the maximum soil storage for

any texture class (see Figure below). The linear relation found can be used to extrapolate the top soil moisture change for the other fields.

	Backscattering coefficient (dB)		s	i	Δm_v
	18 April 1992	5 September 1992			
Area A, 70 m s.l.m.	-5.1	-8.3	28.2	-12.6	**11.4%**
Area B, 65 m s.l.m.	-4.3	-7.7	27	-11.8	**12.6%**
Area C, 60 m s.l.m.	-6.1	-9.1	30	-13.6	**10%**
Area D, 55 m s.l.m.	-5.9	-8.2	27.9	-12.4	**8.2%**
Area E, 90 m s.l.m.	-7.1	-8.5	28.5	-12.8	**5%**
Area F, 95 m s.l.m.	-6.8	-7.5	36	-17.6	**2%**
Area G, 65 m s.l.m.	-5.6	-7.6	36.2	-17.7	**5.5%**
Area H, 55 m s.l.m.	-6.2	-7.1	34.9	-16.9	**2.6%**
Area I, 75 m s.l.m.	-5.8	-7.8	36.8	-18.1	**5.5%**
Area L, 60 m s.l.m.	-5.6	-8.1	37.6	-18.6	**6.6%**

Table 1: Slope (s) and intercept (i) of the regression curves for each test fields and soil moisture estimates change (Δm_v) obtained from the microwave backscattering coefficient.



By using the linear regression found for any test-fields, it was possible successively to specify for each of them the value of the backscattering coefficients at which the top soil is saturated (see Table 2).
These values correspond to the top soil moisture content at a pressure head about 5kP.

Texture class	Area	Critical backscattering coefficient (dB)
Medium	A	-1.9
	B	-1.6
	C	-2.3
	D	-1.9
	E	-2
Medium-fine	F	-1.5
	G	-1.5
	H	-1.3
	I	-1.6
	L	-1.8

Table 2: Critical backscattering coefficient at which the top soil layer is saturated.

Conclusions

Remote sensing data is a powerful tool for the provision of information for flood control purposes. Their application to flood prevention relates mainly to the estimation of hydrological parameters and variables.
The focus of this study is on top soil moisture retrieval by ERS SAR interferometric data. Data acquired over Tordino River Basin in 18 April and 5 September 1992 were used. The soil moisture monitoring was applied to bare and sparsely vegetated fields with constant surface roughness, which were identified by means of the high interferometric correlation.
The dependence of the backscattering coefficient on the volumetric top soil moisture content was used to estimate the relative soil moisture change. The absolute top soil moisture content can be estimates if the soil moisture is known for one reference data set. The study used as reference, data acquired during a dry period (September 1992).

References

Bates P.D., Anderson M.G. (1995). Issues of hydraulic model validation and design using remotely sensed data. In First ERS Thematic Working Group Meeting on Flood Monitoring, June 26-27, 1995, ESRIN, Frascati, Italy.

Blyth K. (1997). Floodnet: a telenetwork for acquisition, processing and dissemination of earth observation data for monitoring and emergency management of floods. Hydrological processes, vol.11, 1359-1375.

Kasischke E.S., French N.H.F., Bourgeau-Chavez L.L., Romanowicz E., Richardson C.J., (1997). Monitoring hydropatterns in south Florida ecosistem using ERS SAR data. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Mendel H., Portmann F. (1997). Soil moisture estimation in hydrological mesoscale modelling using ERS SAR data. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Oberstadler R. (1995). Assessment of flood mapping capabilities with the aid of ERS-1 SAR data: an experience in Germany. In First ERS Thematic Working Group Meeting on Flood Monitoring, June 26-27, 1995, ESRIN, Frascati, Italy.

Portmann F.T. (1997). Hydrological runoff modelling by the use of remote sensing data with reference to the 1993-1994 and 1995 floods in the River Rhine catchment, Hydrological processes, vol.11, 1377-1392.

Portmann F.T., Mendel H.G. (1997). Soil moisture estimation in hydrological mesoscale modelling using ERS SAR data. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Profeti G., Macintosh H. (1997). Flood management through LANDSAT TM and ERS SAR data: a case of study. Hydrological processes, vol.11, 1397-1408.

Rombach M., Mauser W. (1997). Multi-annual analysis of ERS surface soil moisture measurements of different land uses. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Tholey N., Clandillon S., De Fraipont P. (1997). The contribution of spaceborne SAR and optical data in monitoring flood events: examples in northern and southern France. Hydrological processes, vol.11, 1409-1413.

Troch P.A., De Troch F.P., Grayson R., Western A., Derauw D., Barbier C., (1997). Spatial organization of hydrological processes in small catchments derived from advanced SAR image processing - Field work and preliminary results. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Verhoest N., Troch P.A., De Troch F.P., Deckmyn J., Paniconi C., (1997). Spatial soil moisture mapping through multi-temporal analysis of ERS SAR PRI data. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Wagner W., Borgeaud M., Noll J., (1997). Soil moisture mapping with the ERS Scatterometer. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

Wegmuller U., (1997). Soil moisture monitoring with ERS SAR interferometry. In Proceedings of 3rd Symposium ERS on Space at the service of our environment, Firenze, 1997.

THE SPATIAL DISTRIBUTION AND ACTIVITY OF GULLY HEADS ALONG THE RAMBLA SALADA (SE SPAIN).

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Abstract. South-east Spain is an area with high soil erosion rates. Gully-head retreat from incised ephemeral channels (ramblas) can be a significant source of sediment and a major form of land degradation. A 2.5 km long stretch of the Rambla Salada was selected for further studies. In total, 458 gully heads were mapped and classified according to their apparent activity. The distribution of active and non-active gully heads along a channel not only locates the areas with high sediment production but also reveals major factors controlling gully erosion such as geology, land use and topographic attributes.

Keywords: Rambla, gully heads, land degradation, spatial distribution.

Introduction and objectives

South-east Spain is an area with a marginal climate that is severely affected by desertification. The European Commission funded a project, MEDALUS (Mediterranean Desertification and Land Use), which aims to examine, understand and mitigate the problems of desertification in Mediterranean Europe.

Out of all the land degradation processes, namely water erosion, wind erosion and mass movements, water erosion is one of the most important land degradation processes in Mediterranean environments (Poesen and Hooke, 1997). The main conveyers of sediments in South-east Spain are the numerous ramblas (ephemeral dry river beds) with their many tributaries. There are indications that these sediments are filling up the reservoirs. Consequently, it is necessary to know the processes that influence gully erosion so that further erosion can be diminished.

Gully erosion should not be confused with rill erosion. Both are the result of erosion caused by overland flow but a gully is larger than a rill: the critical channel cross-sectional area of a gully is one foot² (Poesen et al., 1996).

The definition of a gully according tot the United States Soil Conservation Service (1966) is: *'gully erosion is the removal of upland soil and parent materials and formation of channels by concentrated flow of water. A channel formed in this manner is classified as a gully when it cannot be obliterated by normal tillage operations'.*

The general objective of this paper is to study the activity and distribution of gully heads. In detail this means:

- Mapping bank gullies along a rambla in a semi-arid climate using field observations, ortho, aerial and digital photos. During the field work the activity of each bank gully was determined in order to come to a decision about its overall activity.
- Investigating and understanding the activity of the bank gullies. It is attempted to establish relationships between erosion activity of the gully heads and various major environmental factors such as land use, lithology and topography.

For this project a 2.5 km long stretch was chosen along the Rambla Salada. The Rambla Salada was chosen because of its accessibility, the high erosion rates, the presence of several lithological units and its representative setting within one of the typical sedimentary basins in south-east Spain.

Study area

Location of the study area

The Rambla Salada is situated in the South-east Spain and is part of the Guadalentin basin. It is located in the north-east of the province Almería and in the south-west of the province Murcia. The Guadalentin basin has an area of 3300 km² and is drained by the 121 km long Guadalentin river (MEDALUS, 1993). There are two dams: the Puentes and the Valdeinfierno (figure 1). The Guadalentin river joins the Segura River near the city of Murcia.

The Rambla Salada is a tributary of the Rio Turilla, which connects with the Rambla Luchena. The chosen stretch is 2.5 km long and descends from 630m to 590m.

Geology and lithology

The Guadalentin basin lies within the Betic Cordillera, an Alpine mountain range that covers the south-eastern part of the Iberian peninsula. It is the result of the collision between the European and African plate during the Jurassic period (190 to 135 million B.P.) until the Miocene period (26 tot 6 million. B.P.). The Betic Cordillera is divided into three zones, based on differences in lithology and structure. The Rambla Salada is part of the Betic zone, consisting of non-metamorphic and meso-metamorphic rocks ranging from Paleozoic to Mesozoic age. Tertiary rocks are found locally (Van Veen, 1969).

As a result of the collision between Jurassic and Miocene, a topography of sierras and sedimentary basins was formed. During Miocene and Pliocene the basins were filled mainly with unconsolidated materials like limestones, sandstones, conglomerates, gypsiferous marls and sodium rich marls (Wise et al., 1982).

Today, the landscape is characterized by the many pediments. These pediments are the results of the enormous amounts of debris supplied by the tectonic active mountains. The top layers of the basin consist mainly of sandy and loamy colluvium, alluvium and conglomerates (Atlas of Mediterranean Environments in Europe, 1998).

Even though the presence of petrified calcics offer the pediments a certain resistance to erosion, the erosion rates are still high in the basins. A reason for this phenomenon are climatological changes: the area has become a lot dryer during the past thousands of years. As a result the amount of vegetation has declined and the surfacing rocks are subjected to intense erosion.

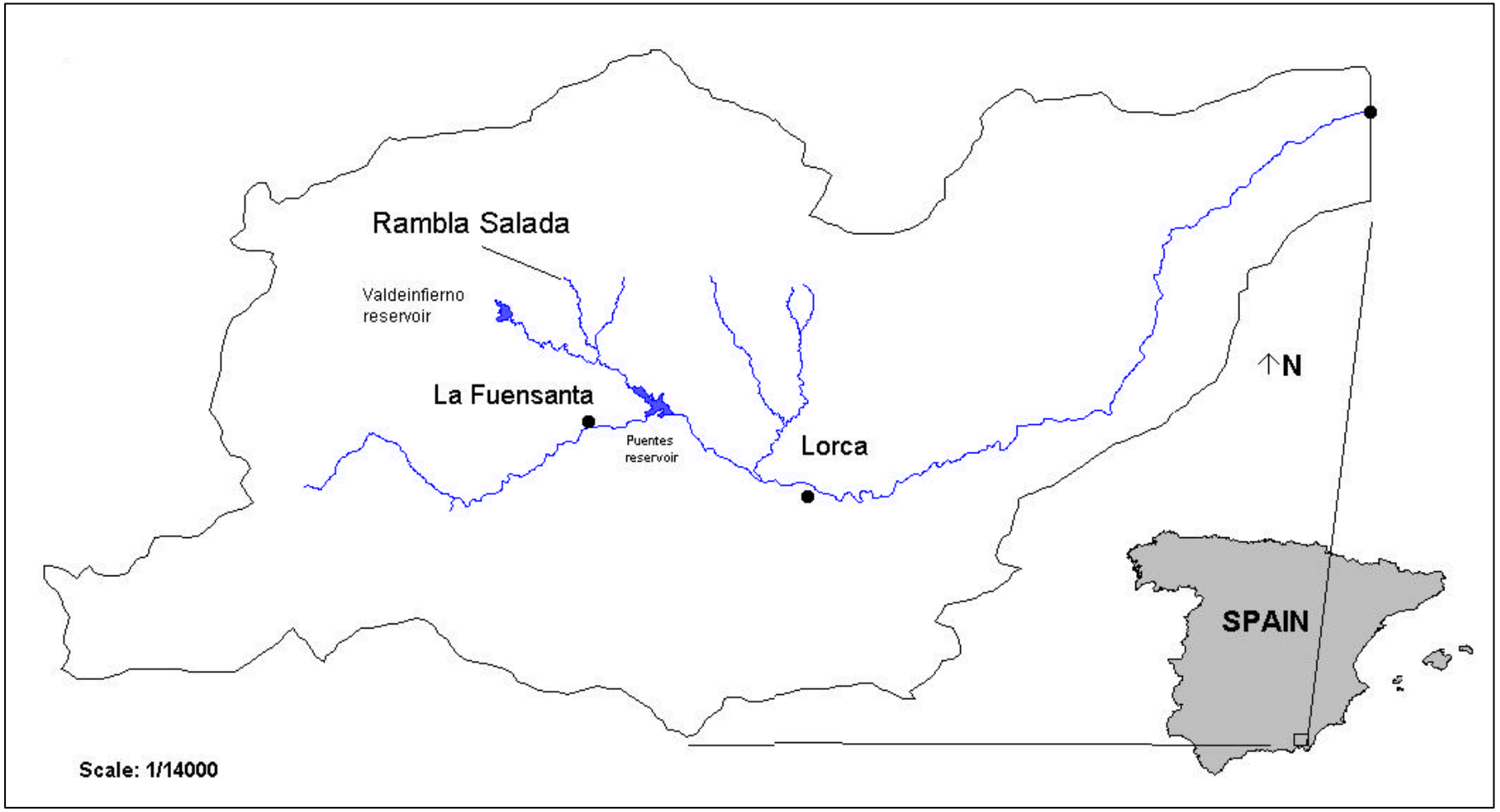


Figura 1: The Guadalentin basin

Climate

Mediterranean Europe is classified as a semi-arid area, with annual rainfall less than 600mm and rainfall mostly coming in the winter months. The summers are dry and warm (MEDALUS, 1996).

The driest areas (with annual rainfall less than 300mm) are found in south-east Spain, in the provinces of Almería, Granada, Murcia and Alicante. The average annual temperature is around 18°C and the annual rainfall between 150mm and 400mm (Conte, 1993). The Guadalentin basin is located in the transition zone between semi-arid and arid climate.

Vegetation

Rainfall amount and distribution are major factors controlling the growth of vegetation. In the study area, the growth of vegetation is limited by the extreme climate (an average annual rainfall of 300mm and potential evaporation of 900-1200mm) and the marginal soils. Only plants adapted to these extreme conditions can survive. The following three perennial plant species are widely found: the tussock grass *Stipa tenacissima*, the summer deciduous *Anthyllis cytisoides* and the leafless shrub *Retama sphaerocarpa* (MEDALUS, 1996).

Stipa is a slow growing, shallow rooted plant and a drought-endurer. The Anthyllis is more sensitive to rainfall and survives droughts by shedding its leaves. During dry years the amount of Anthyllis shrubs drop drastically, but during wet years they regenerate quickly. The deep root system of the Retama shrub can permanently reach water resources. Stipa and Anthyllis regenerate quickly after a drought, but after an extreme long dry period, only stipa will survive (MEDALUS, 1996 and Atlas of Mediterranean Environments in Europe, 1998)

Agriculture

Agriculture is drastically limited by the low and unreliable precipitation. At present 49% of the total area is used for agriculture. Land use without irrigation (secano) takes up 30% and irrigated agriculture (regadio) occupies 19.5% (Tout, 1987 and Atlas of Mediterranean Environments in Europe, 1998).

The crops harvested in Mediterranean environments are adapted to the climate. A distinction has to be made between annual crops (e.g. grain) and permanent crops (e.g. olives and almond trees). The crops are not only harvested on the lower slopes but also on steeper slopes. This is possible by building terraces, which is also a good water-conserving strategy (Atlas of Mediterranean Environments in Europe, 1998).

Around the Rambla Salada grain is harvested but the yield is mostly for the sheep and goats. Almond trees are widely spread as they can survive extremely well with a little amount of water. Olive trees are found less frequent as irrigation is needed (Obando, 1993).

Methodology of the fieldwork and data analysis

The right as well as the left bank of the Rambla Salada were separately surveyed in the field in order to map each bank gully. Digital photos taken in April 1997 at a scale of 1:1500 were used to mark each incision as seen on the field. Each gully was then digitized using the orthophoto map at a scale of 1:5000.

Present land use, (September 1997), was also digitized using the same map and the field observations. Figure 2 shows the gullies and the land use in the study area.
The second specific objective was to determine the spatial distribution of the active and non active gully heads. In order to achieve this, the gully heads were divided into four classes: very active (va), active (a), moderately active (ma) and non active (na). Each gully had to meet a few criteria to be able to belong to a certain group. To each gully head a grade of activity was assigned based on the following criteria:

- A gully head was classified as active if one or more of the following characteristics were present:

sharp or vertical wall, plunge pool, tension cracks, piping, flow marks, recently deposited material.

- A gully head was classified as non active if one or more of the following characteristics were present:

sloping gully head, rounded of walls, vegetation on the walls or in the bedding, dams or other gully control measures, the absence of a plunge pool.

- A gully head was classified as moderately active if characteristics from both were present.
- A gully head was classified as very active if the first series of characteristics were very obvious.

In total, 458 gullies were marked. Out of the 458 gully heads, 39 were very active, 166 active, 150 moderate active and 103 were not active.
The following characteristics were also noted:

- In which lithological layer the gully head was situated, namely:

- marls: white to gray sediments with a popcorn appearance;
- calcareous marls: extremely white marls;
- red marls: marls with a red colour;
- gypsiferous marls: marls with obvious crystals and darker of colour;
- quaternary fills: brown, sandy loam sediments rich in loam with small individual stones;
- gravel: quaternary fills with thick gravel-rich layers;
- conglomerate: quaternary fills with consolidated coarse gravels.

- Land use in the neighborhood.

The spatial distribution and activity of the bank gully heads

Lithology

Observations

It is interesting to know whether or not the grade of activity depends on the lithological class. By only considering the relative figures a wrong interpretation is quickly made: the very active, active and non active gully heads are mostly found in quaternary fills. This isn't surprising as 60% of the gully heads lie in quaternary fills. Before checking if the activity is different for every lithological class, the data have to be transformed. This was done by converting the total amount of gully heads in each class to one hundred.

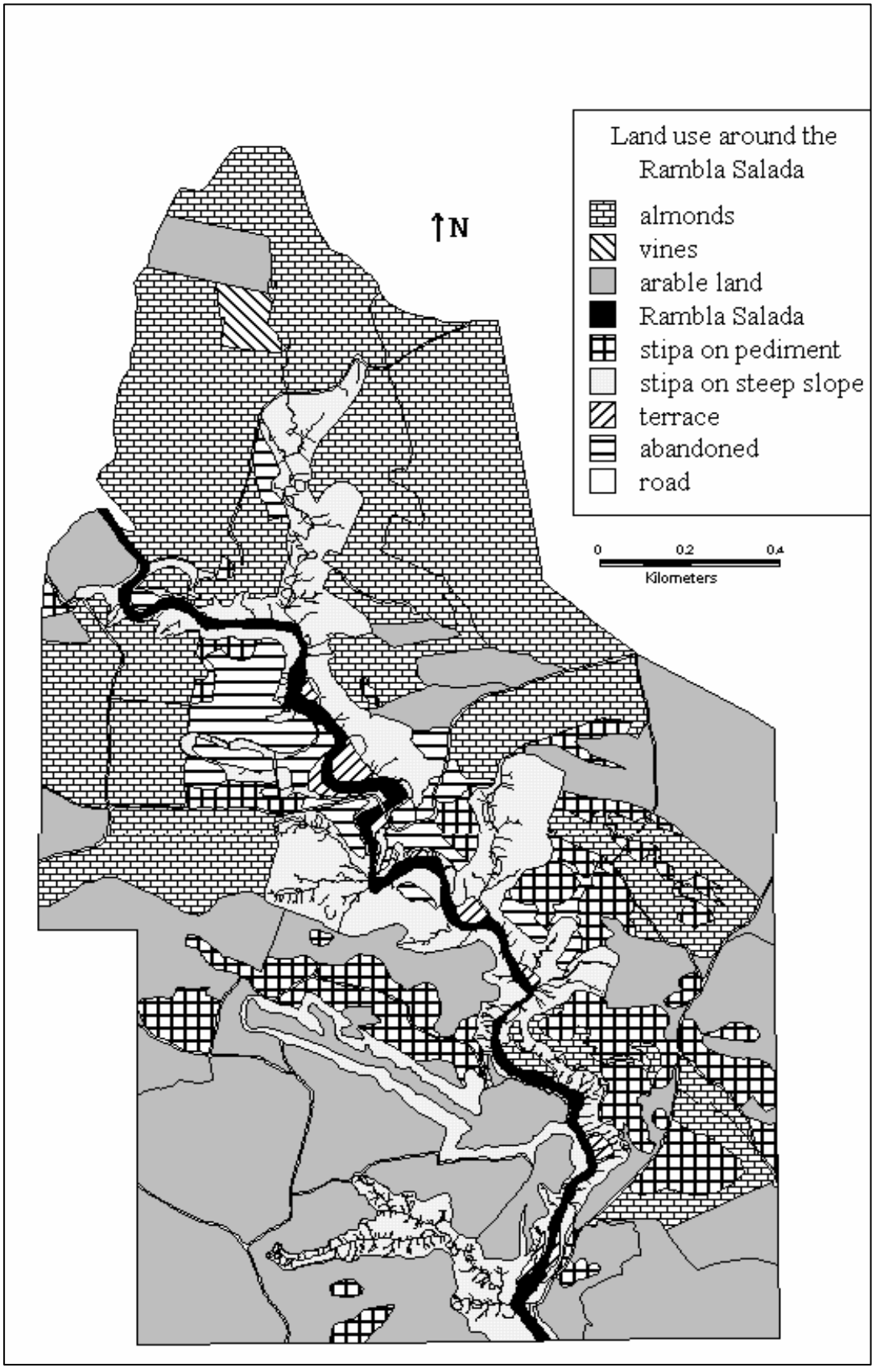


Figure 2: Gullies and land use

From table 1 the following conclusions can be drawn:

- Most of the non active gully heads can be found in conglomerates, less in gravel, while there are non in red marls.
- The moderately active gully heads are mainly found in gypsiferous marls; the red marls have the least moderately active gully heads.
- Most of the active gully heads occur in red marls, less in quaternary and the least in gypsiferous marls.
- The very active gully heads are mainly found in calcareous marls and red marls, while none are found in conglomerates and gypsiferous marls.

	va	a	ma	na	total
Conglomerate	0	20	40	40	100
Gravel	1,5	20	47,7	30,8	100
Quaternary	8,5	41,6	28,1	21,8	100
Marls	11,3	38,7	32,3	17,7	100
Gypsiferous marls	0	17,4	56,5	26,1	100
Calcareous marls	44,4	22,2	22,2	11	100
Red marls	37,5	50	12,5	0	100

Table 1: *The activity of gully heads according to lithology and converted to hundred (the underlined data give per activity class to which lithological class most gully heads belong). Va = very active; a = active; ma = moderately active; na = non active (In total 458 gullies).*

The calcareous and red marls seem to be most sensitive to erosion, which corresponds with the literature where it is said that when marls surface the infiltration decreases while the overland flow increases through the development of a surface crust. Not al marls are as sensitive; the gypsiferous marls are a lot less sensitive to erosion. The difference of activity according to lithology can be measured and represented by one figure by using the Chi square test.

A Chi square test is used to test the independence of activity and lithology. An actual range and an expected range are compared. If the given p-value is smaller than 5%, we can conclude that activity of gully heads is dependent of lithology.

The Chi square test applied to the data used in table 1, resulted in a p-value of 5.10^{-06}. This means that the activity of the gully heads is dependent on the lithology.

Explanations

The area where the gully heads are situated in *marls*, are badlands. In Mediterranean Europe badlands are mainly found in unconsolidated or poorly sorted materials such as shales, sodium rich marls and silt-clay deposits of Tertiary and Quaternary age (Yassoglou, 1993). Badlands evolve mainly by surface and subsurface flow and chemical erosion. Chemical erosion is important when the concentration of salts are high as this causes soil dispersion. For example montmorilloniet, when present in an extremely sodium rich environment, shows strong swell

and shrink potential (Bryan et Yair, 1982). The less it rains, the less the soluble salts are leached: in humid areas the soils contain a lot less salts than soils in arid areas (Yassoglou, 1993).

Marls are also sensitive to splash erosion. The most important physical effects of falling raindrops are: compaction of the top layer and dispersion of aggregates (Poesen and Paulissen, 1996). The compaction and broken aggregates fill the pores which results in a dense crust that causes water to flow overland (Abrahams 1986).

Gypsiferous *($CaSO_4.2H_2O$) marls* are in the study are less sensitive to erosion than the other marls. Literature confirms this result. (Grierson, 1979). During a shower the infiltration rate decreases rapidly in an unstable soils as a result of the demolition of the aggregates. By adding gypsum the aggregate stability increases and thus also the resistance to rain drop impact. The amount of surface flow will be lower as it takes longer for a crust to form. The aggregate stability increases as the exchangeable sodium and magnesium are replaced by calcium (Grierson, 1979)

Gully heads situated in *conglomerates* are the least active. This confirms the negative relationship between rock contents and erosion. The rock fragments favor infiltration, reduces runoff and soil loss and cover the materials sensitive to erosion (Poesen, 1993). Conglomerates are also consolidated which increases the resistance to erosion.

Land use

Observations

The grade of activity can also be linked to land use. As 70% of the gully heads are situated in Stipa, the data has also been converted to 100 (table 2). As only one gully head has a catchment in a vineyard, it has been left out of the following review.

From table 2 the following conclusions van be drawn:

- Most non active gully heads have a catchment in an abandoned field, and least in arable land.
- Most catchments of moderately active gully heads are found in abandoned fields. They are found the least in an almond grove.
- Most active gully heads have a catchment in arable land, and least in an abandoned field.
- Most very active gully heads have a catchment in an almond grove, the least are found in stipa.

	va	a	ma	na	total
Stipa	6,6	36,4	34,1	22,9	100
Arable land	10,5	<u>42,1</u>	30,3	17,1	100
Almonds	<u>24,1</u>	34,5	17,3	24,1	100
Abandoned	9,1	24,2	<u>36,4</u>	<u>30,3</u>	100
Vines	0	0	<u>100</u>	0	100

Table 2: *The activity of gully heads according to land use and converted to 100 (the underlined data give per activity class to which lithological class most gully heads belong). Va = very active; a = active; ma = moderately active; na = non active (in total 458 gullies).*

The indication is that abandoned fields and stipa zones supply the least amount of runoff, while almond plantations and arable land supply the most amount of runoff.
The Chi square test can also be used to test the independence of land use and activity. The p-value is now 9.5%, which means we can't conclude that the activity of gully heads is dependent of land use. We can say that there is a certain amount of dependency but not as outspoken as with lithology.
The noted observation can scientifically be supported by looking at the curve numbers (this is an empirical classification value of the runoff-response of a basin) of the soils (USSCS, 1986). The hydrological class C was chosen as the infiltration rate is quite slow (quick formation of a crust) and also because of the moderate to fine grain size. For the arable land the resulting curve number is 83% (row crops and poor hydrological conditions) and for the abandoned fields a curve number of 63% (sagebrush with grass understory with a ground cover of 30-70%). The arable land has a higher curve number so the runoff will be greater

The influence of dams

Although there is an indication that arable land and almond plantations supply the most amount of runoff, a lot of these gully heads are non active. A reason for this phenomenon can be the presence of the protecting influence of control dams around gully heads. In the study area, ten gully heads with a catchment area situated in arable land or an almond grove are protected by a dam.
It can be assumed that the moderately and non active gully heads were active if no gully control measures were taken. Considering this assumption we can once more classify the gully heads. The same changes weren't made for gully heads situated in abandoned fields or stipa zones as these dams are probably a lot older and thus in a bad state. The resulting classification can be seen in table 3. The p-value of the Chi square test is now only 1.4%, so now we can definitely say that the activity of the gully heads is dependent on the land use.

	va	a	ma	na	total
Stipa	6,6	36,3	34	23,1	100
Arable land	10,5	46,1	26,3	17,1	100
Almonds	<u>24,1</u>	<u>51,7</u>	13,8	10,4	100
Abandoned	9,1	24,2	<u>36,4</u>	<u>30,3</u>	100
Vines	0	0	100	0	100

Table 3: *The activity of gully heads according to land use corrected for human intervention (the underlined data give per activity class to which land use most gully heads belong). Va = very active; a = active; ma = moderately active; na = non active (in total 458 gullies).*

Explanation

An obvious explanation for the link between land use and activity is the grade of vegetation cover. Almond plantations are nearly bare the whole year through as they are ploughed 3 to 5

times a year. Arable land has little cover for most of the year. The abandoned fields and stipa zones on the contrary, are protected the whole year through from rain drops and runoff (the vegetation cover is however less than 100%).
The advantages of vegetation are (Poesen and Paulissen, 1996):

- the interception of rain;
- reducing the velocity of runoff;
- reinforcing the soil and increasing the porosity;
- the stimulation of biological activity;
- the transpiration of water.

Lithology and land use

The intensity of gully erosion in a certain lithology depends on the amount of runoff, which is strongly dependent on the land use. Land use and lithology have to be considered together. In table 4 land use and lithology are combined
In the study area, the combination most sensitive to erosion is marls and arable land followed by quaternary and almond plantations. The least sensitive to erosion is the combination abandoned fields and gravel or conglomerate.

	va	a	ma	na	total
	100	100	100	100	100
conglomerate and abandoned	0	25	25	50	100
conglomerate and stipa	0	0	100	0	100
gravel and abandoned	0	0	0	100	100
gravel and arable land	4,3	8,7	52.2	34.8	100
gravel and almonds	0	50	50	0	100
gravel and stipa	0	26,3	50	23,7	100
marls and stipa	8,2	35,3	38,8	17,7	100
marls and arable land	38,9	27,8	16,7	16,7	100
quaternary and abandoned	14,3	28,6	42,9	14,3	100
quaternary and arable land	5,4	67,6	24,3	2,7	100
quaternary and stipa	6,2	39,2	28,4	26,3	100
quaternary and almonds	26,9	34,6	15,4	23,1	100

Table 4: *The activity of gully heads according to lithology and land use (n=458). Va = very active; a = active; ma = moderately active na = non active.*

Topography

Slope

Steep slopes are common in the mountainous area of southern Spain. Steep slopes increase the velocity of runoff and thus also the transporting capacity. The length of the slope is also important: the amount of runoff increases with the length of the slope (Yassoglou, 1993).
When looking at the topographic map of the area, three large branched systems can easily be recognized. The gradient of the area above the systems varies between 4 and 6%. It is not the gradient of the slope that is important but the length. As can be seen on the topographic map,

these three branched systems are situated in the lowest part of large concavities. We can assume that without human interference further regression will be along the thalwegs
The gradient of slopes can be used to explain why gully heads in abandoned fields are less active than gully heads in stipa zones. The abandoned fields are old cultivated lands and occupy rather flat areas. The unused areas are on the steeper slopes and covered with stipa.

Orientation of the slopes

In the northern hemisphere the southerly orientated slopes receive the most sun. The temperatures of these soils are thus higher which results in drier soils. The percentage of organic matter (quicker oxidation) and vegetation cover is lower. The southerly orientated slopes should thus be more sensitive to erosion than the northerly orientated slopes.
All the gullies along the 2.5 km long stretch that were either orientated to the north or to the south were counted (table 5). The p-value is 20.8%, which means the activity of the gully heads is independent of the orientation of the gully heads.

Orientation	Lithology	va	a	ma	na	total	total
	Quaternary	9	14	13	14	50	
Z	Gravel	1	5	3	4	13	88
	Marls	3	8	9	1	21	
	Conglomerate	0	0	4	0	4	
	Quaternary	7	23	23	13	66	
N	Gravel	1	4	4	0	9	86
	Marls	3	4	4	6	17	
	Conglomerate	0	0	2	0	2	

Table 5: *The orientation of the slopes in combination with the activity of the gully heads. Va = very active; a= active; ma = moderately active; na = non active.*

Bends

When looking at the position of the gullies, it can be seen that the complex gully systems always starts in the outside bends of the Rambla Salada. This is partly because water concentrates in the outside of bends through which regressive erosion is higher in the outside than inside of bends. Secondly, large gully systems can't be formed in the inside bends as the catchments aren't large enough (Govers, 1997).
It is interesting to check whether the positions of the gullies can be connected with the activity of the gully heads: in an inside or outside bend. The number of gullies clearly in an inside or outside bend were counted and divided according to activity (table 6). The number of gullies in outside bends are higher and they are also more active. The p-value of the Chi square test is 0.15%, and so we can conclude that the activity of gully heads depends on the side of the bend.

	va	a	ma	na	total
Outside bend	4	24	23	12	63
Inside bend	0	4	3	13	20

Table 6: *the activity of gully heads according to the side of the bend.*
Va = very active; a= active; ma = moderately active; na = non active.

Conclusion

As part of the MEDALUS project, the spatial distribution and activity of gully heads were investigated along the Rambla Salada. During the field work, all the bank gullies inside the study area were mapped and classified according to their activity (very active, active, moderately active and non active).
In order to explain the activity of gully heads, relationships with three major environmental factors, lithology, land use and topography, were established.
The lithology is an important factor explaining the differences in activity. The least active gully heads are situated in conglomerates or gravels. The gully heads located in marls, gypsiferous marls and quaternary fills are more active, while the most active gully heads can be found in red and calcareous marls. The lithology is thus an important factor when explaining the level of activity.
Land use is also an important factor when explaining the differences in activity. Without adjustment for gully control measures activity is less dependent on land use as it is on lithology. After adjustments for the effect of control measures, however, a much stronger relationship is found. The least active gully heads have a catchment located in abandoned fields, those of the most active gully heads are found in almond plantations. These findings are confirmed by the runoff curve number technique.
Thus, both lithology and land use determine the activity of gully heads. When combining both factors, the combination most sensitive to gully head erosion seems to be marls and arable land followed by quaternary fill and almond plantations.
The topography can not only explain the grade of activity, but also the position of the gully heads. The gradient of the slope where the gully head forms, influences the activity, while the topographic concavities determines the position of the gully heads. The presence of outside bends influences the position and the activity of gully heads.
The research shows that a decision by the farmer to increase his share of almond plantations and arable fields, will lead to an increase in soil loss by gully erosion . If he does, he should make sure the areas are as flat as possible and not located in the lowest parts of topographic concavities.

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References

Abrahams, A.D. (1986). Hillslope processes, The Binghamton Symposia in Geomorphology: International Series, Allen and Unwin London, 16: 55-76.

Atlas of Mediterranean Environments in Europe, The Desertification Context, 1998. Mairota, P., Thornes, J.B. and Geeson, N. (eds.), Wiley, 200 pp.

Bryan, R and Yair, A. (1982). Perspectives on studies of badland geomorphology. In: Bryan, R. and Yair, A. (eds.), Badland geomorphology and piping, Norwich, Geobooks, pp.1-12.

Conte, M. and Colacino, M, (1993). Notes on the climate of the Mediterranean and future scenarios. In: Rubio, J.L., Peter, D., Balabanis, P., and Fantechi, R., Desertification in a European context: Physical and socio-economic aspects, Symposium in Pueblo Acantilado, Alicante (Spain), 6 tot 13 October 1993, pp.79-109.

Dohrenwend, J.C., (1993). Pediments in arid environments. In: Abrahams, A.D. and Parson, A.J. (eds.), Geomorphology of desert environments, Chapman and Hall, pp. 321-353.

Govers, G. (1997). Fluviatiele Geomorfologie, Cursus 2de licentie Geografie, K.U.Leuven.

Grierson, I.T. (1979). Gypsum and Red-Brown Earths. In: Emerson, W.W., Bond, R.D., and Dexter, A.R. (eds.), Modification of soil structure, John Wiley & Sons, pp. 315-324.

MEDALUS (1993). Mediterranean Desertification and Land Use. Executive summary abstracted from the Report of the First Phase of the MEDALUS Project. Commission of the European Communities. Directorate general XII for science, research and development. Environment Program.

MEDALUS II (1996). Mediterranean Desertification and Land Use. Executive summary phase II. Commission of the European Communities. Directorate general XII for science, research and development. Environment and climate program.

Obando, J. (1993). Modeling vegetation-erosion competition on abandoned land under fluctuating rainfall regimes. In: Rubio, J.L., Peter, D., Balabanis, P., and Fantechi, R., Desertification in a European context: Physical and socio-economic aspects, Symposium in Pueblo Acantilado, Alicante Spain), 6 tot 13 October 1993, pp. 553-565.

Poesen, J.W.A. (1993). Soil erosion in Mediterranean environments. In: Rubio, J.L., Peter, D., Balabanis, P., and Fantechi, R., Desertification in a European context: Physical and socio-economic aspects, Symposium in Pueblo Acantilado, Alicante (Spain), 6 tot 13 October 1993, pp. 123-152.

Poesen, J.W.A. and Hooke, J.M., 1996. Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Progress in Physical Geography*, 21, 2: 157-199.

Poesen, J.W.A. and Paulissen, E. (1996). Hellingsmmorfologie and Bodemconservatie, Cursus 1ste licentie Geografie, K.U.Leuven.

Poesen, J.W.A., Vandaele, K. and Van Wesemael, B., 1996. Contribution of gully erosion to sediment production on cultivated lands and rangelands. *Erosion and Sediment Yield: Global and Regional Perspectives*, 236: 251-266.

Soil Conservation Service, 1966. Procedure for determining rates of land damage, land depreciation and volume of sediment produced by gully erosion. *Technical Release no. 32 (Geology), Engineering Division, Soil Conservation Service, U.S. Department of Agriculture.*

Tout, D.G. (1987). Southeast Almeria province- the driest region in Europe. Weather, vol. 42, 8: 242-247.

United States Soil Conservation Service, (1986). Urban Hydrology for small watersheds. Technical Release no. 55, Engineering Division, Soil Conservation Service, U.S. Department of Agriculture.

Van Veen, W. (1969). Geological Investigations in the region west of Caravaca, South-eastern Spain, Proefschrift K.U.Leuven.

Wise, S.M., Thornes, J.B. and Gilman, A. (1982). How old are the badlands. A case study from the south of Spain. In: Bryan, R. and Yair, A (eds.), Badland geomorphology and piping, Norwich, Geobooks, pp. 259-277.

Yassoglou, N. (1993). Land and Desertification. In: Rubio, J.L., Peter, D., Balabanis, P., and Fantechi, R., Desertification in a European context: Physical and socio-economic aspects, Symposium in Pueblo Acantilado, Alicante (Spain), 6 tot 13 October 1993, pp. 35-56.

CONSEQUENCES FOR THE MITIGATION OF DESERTIFICATION OF E.U. POLICIES AFFECTING FORESTRY ACTIVITY: MEDAFOR PROJECT: THE PHYSICAL ENVIRONMENTAL APPROACH IN EXTREMADURA STUDY AREA, SW SPAIN

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Abstract. In the region of Extrenadura dehesas (wooded pasturelands), treeless pasturelands and plantations of evergreen oaks are being investigated as part of the lands uses contemplates on the MEDAFOR project. This project focused on the role of EU policies affecting forestry activity in terms of desertification and land degradation mitigation. A mixed methodology (socio-economic and physical environmental) is being applied which, in terms of the physical environmental approach, is bases on the premise that soil erosion susceptibility, when affected by land management changes, can be gauged successfully with two relatively easily measured variables: near-surface soil moisture variations and aggregate stability.
The paper describes this methodology and the localities chosen for the development of the project in SW Spain.

Key words: Soil degradation, desertification, dehesa, afforestation, soil moisture, land uses.

Introduction

In mediterranean countries forestry activity and land management practices in forested areas are regulated by national action plans to combat desertification, following the UN International Convention to Combat Desertification. E.U. policies also contemplates aid schemes and funds to promote forestry activities and CAP reforms concerned to environmental protection and agricultural land afforestation (e.g. Council Regulation 2080/92 of 30/6/92).
On this context, MEDAFOR project started in 1998. The project focused on the hydrological consequences of EU policies and funds affecting forest expansion, development, change and management in desertification prone-areas of the northern Mediterranean. The overall objective is to develop, apply and test methodologies applicable widely within the EU for investigating the socio-economic and soil sustainability impacts of land use and land management practice changes arising from various EU policies and aid schemes which affect forestry activity in selected areas of the Mediterranean vulnerable to land degradation and desertification.
The work is being carried out in several sites of Central and SW Spain, Portugal and Northern Italy and the methodology applied based on two main approaches: the socio-economic and the physical environmental.

This paper is intended to be an approach to the methodology and first soil moisture results obtained on the SW Spain study areas (Extremadura region).

The Study Area

In the region of Extremadura dehesas, treeless pastureland and plantations of evergreen oaks are being investigated. There are a number of different definitions of the term *dehesa*, but generally it refers to wooded pastureland located in south-western Iberia (fig. 1). Dehesas are dominated by evergreen *Quercus* species, mainly holm oaks (*Q. rotundifolia*) and to a lesser extent, cork oaks (*Q. suber*). The extension of wooded dehesas in south-west Spain is estimated to cover 2.248.000 ha. Pastureland occupies a further 4.080.000 ha, and both units represent 47% of the useful agricultural land in this part of Spain (Extremadura, Andalucia, Castilla La Mancha, Castilla León; Campos, 1993, Diáz et al., 1997). These areas, especially dehesas, include a variety of land management systems and also present a large number of bio-physiographical characteristics. It is hence a complex system, and past and present changes of the socio-economic conditions cause even higher complexity.
Abandoned cultivated lands and treeless rangelands are subject to afforestation within the EU programme EEC 2080/92. In the Extremadura region a surface of 7400 ha each year is affected by afforestation projects in former agricultural lands. The main tree species are (expressed as a percentage of the area of the plantations): *Quercus rotundifolia* 57%, *Q. sub*er 17%, and mixture of *Q. ilex* and *Q. suber* 13%. Thus, 87% of the afforested areas are planted with these evergreen species. During the last five years 739 projects were carried out, each with an average size of approximately 50 ha.
The decision of choosing dehesas and areas effected by afforestation schemes for this investigation as selected study areas is justified by the lack of knowledge of these systems. In order to improve or maintain their natural potential (biodiversity, soil quality and agricultural productivity) a better understanding of the relationship between the land use/land management systems and the degradational processes is needed.

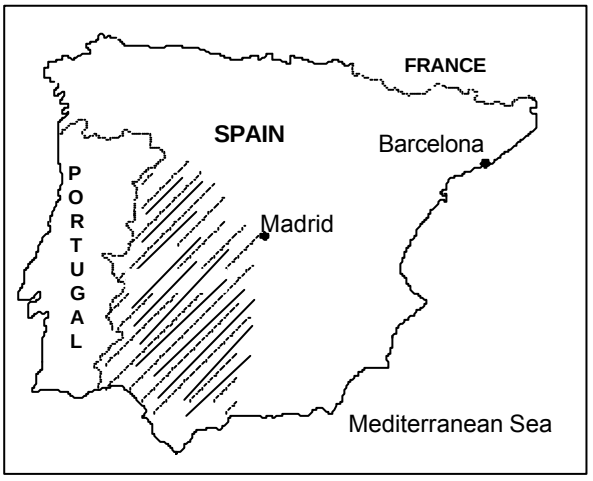


Figure 1: Distribution of the dehesa land use in Spain

Location and Characteristics of the Study Sites

Six study sites, located in five different municipalities, were chosen for the physical environmental approach of the project. The study sites, while centred on the dehesa land use, differ respect to the dominant land management and vegetation, being similar other physical-environmental characteristics. The location of this sites is shown in Fig. 2:

- Fuentes del Guijo (TA): Treeless pastureland with sheep grazing.
- La Desesperada (HO): Reforestation in 1998 with *Quercus rotundifolia* (holm oack) in strips following the contour, i.e. the tress area planted in ploughed strips with strips of herbaceous cover in between. Livestock excluded.
- Azagala 1 (A1): Reforestation with *Quercus suber* (cork oak) in 1993, the entire hillslope was ploughed. Livestock excluded.
- Azagala 2 (A2): Reforestation with *Q. suber* in 1968, the entire hillslope was ploughed. Livestock excluded.
- Guadalperalón (GU): Degraded dehesa. Dominant tree species: *Q. rotundifolia*. Grazing by sheep, cows and pigs.
- Las Cañas (CA): Dehesa. Dominant tree species: *Q. rotundifolia* and *Q. suber.* Sheep grazing.

Past and present land management in the study sites

Figure 3 shows a detailed scheme of the land uses and changes practised over natural vegetation from the past until the present and the resulting land units in a general scale. Dehesas were created by clearing the shrub layer and by thinning out the tree cover. During roman times deforestation experienced an increase and, after the expulsion of the Moors, the Spanish Crown distributed the reconquested land between the nobility, the church and the order of knights. Still existing, large land properties were created, and the extensive livestock breeding achieved great importance, livestock breeders with their organisation, the Mesta, had more influence than the other farmers. The consequence was the transformation of immense areas into grazing land.

At the present time, dehesas are used in a variety of manners. Livestock breeding is the most important landuse. The main food source of sheep, goats and cows are the herbaceous plants; however, also leaves and branches of oaks and other shrubs are eaten. Acorns are especially important for the nutrition of the pigs. Oak trees are pruned at intervals of about ten years in order to increase fruit production. Branches are used for firewood or charcoal production and small branches and leaves are consumed by sheep and goats. Where soils are deep enough and the slopes not too steep, cereals and increasingly forage is cultivated. Because the soils are rapidly exhausted they are cultivated in crop rotation. Another important income is cork production and hunting.

As result of past and present land management practices, the more common degradation processes in the dehesas are: Lack of regeneration of the trees (mainly due to overgrazing), decrease of tree biomass (due to excessive pruning for firewood production and soil degradation and erosion as a consequence of excessive stocking rates.

Soil characteristics

The most widespread soils in the area are Cambisols and Leptosols. The Cambisols (A_h-(B)-C) usually have a poorly developed illuvial horizon and are shallow, with

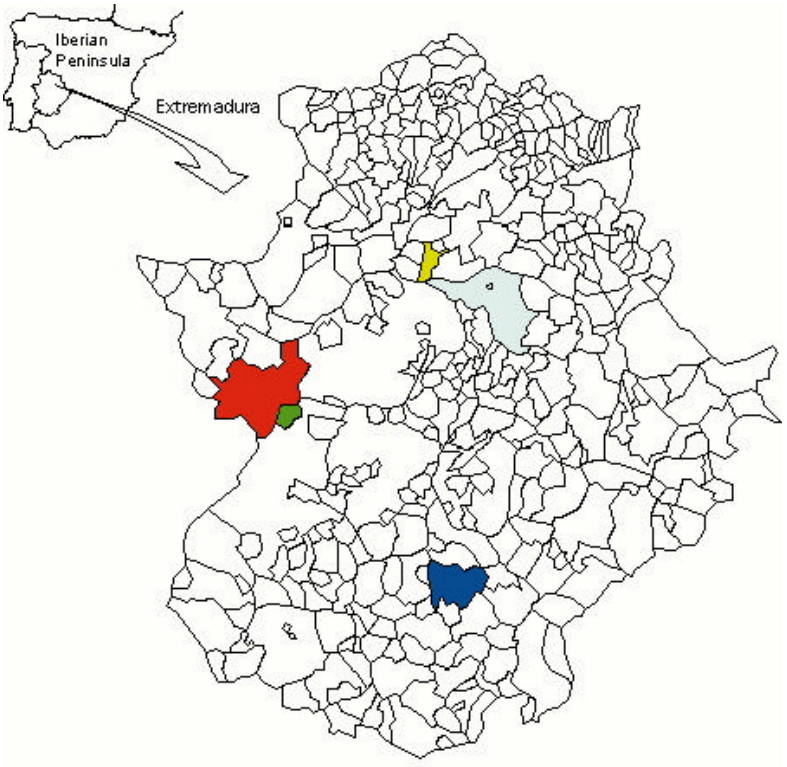
depths in the order of 30 to 50 cm (CSIC, 1970). In large areas Leptosols and lithic Leptosols are found. Soil depths vary strongly in relation with the irregular surface of the underlying rocks. The texture is predominantly silty loam. Organic matter content is generally low, with values of 2 to 4% in the upper layer. Cultivated or abandoned fields have even less organic matter. The soils are acid with a pH in the order of 5,3 to 6,5 in the upper horizon and 5,0 to 5,9 in the B-horizon (CSIC, 1970). They are poor in nutrients, with low contents of plant available phosphorous and calcium.

Climate

Data of the meteorological station of the city of Cáceres, close to the study areas, is used to characterise the climate.

The climate is Mediterranean, with Atlantic and continental influences, giving rise to moderate winters and hot and dry summers. Mean annual temperature amounts to 16,1ºC, with a maximum in July (26ºC) and a minimum in January (7,7ºC).

Annual precipitation averages 514 mm, distributed over 85 rain days. The annual distribution shows a dry season lasting from June to September and a wet season from October to April.



Grid ID	Municipality (Province)	Study area
A1	Villar del Rey (Badajoz)	Azagala 1
A2	Villar del Rey (Badajoz)	Azagala 2
CA	Alburquerque (Badajoz)	Las Cañas
HO	Hornachos (Badajoz)	La Desesperada
GU	Trujillo (Cáceres)	Guadalperalón
TA	Talaván (Cáceres)	Fuentes del Guijo

Fig. 2: Location of the study sites

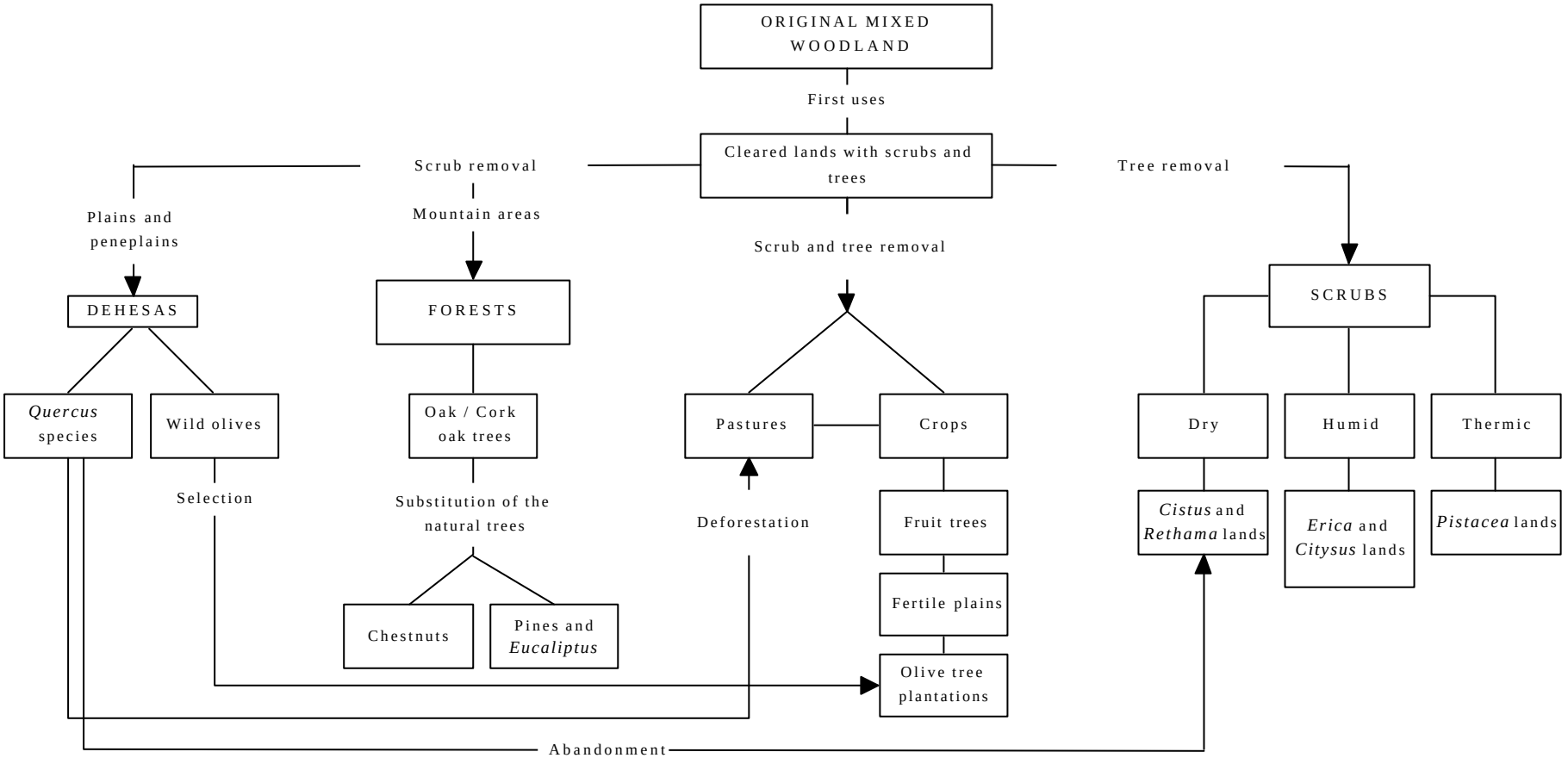


Figure 3: General scheme of the evolution of vegetation in Extremadura en relation with land use and management

Annual and interannual variability of rainfall is high. Droughts with a duration of more than two years are a common feature. Their mean frequency is estimated to be 7,8 years (Schnabel, 1997). Using the Unesco aridity index the climate of Cáceres is semiarid.
Although high intensity rainfall events are less frequent than in the Mediterranean coastal zone, potentially erosive rainstorms do occur: Mean annual frequency of daily rainfall > 30 mm amounts to 1,48. The 10-year return period of the 10-minute maximum intensity is 72,0 mm/h. On average three times a year the 60-minute maximum intensity is higher than 10 mm/h.

Methodology used

While the MEDAFOR project has two methodological approaches, the physical environmental and the socio-economic, only the first one will be described hire.
A methodology is tested which is based on the premise that soil erosion susceptibility when affected by land management changes can be gauged successfully with two relatively easily measured variables: near-surface soil moisture variations and aggregate stability. During rain, soil moisture tends to be unevenly distributed, some areas becoming more susceptible to runoff generation, and hence also potentially to soil loss than others.
In addition to being influenced by runoff generation, soil erosion is strongly affected by soil properties. Soil aggregate stability reflects the magnitude of disruptive compared with stabilising forces (e.g. De Ploey & Poesen, 1985; Imeson, 1986; Bryan et al., 1989; Ternan et al., 1996). Soil structural stability, particularly in semi-arid environments, may also depend on soil chemistry.
Multi-date sample grid measurements of soil moisture using Time Domain Reflectometry (TDR) enable rapid and precise determinations of spatial soil moisture patterns in dry and wet conditions and can indicate threshold moisture contents for connecting runoff-generating areas. Determining soil aggregate stability on a grid basis is relatively simple and can indicate likely erosion-resistance of soils when wetted. Together with relief and vegetational cover data, these two soil parameters can highlight the most vulnerable locations for runoff and erosion and the impact of different land use and management configurations on soil moisture patterns.
This method involves gathering physical environmental data on hydrological, erosional and soil properties of the land use/land management practice types within each of the study areas.
Baseline data on geology, soil characteristics, soil depths, vegetation etc...for the study areas is needed. Once study sites are selected (in consultation with the socio-economic specialists of the project), sample locations are identified in which topographic survey using EDM/GPS will be done to produce digital elevation models and fix locations for soil sampling and soil moisture monitoring networks. The surveys will also include details of erosional features (e.g. gullies, rills, pipes) and will provide the basis of a GIS database with terrain lithology, land use, slope and vegetational layers.
For each sample lacation, (1) multi-date soil sampling and subsequent laboratory analysis of key surface and soil properties that influence soil erodibility, hydrology and soil nutrient status and (2) measurement of soil moisture characteristics.
The different quantified parameters and the methods used are shown in Table 1.

Parameter	Method
Baseline physical environmental data	
Geological mapping and soil classification	Geological and soil mapping
Geomorphology, vegetation	Geomorphological and vegetation mapping
Measurements made at sample sites	
Volumetric soil moisture (multi-date measurements)	Time domain reflectometry
Aggregate stability	Laboratory rainfall simulation Water atable aggregates
Soil texture	Wet sieving (>0.063 mm) and laser/x-ray particle sizing
Bulk density	Oven dried (105 °C) 1000 cm^3 cores
Organic carbon	High temperature catalytic oxidation with nondispersive infrared detection using Shimadzu TOC 5000
Hydraulic conductivity	Falling head permeameter
Moisture retention characteristics	Sand table and pressure plate apparatus
Soil hydrophobicity	Drop test
Soil mineralogy (clay mineralogy)	XRD
Soil pH, sec, cec, water soluble and extractable salts	Various
Vegetation characteristics	Various

Table 1: Different parameters and methods used for the physical environmental assessment.

Establishment of Soil Moisture Sampling Grids and First Results

Six grids for soil moisture measures were installed in the five selected municipalities: 2 grids were located in the municipality of Villar del Rey (Badajoz province) and 1 in each of the other localities (see Fig. 2). The main characteristics of each grid are listed in Table 2.

Grid ID.	Rows/Columns	Rods no.	Aspect	Length (m)	Width (m)	Slope angle
A1	35/16	210	SE	136	20	3.6°
A2	31/6	186	SE	150	25	3.6°
HO	30/6	180	SW	116	20	7.6°
GU	28/6	161	SE	108	20	9.9°
TA	28/6	168	SW	108	20	4.6°
CA	28/6	164	SE	108	20	4.6°

Table 2: Grid characteristics (see Fig. 2 for grid ID location)

Soil moisture measures were carried out during January 1999. The data obtained from the TDR measurements are sintetised in table 3, and plotted for each of the grids in Fig. 4 and 5, showing soil moisture patterns differences among all the land uses selected.

Grid ID.	Average	Maximum	Minimum	Standard Deviation
A1	32.86	40.69	20.94	3.98
A2	28.06	38.03	18.47	3.98
HO	14.93	25.87	7.59	2.99
GU	23.87	36.64	0.00	6.21
TA	29.79	39.38	20.94	3.80
CA	26.42	35.21	0.00	5.69

Table 3: Summary data of percentage volumetric soil moisture.

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References

Díaz, M.; Campos, P. and Pulido, F. J. (1997): *The spanish dehesas: a diversity in landuse and wildlife*. In Farming and Birds in Europe: The Common Agricultural Policy and its Implications for Bird Conservation. Deborah J. and Michael W. Pienkowski Editors. Academic Press, pp179-209.

Campos Palacín. P. (1993): Valores comercia les y ambientales de las dehesas españolas. *Agricultura y sociedad*. 66:9-41.

CSIC (Consejo Superior de Investigaciones Científicas) (1970): Suelos, estudio agrobiológico de la província de Cáceres.Centro de Edafología y Biología Aplicada de Salamanca. Sala manca, Spain.

Schnabel, S. (1997): Soil Erosion and Runoff production in a Small Watershed under Silvo-Pastoral Landuse (Dehesas) in Extremadura, Spain. Geoforma Ediciones. Logroño, Spain. 1997. 167 pp.

De Ploey, J. and Posesen, J. (1985). Aggregate stability, runoff generation and interrill erosion. In: Richards, K. S., Arnett, R. R. ans Ellis, S. (eds.). *Geomorfology and soils*. Allen and Unwin, London, 99-120.

Imeson, A. C. (1986). An eco-geomorphological approach to the soil degradation and erosion problem. In: Fantechi, R. y Magaris, N. S. (Eds.). Desertification in Europe. Proceedings of the information Symposium in the E. E. C. Programme on Climatology, held in Mytilene, Greece, 15-18 April 1984, D. Reidel, Dordrecht, 110-125.

Bryan, R. B.; Govers, G. y Poesen, J. (1989). The concept of soil erodibility and some problems of assessment and applicability. *Catena* 16, 393-412.

Ternan, J. L.; Williams, A. G.; Elmes, A. y Hartley, R. (1996). Aggregate stability of soils in Central Spain and the role of land management. *Earth Surface Processes and Landforms* 21, 181-194.

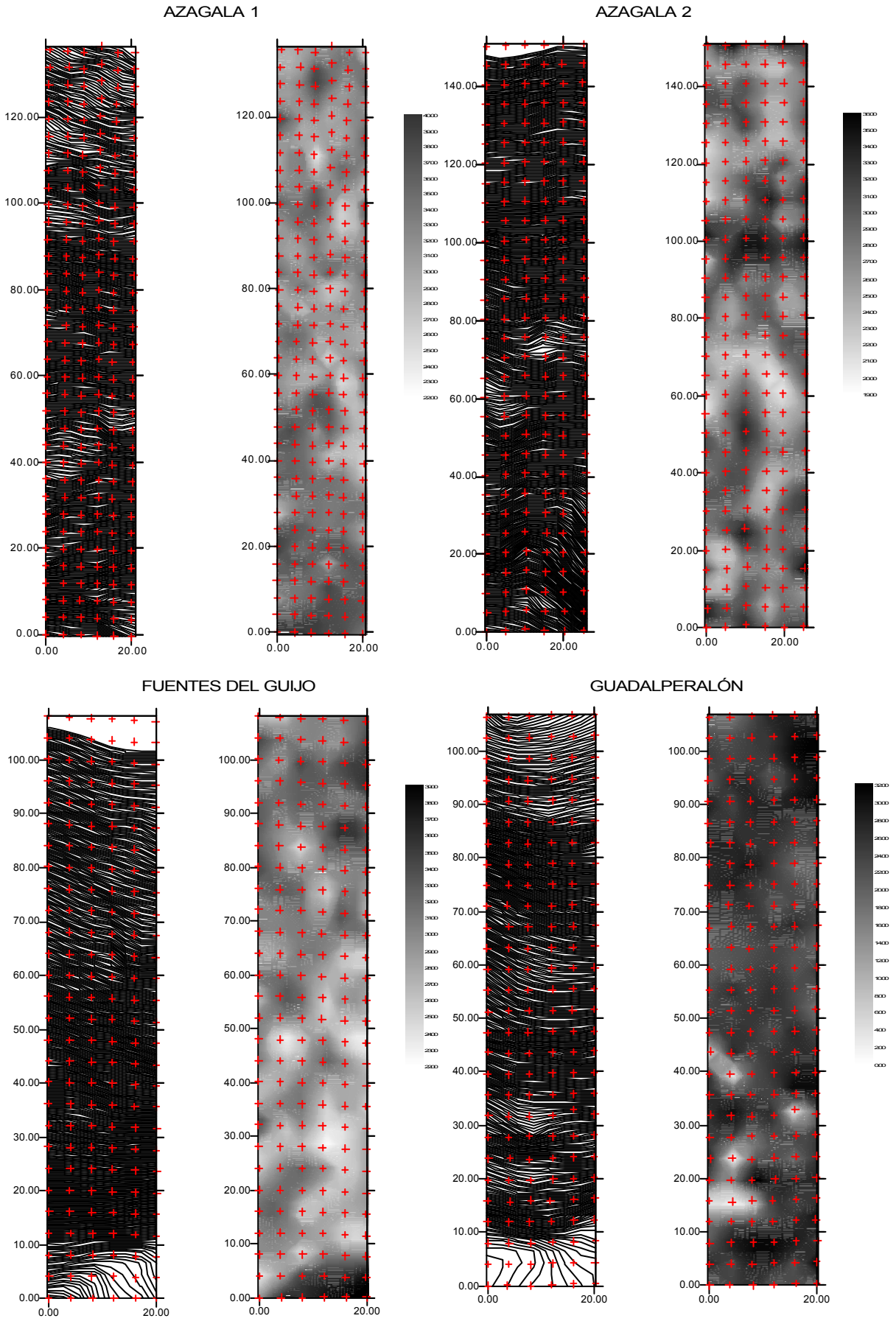


Fig. 4: Microtopography survey (left figures) and soil moisture pattern obtained for the different study sites.

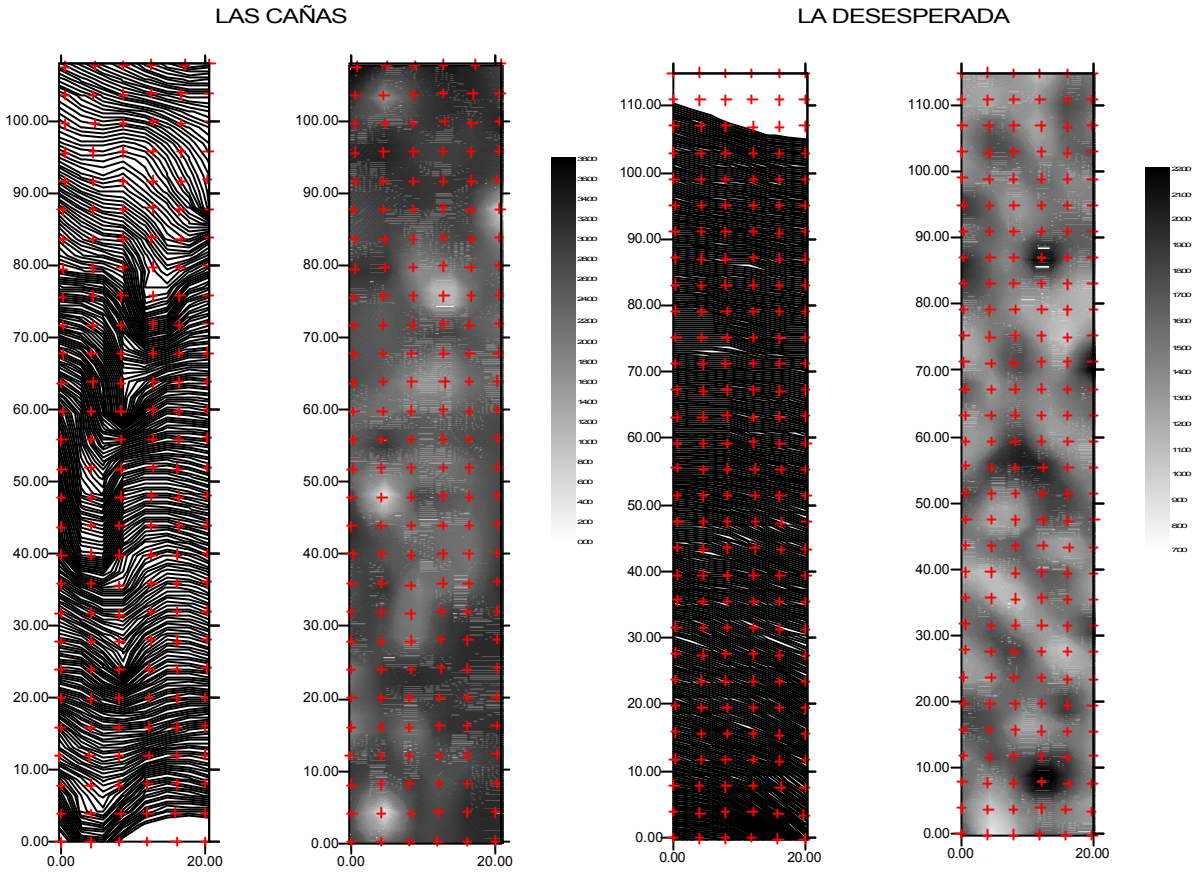


Fig. 5: Microtopography survey (left figures) and soil moisture pattern obtained for the different study sites.

RISK OF LAND DEGRADATION IN MEDITERRANEAN LANDSCAPES: KARST AREAS OF SUPRAMONTE

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Abstract. Recently have been investigated three "pilot" areas which are among the most highly vulnerable to desertification in Sardinia, where the regeneration of soils and vegetation is more difficult. In fact, soil genesis in calcareous areas in Sardinia is a very slow process in that solubilization of the limestones occurs above all in those brief wet periods during the year.
What is more, the soil only develops if the mineral residues are kept in place by an effective plant cover that produces abundant organic matter and ensures its accumulation in the form of litter and humus. When the land is left bare by wood clearance thus resulting in an increase of sunlight and temperature on the ground, this triggers off rapid mineralization of the organic matter which encourages rapid and intense sheet erosion processes. Here surveys have been carried out both in well preserved areas in equilibrium and in severely degraded areas through a series of representative catenas. Degradation and evolution were observed to be directly related to land use.
In the study areas (Lanaitto valley, M. Corrasi, the Montes holm oak forest), province of Nuoro, 40 profiles have been observed along with 8 sample areas ranging from 400 to 2,500 m^2 , in size for studying soils, vegetation and forest structure.

Keywords: Karst areas, degradation indicators, soils, humus forms

Methods and techniques

The research pursued can be divided, as regards methods and techniques, into two main groups:

1. direct field and laboratory investigations, of a qualitative and quantitative kind;
2. indirect investigations based on processing data or on available sources of information.

The first group includes:
a. Soil surveys and relative applications.
In the case at hand, during investigations on the state of preservation of soils and vegetation in karst areas, “free” soil surveys were conducted, so as to facilitate characterization of the map units. Preliminary maps were drawn up at a scale of 1:25,000, which were then used as groundwork for organizing the soil surveys. For a better definition of the single map units numerous field checks were done so as to verify to as great an extent as possible the data drawn from photointerpretation.
Soil profiles were excavated with the aid of mechanical diggers where topography permitted access. In those areas where it was not possible to resort to mechanical excavators the profiles were bored using a hand auger and pickaxe.

The soils were surveyed and mapped as a function of the main pedogenetic factors, namely parent material, topography and present land use. Only in the semi-natural forest at Montes were soil surveys organized as a function of type of plant cover, on account of the relative homogeneity of the geolithology. All the soils samples were grouped into landscape units, following the scheme indicated in the map legend, where the most representative soil profiles are described for each unit.
For classifying the soils the 1994 edition of the Soil Taxonomy System of the U.S.D.A Soil Service has been consulted.
The samples collected have been analysed in the laboratory following standard soil analysis procedures. Texture, pH in water, pH in potassium chloride (KCl), carbonates, organic matter, organic carbon, total acidity, total nitrogen, exchange bases, base saturation and cation exchange capacity have been determined,

b. Survey and classification of humus forms.

In wooded areas the forms of humus have also been described for each soil profile. Of the numerous classification systems available, the taxonomy proposed by R. Green et al (1993) has been adopted, which is simpler than the system proposed by K. Klinka (1981). It is based on the readily recognizable morphological properties such as the sequence of the horizons, their thickness, structure and colour and the organisms present and is organized in a hierarchical manner, similarly to the soil taxonomy. The humus forms have been described for each profile on the basis of field observations.

c. Transect

In order to evaluate the variations of humus forms in space, in the middle part of the most representative sample plots a transect was cut with variable length depending on the surface of the plot, starting from the soil profile and moving uphill along the maximum slope line. Observations were then made, at regular intervals, for describing the morphological properties of the organic horizons, which were then classified as humus forms. Transects were studied in areas under holm oak woods or high macchia in a total of eight sample plots.

d. Vegetation surveys

For the purpose of establishing relationships between variations in vegetation cover and environmental factors, in particular the soil, it was decided to adopt a method that permitted the floristic and vegetation differences as well as the differences in physiognomy to be recognized.
In the terrains studied, differentiations in vegetation may be attributed on the one hand to variations in geomorphology and topography and on the other to a variety of anthropic factors that have brought about profound modifications in the original plant cover over time.
The study of the vegetation, which aimed at defining the diversity of the plant cover and the types of vegetation, focussed on the following aspects:

- determination of the horizontal dimension of the vegetation structure within the sample plots;
- measurement of the vertical dimension (stratification) of the vegetation;
- reconstruction of what effect human intervention has had on the terrains

For quantitative measurements the Braun-Blanquet scale has been adopted:

5	cover of more than 75%	2	cover ranging between 5 and 25%
4	cover ranging between 50 and 75%	1	cover ranging between 1and 5%
3	cover ranging between 25 and 50%	+	cover of less than 1%
		r	rare or sporadic species

The value of the Braun-Blanquet scale has been determined for each layer of vegetation, in accordance with the following structural scheme:

tree layer	height over 5 m
tall shrub layer	height ranging from 2.5 e 5 m
low shrub layer	height ranging from 0.5 e 2.5 m
herb layer	height below 0.5 m

Anthropic interventions can be recognized by the modifications that they have induced in the structure of the forest vegetation, and in the different degradation stages, by the thinning of woody plants, the degree of soil erosion and the denudation of the substrata.
As far as floristic composition is concerned, the main natural factors contributing to its variation are altitude, the nature of the parent material, soil type, slope and exposure.

e. Dendrometric measurements

Dendrometric measurements were carried out so as to quantify wood mass, the number of trees per hectare and to determine the dendrologic composition and density.
Within each sample plot total diameters of all the species of the tree and shrub layers having a diameter at chest height (1.30 m) of over 2.5 cm were measured. Mean diameters around the bark were determined, proceeding downhill in sloping terrains following the contours. The diameters, measured only for live trees, were then grouped into classes (intervals of 2.5 cm) and the basimetric area was calculated for each class.
A Suunto ipsometer was used to measure the height of model trees distributed in the different diameter classes for the purpose of better defining the stratification of the population.
By so doing, the average height of the layers has been calculated for each sample plot along with tree density, intended as the number of total plants or stumps and per species, the number of standards in the coppice, the basimetric composition per species. Data were then referred to one hectare.
The second group includes:

f. Literature search

Includes the collection of literature data, information and work already conducted, available on the research topics and on the areas studied, both in paper and software form (CD-ROM, Internet, etc.) concerning in particular, climate, geology, vegetation, land use, etc.
Considering the wide variety of useful information available for soils, vegetation and dendrometric surveys a large amount of technical and scientific documents had to be examined. However, in some cases, information was fragmentary or data were lacking completely. For some sectors of the karst areas, the general vegetation has been widely studied, given the botanical significance of the zone, but information on climate, paleoclimate, geology and pedology is more difficult to come by.

g. Photointerpretation and remote sensing

Includes stereoscopic vision of aerial photographs for defining land units.

Aerial photography cover, which was not always very recent, was satisfactory for the seminatural areas but less so for urbanised areas, especially for those urban settlements where rapid transformation has taken place.
The following aerial photographs from the library of the Dipartimento di Scienze della Terra have been used:

1. Reg.Sardegna flight 1968, scale ca. 1:23.000 (b/w).
2. Reg.Sardegna flight 1977, scale ca. 1:10.000 (colour).
3. I.G.M. Flight 1987, scale ca. 1:33.000 (b/w).
4. A.F.D. Reg.Sardegna flight 1996 scale ca. 1:20.000 (colour)

Remote sensing techniques and interpretation of 1998 satellite imagery (Landsat TM) will be used for mapping and characterization of the land and environment in karst areas (MODEM Project).

Pedological frames

Climate

In the mountainous area studied here, a clear differentiation in climate can be recognized in relation both to altitude and distance from the sea, but also a differentiation in the mesoclimate in relation to soil slope and exposure, to the soil type and thickness of cover.
In particular, the Valle di Lanaitto area is characterized by a mesothermal climate, from humid to sub-humid but, despite having relatively high rainfall, (annual precipitation of 739 mm in Oliena); the vegetation is limited, owing to the long summer drought and the poor water holding capacity of the soil.
The Montes holm oak forest, with annual rainfall of over 1.100 mm., is characterized by a mesothermal sub-humid climate. Rainfall is concentrated in the autumn and spring months; mean annual precipitation is particularly irregular, ranging from less than 500 mm to over 2,000 mm. Drought persists throughout the summer (about 3 months water deficit according to Thornthwaite).

Characteristics of the (typical) soil profile

Theoretically speaking, in climates such as the one described above, with a climax vegetation composed of holm oak forests on limestone parent material, the soils that have formed are usually represented as follows:

- **A** *horizon*, more or less dark brown as it is enriched in organic matter and characterized by biological activity in alternate cycles;
- **B** *horizon*, brown or reddish whose structure differs from the overlying horizon, characterized by alteration of the primary minerals, high saturation and oxidation;

At the bottom of the profile lies the parent rock, that is generally only weakly altered.
In reality, the soils studied here have been observed to exhibit alterations of a different nature and intensity. These are all the more evident in those zones where the original forest is degraded or has been destroyed owing to the direct or indirect interference of man, including the conversion of high forest to coppice stands and land use changes to make way for agricultural activities, then often abandoned or unprofitable.
In the majority of profiles observed, the organic horizon is thin, highly discontinuous and in some places absent altogether. The most favourable conditions for its development have been found in those places where the forest cover exceeds 85%, with a stratification of the forest structure.

In general, at this stage of the research the following considerations emerged on the development of the soil profiles in relation to soil cover, taking into account the equally important role of the substrata:

- in the upper parts of the slopes, where the shrub cover is discontinuous, the profile is frequently truncated and the soil has formed in small pockets within the rock fractures and is hence weakly developed (Lithic Entisols or Alfisols);
- at midslope, and more limitedly at the foot of the slopes, where plant cover is composed prevalently of holm-oak woods or evolved macchia, the soil profile is generally better developed and better differentiated into horizons, for the most part argillic (Alfisols);
- at the foot of the slopes, in those places where the original plant cover has been destroyed to make way for agro-pastoral activities, the soils are not so well developed, and Inceptisols prevail;
- in all the profiles observed in the valley bottom the soils are immature (Entisols) despite the fact that in some places they are quite deep which has allowed them to be used for agricultural purposes.

In the Lanaitto valley, the more evolved soils are represented by Typic Haploxeralfs and Typic Rhodoxeralfs and the vegetation is composed of tall "macchia" with a predominance of Quercus ilex, Pistacia lentiscus, Arbutus unedo, Smilax aspera, Rhamnus alaternus, the climax formation being a kind of thermophilic holm oak forest.
Where the vegetation is more developed, it produces closed formations where few or no herbaceous species grow because tree and shrub cover is more than 100%, as the layers overlap each other. The prevalent humus form is of the Mullmoder type.
As far as was possible, depending on accessibility, we tried to delineate catenas in the Lanaitto valley that included significant observation points that were also representative of the large area, in relation to the parent material, morphology and soil cover. In some cases, on the other hand, point observations and surveys were also carried out that did not fall into any catena, with a view to gathering further information.
Fig. 1 shows the layout of the catenas.

Characteristics of the (typical) surface soil horizons

From the surveys carried, the humus forms have been observed to be relatively similar in type. Where forest cover prevails, the typical profile of the organic horizons is as follows:

- layer of dry leaves, small branches, buds and bark fragments which compose the litter and which are derived from the partly decomposed plant remains (**Ln** and **Lv** layers);
- thin layer of decomposing litter (**Fz** horizon);
- layer of humus proper, dark brown to black in colour, formed of litter transformed into humus, mixed or cemented with the mineral grains of the soil (**Hz** horizon).

In the majority of cases they can be classified as *Mullmoders* (81% of observations) and more rarely as *Leptomoders* (8%) and *Mormoders* (8%) (Green, Trowbridge, Klinka, 1993).
These forms of humus are characterized by more or less decomposed litter, beneath which usually lies a thin layer of organic matter, reduced to fine crumbs by the soil fauna, and less frequently decomposed by fungi.

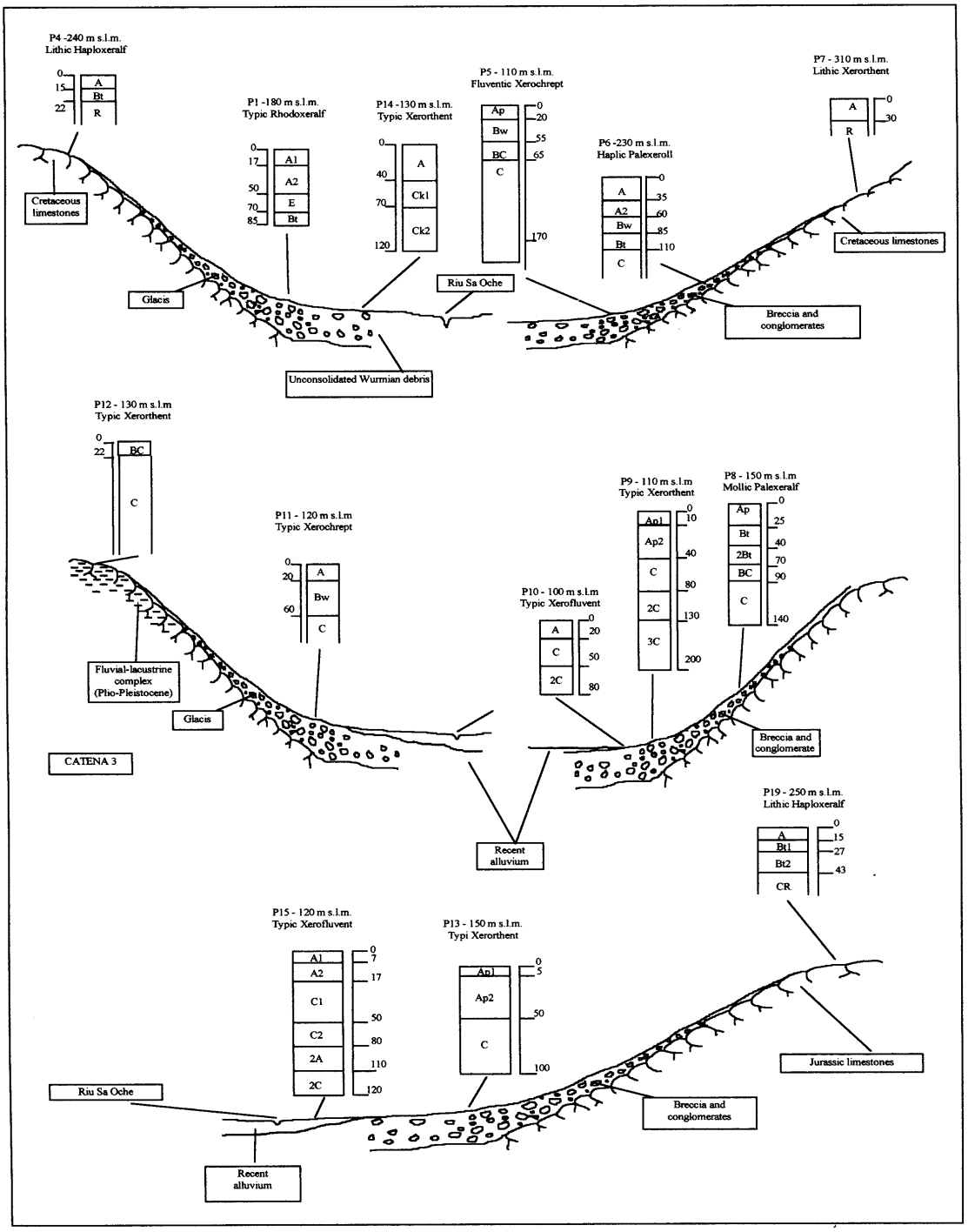


Figure 1: Lanaitto valley – Layout of the catenas.

Lastly there is a layer of humus characterized by a typically granular structure with high porosity, indicative of considerable activity on the part of soil fauna.
In prairie ecosystems Mulls are the most common humus form, in which organic matter is finely intermingled with the top mineral soil instead of accumulating on the surface:

Mulls humus forms are characterized by a well developed A horizon. Rapid decomposition and mineralization of organic matter is encouraged by active populations of soil fauna.
The Mor order can be observed under *Juniperus oxycedrus* cover; in this humus form organic matter accumulates on the soil surface and matted Fm horizons reflect dominant mycogenous decomposers. They are the least biologically active humus forms observed.
In all cases, significant spatial variation has been observed, as can be seen from the transects, with the presence of different phases of the same form of humus.
In particular, the large number of grazing animals (pigs and goats), hinders regeneration of the woods, and they also tread new paths, resulting in compaction and reduced permeability of the soil, deterioration of litter quality. Consequently the humus formation processes are slowed down or impeded locally.
What is more, the density and degree of cover of the holm oaks within the woods varies considerably. These differences do not produce any significant variations in the floristic composition but do lead to strong variability in sunlight penetration and microclimate beneath the canopy which, in turn affects the quality and thickness of the soils' organic horizons. Tab. 1 shows the humus forms observed during the surveys.
In the specific case of the study areas, given the semi-natural conditions existing in certain places, the following parameters have been taken as indicators of desertification:
- thickness and type of organic soil horizons;
- depth of mineral soil;
- organic matter content;
- degree of structure and permeability;
- cation exchange capacity, exchange base and base saturation rate;

The above parameters should be correlated with the following characteristics of the vegetation:
- composition of the flora;
- tree and macchia cover and development
- total biomass.

Thus to define the desertification indicators, the relationships between vegetation, parent material, soil, morphology, exposure and climate should be taken into account.

Indirect assessment of soil erosion.

The clearings created by woodcutting in the past have triggered the onset of soil erosion processes, intensified by slope inclination. Even in those places with relatively dense plant cover, signs of sheet erosion are visible. In the main the effects of erosion are thin organic horizons (for the most part newly formed) and exposure of the tree collar, all the more so on steeper slopes. The loss of soil due to erosion, estimated on the basis of the degree of exposure of the tree collar and roots, ranges from a few to fifty cm, depending on slope. At this stage of our investigations some conclusions can be drawn, based on analysis of the data observed in the 8 sample areas considered being representative and shown in Tab. 2
It emerges from these data that the organic horizons are developed and preserved where tree and shrub cover exceeds 80-85%, in undisturbed conditions. In this case slope seems to play a less important role in the humus and soil formation processes but it

clearly continues to be one of the main causes underlying erosion when the barrier action of the vegetation is reduced or ceases altogether.

ORDER	GROUP	PHASE	OBSERVATIONS
Mull	Rhizomull	-	2%
Moder	Mullmoder	(Typic) Mullmoder	58%
		Turbic Mullmoder	10%
		Lignic Mullmoder	5%
		Turbic Mineric Mullmoder	3%
		Rhizic Mullmoder	2%
		Mineric Mullmoder	1%
		Xilic Mullmoder	1%
		Tenuic Mullmoder	1%
	Leptomoder	Pachic Leptomoder	4%
		(Typic) Leptomoder	2%
		Rhizic Pachic Leptomoder	2%
	Mormoder	(Typic) Mormoder	3%
		Clastic Mormoder	2%
		Lamnic Mormoder	2%
		Mineric Lignic Mormoder	1%
Mor	Hemimor	Clastic Hemimor	1%

Table 1: Humus forms.

A	B	C				D	E	F				
		A	Aa	Ab	E			Ln	Lv	Fz	Hz	Fz+Hz
1	20%	65	30	15	5	1925	34,7	0,5 - 3 - 1,37	0,5 - 2 - 1,06	0 - 2,5 - 1,25	0 - 3 - 1,31	0 - 5,5 - 2,56
2	25%	80	5	5	15	400	69,9	0,5 - 5 - 2	0,5 - 4 - 1,78	1 - 3 ,0- 2,36	1 - 4 - 2,28	2 - 7 - 4,64
3	35%	20	70	50	20	1225	14,5	0,5 - 5 - 2,66	0,5 - 2 - 1,3	1 - 2 - 1,6	1,5 - 3 - 2,3	2,5 - 5 - 3,9
4	60%	60	40	35	5	775	40,9	1 - 4 -1,85	0,5 - 5 - 2,35	0 - 9 - 4,31	0 - 30 - 14,61	0 - 39 -18,92
5	50%	40	30	30	15	2200	31,1	0 - 2 - 0,94	0 - 2 - 0,94	0,5 - 2,5 - 1,5	1,5 - 5 - 3,05	2 - 7,5 - 4,55
6	35-40%	50	<5	<5	20	500	28,7	0,5 - 4 - 1,83	0 - 2 - 0,66	0 - 6 - 1,78	0 - 15 - 5,7	0 - 21 - 7,48
7	2%	80	-	-	5	780	74,1	0 - 3 - 1,56	0,5 - 2 - 0,83	0 - 1,5 - 0,33	0 - 5 - 2,1	0 - 6,5 - 2,43
8	0-25%	85	-	-	15	592	81,4	0,5 - 4 - 1,55	0 - 2 - 0,53	0 - 3 - 1,19	0 - 5 - 1,47	0 - 8 - 2,66

Legend: **A** Sampling area; **B** Slope; **C** % cover referred to the following layers: (A) trees, (Aa) tall shrubs, (Ab) low shrubs, (E) herbaceous species; **D** Number of plants per hectare; **E** Basimetric area per hectare; **F** Minimum, maximum and average thickness of organic horizons in cm. (Classified after Green et al, 1993).

Table 2: Summary of plant cover, dendrometric data and thickness of organic soil horizon.

Considering the important part played by parent material and morphology on the evolutionary trend of the soils in the study area, the most important indicator of soil and plant degradation is land use. It is in fact due to the direct or indirect action of man that the structure of the vegetation varies widely even within confined areas, the density, number and age of the plants being highly irregular. For this purpose, when correlating

plant cover data, it is important to consider the basal area referred to one hectare of land. For tree formations this area should more than 30 m^2 if the organic horizons are to be preserved, while, because of their more compact canopies, for formations of tall shrubs the basal area should be more than 15 m^2.

With regard to the analytic data on Lanaitto valley soils (Table 3), as can be observed profile 2 shows some of the lowest pH values and this may likely be attributed to the higher organic matter and organic carbon content. The same profile also has higher cation exchange capacity and base saturation percentage. These data, together with the dendrometric measurements and observations on the structure of the vegetation, indicate that the sample area N°.2 (*profile N°.2: Tiscali doline*) exhibits the greatest equilibrium. This affirmation is also borne out by the regeneration observed in the area: more than 70 holm oak seedlings were counted (over 1.750/Ha). The large number depends on the fact that grazing is prohibited here.

It should however be noted that, on account of its particular topography, this part of the valley has a peculiar microclimate and the soil, forest and vegetation aspects are all influenced thereby.

Sample area N°.4 (profile N°. 16) is also of significant in that is bears testimony to the existence in the past of woods in the valley floor where olive trees and vines are now cultivated and arable farming is practised, certainly among the most productive in the catchment basin under study.

In this case, as far as the laboratory data are concerned, the situation observed is the opposite of sample area N°.2 inasmuch as here the soils have the lowest organic matter and organic carbon content of the five representative profiles, accompanied by the highest pH values. Possible relationships between these two aspects are to be examined.

Profiles N°. 2, 16 and 17 have the highest base saturation percentage, while some discrepancies exist for the cation exchange capacity, with some of the highest values for profile N°.2 and the lowest for profile N°.16. This feature is associated with the high organic matter content of profile N°.2. The strong variability of the analytic parameters processed to date does not allow them to be used yet as reliable parameters for defining the degree of degradation of the soil. Consequently, for the moment we propose assigning the degree of degradation as a function of state of preservation of plant cover, structure of the vegetation, dynamic stage of evolution of the plants, following the scheme outlined below:

Degree of degradation	Vegetation	Tree cover	Basal area	Average thickness organic horizons
Slight	High forests and coppices with standards	> 85%	> 40 m^2/Ha	> 5 cm.
Moderate	Multilayered woods, average density and/or developed "macchia"	50 – 85%	20–40 m^2/Ha	2 – 5 cm.
High	Poorly developed and/or moderately developed "macchia"	15 – 50%	< 20 m^2/Ha	< 2 cm.
Severe	Degraded "macchia"	< 15%	Small or absent	Small or absent

The above parameters, when accompanied by phytosociological observations, apart from providing indications about the evolutionary stage of the vegetation, can also be applied to silvicultural practices, like for example conversion thinning to high forest of the holm oaks coppices. Of course, on hillslopes, the extent of cutting will necessarily depend on inclination.

Montes holm oak forest

The holm oak forests in the Supramonte can be regarded as mountainous forests (*Aceri monspessulani - Quercetum ilicis* - Arrigoni, Di Tommaso & Mele, 1990) where the predominant structure is a high forest with dense upper layer, of uneven age with sparse or no undergrowth. The forest is old and has never been regularly exploited. Floristically it is characterised by the presence of species associated with mountainous climates such as *Acer monspessulanus, Rosa pouzini.*

In spite of the general equilibrium prevailing in the forest (forest structure, generally regular organic matter flow), there are direct disturbance factors that influence the holm oak forest structure and its functionality (forest cutting and grazing).

Although exploited to a minor extent in the past for firewood, tree cutting was stopped after the last world war except for sporadic cutting by shepherds. This has however left traces in some parts of the stand, where the number of suckers has been observed to increase by 70-80%, even if the coppice has also formed during the course of nature. The abundant presence of suckers can only be partly attributed to wood-cutting, as the major cause appear to be grazing. Pigs and other domestic animals graze on acorns, seedlings and saplings, which are therefore unable to compete with the suckers that are more resistant and grow more rapidly. New suckers then develop on the saplings that animals have grazed on,

Grazing therefore impairs gamic regeneration but it does not prevent it; this fact is also shown by the number of acorns found rotting in the litter and by the number of seedlings (480 holm oak seedlings/ha in area 7, 128/ha in area 8). In spite of grazing, the forest appears to be able to regenerate by seed.

Today the forest still shows indirect signs of the fire in 1931 after which the population of ruminating animals probably increased significantly. Ruminants have probably only had a minor impact on the holm oak forest compared to pigs which by contrast have impaired the perfect functionality of the holm oak forest. The following are evident signs of some functional imbalances, attributable to pig grazing:

- interruption of humus evolution at the Moder stage
- reduction of annelids
- disturbance of the first 15-20 cm of soil horizons
- contribution to surface erosion

Two measures are absolutely essential for holm oak forest conservation:

- exclusion of systematic cuts of any kind and intensity, except for eliminating diseased trees, where required;
- strict fire prevention measures .

As far as conservation is concerned, factors of a socio-economic nature also intervene, that are difficult to suppress in the short term but that may be overcome in the long term, especially excluding grazing all over the holm oak forest area.

Pasture and garrigue ecosystems

As a consequence of the fire in 1931, the ecosystems altered and land use changed, the number of grazing animals increasing in the burned areas.

The numbers of pigs grazing on acorns in the forest has very likely decreased, to be replaced however by other animals (cows, goats and sheep) which have found better and more food under the new plant conditions.
In grasslands where grazing is forbidden, the evolutionary trend towards forest can be clearly observed, while in those where grazing continues this evolution is hindered or even reversed.
With the present number of grazing animals in certain areas a decrease in productivity can be foreseen together with further degradation, which in time will probably reduce livestock numbers. Signs of this trend are the alteration of the plant spectrum, where fodder species diminish, the low biomass increase in areas where grazing is permitted and alteration of soils due to trampling, streamflow, and water and wind erosion (Susmel et al., 1976)

Conclusions

Some considerations may be drawn from the above outline of the natural environment of the Supramonte area, especially considering that this area is going to be included in the rising National Park of Gennargentu.
Planning mitigation strategies and future land uses in an area like this involves defining the optimum Land Utilization Type while reconciling the competing demands for land. Agriculture, including livestock production, is the mainstay of the local economy and for this reason it needs to be supported and improved. This calls for an evaluation of the land suitability to the alternative forms of use, resorting to procedures that guarantee the economic viability and environmental compatibility of the various measures and investments. In this context the choice of land use will depend on the natural resources present; the entire area should be managed with a view to improve production and conservation of its resources. Undeniably, conflicts do exist between the interests of the single individual and those of the community as a whole. Planning a national park requires sensitive management of conflict resolution and public consensus especially on the choice of land use, be it for agriculture, grazing, nature reserve, woodlands, towns, roads, industries, tourism, etc.
Clearly, the best farmland should not be used for urban, industrial or tourist developments and viceversa. Likewise, forest ecosystems should not be transformed into agricultural ones, especially on unarable land. As for forestry plantations, the suitability of the species needs to be first assessed, comparing plant requirements with the environmental qualities and technologies proposed.
In this sense, the study for planning the Gennargentu National Park has identified the areas with different suitability for the alternative kinds of land use, that are both compatible and sustainable, in other words the best uses possible.
The planning of a national park calls for the application of recognised methodologies that also permit continuous updating for improving the economy and making better use of the land.
Agriculture plays a significant role in the socio-economic structure within the park, but this role could be further enhanced by investing in the park using modern planning tools and rational technologies for its transformation and management.
Many difficulties are being encountered in getting the Gennargentu National Park off the ground, on account of the lack of consensus on the part of the local communities.

Perhaps public awareness needs to be heightened, but those opposed to the development of these areas have certainly had a hand in swaying public opinion. They would prefer to leave things as they stand, which can only be deleterious to the local communities and all those who exploit the land either directly or indirectly. The study for the plan of the park indicates the general lines for the development, safeguard and conservation of the natural heritage of the area.

References

Arrigoni P.V. & Di Tomaso P.L. (1991). La vegetazione delle montagne calcaree della Sardegna centro-orientale. *Boll. Soc. Sarda. Sc. Naturali*. **28**: 201-310.

Arrigoni P.V. (1996). Documenti per la carta della vegetazione delle montagne calcaree della Sardegna centro-orientale., Parlatorea, Dip. di Biologia Vegetale, Università di Firenze. **I**: 5-33.

Aru A. (1997) La pianificazione territoriale e la mitigazione dei processi di desertificazione. Il consumo delle risorse non rinnovabili. *Genio Rurale*, **6**: 54-60.

Aru A., Baldaccini P., Dessena M.A., Fantola F., Lai M.R., Loddo S., Madrau S., Puddu R., Serra G., Tomasi D., Vacca A., Vacca S., (1997). La qualità del suolo per un ambiente sostenibile: il caso Sardegna. *Boll. Soc. It. Scienza del Suolo*, **3,** anno XLVII**:** 311-334.

Aru A., Camarda I., Loddo S., Puddu R., Tomasi D., Satta V., Serra G., Vacca A., (1998). Degradation of soil and vegetation in the Santa Lucia field site in Sardinia (Italy). Paper submitted to *Catena* and currently being revised.

Aru A., Loddo S., Puddu R., Serra G., Tomasi D., Pinna G., (1998). Land degradation and desertification indicators in Sardinia. Medalus III - Project 1 - Core project module 1.10, second interim report april-october 1998: in print.

Aru A., Loddo S., Puddu R., Serra G., Tomasi D., Pinna G., (1998). Land degradation and desertification indicators in Sardinia. Medalus III - Project 1 - Core project module 1.10, final report 1997-1999: in print.

Aru A., Melis R.T., Ulzega A. (1982). Alcune considerazioni sull'utilizzazione delle aree carsiche della Sardegna. Atti del II Simposio sulla Utilizzazione delle aree carsiche, Bari-Castellana Grotte.

Carmignani L. et al. (1996) Carta geologica della Sardegna, Foglio Nord, Scala 1:200.000. RAS, Servizio Geologico Nazionale.

Sanfilippo E. (1988). I boschi. Una risorsa fondamentale oggetto di forti antagonismi. in: Boggio F., Pracchi R., Asole A. (ed.), Atlante Economico della Sardegna. Ed. Universitarie Jaca, Banca Popolare di Sassari, Milano: 153-181.

Soil Survey Staff (1994), Keys to Soil Taxonomy, 6th edition. SMSS technical monograph No. 19,. Blacksburg Virginia,: Pocahontas Press Inc., 556

Sommer S., Puddu R., Loddo S., (1998). Indicators of soil consumption by urbanisation and industrial activities. International seminar on Indicators of assessing Desertification in the Mediterranean, Porto Torres (in print)

Susmel L., Viola F., Bassato G. (1976). Ecologia della lecceta del Supramonte di Orgosolo. Annali del CEMV. Ed. CEDAM.

Vacca A., Loddo S., Serra G., Tomasi D., Aru A. (1999). Aspetti della degradazione del suolo in Sardegna (Italia). Mediterraneo **11/12** (in print).

Vacca A., (1999). Effect of land use on forest floor and soil of Quercus suber L. forest in Gallura (Sardinia, Italy). Paper submitted to Forest Ecology and Management.

Profile	**1**				**2**			**3**				**4**			**5**		
Horizon	**A1**	**A2**	**E**	**Bt**	**A1**	**A2**	**Bw**	**A1**	**A2**	**Bw**	**Bt**	**A**	**Bw1**	**Bw2**	**A**	**Bw1**	**Bw2**
Depth cm	0-17	17-50	50-70	70-85	0-15	15-35	35-60	0-35	35-60	60-85	85-110	0-15	15-40	40-90	0-15	15-35	35-70
Total sand %	32.95	38.8	62.6	44.8	51.7	29.75	24.0	37.25	65.2	64.8	40.25	76.2	72.8	72.1	32.1	30.75	34.9
Total silt %	22.35	20.4	14.05	17.55	26.85	42.15	41.6	21.45	8.80	11.35	15.5	4.65	6.85	5.95	21.8	21.05	21.95
Clay %	44.7	40.8	23.35	37.65	21.45	28.1	34.4	41.3	26.00	23.85	44.25	19.15	20.35	21.95	46.1	48.2	43.15
pH in H_2O	7.32	6.87	7.45	7.76	6.97	7.32	7.57	7.90	7.94	8.08	8.14	8.37	8.15	8.26	7.99	8.00	8.11
pH in KCl	6.47	6.07	5.96	6.83	6.58	6.86	6.94	7.01	7.17	7.36	7.39	7.95	7.81	7.96	7.43	7.37	6.93
Total $CaCO_3$ %	traces	-	-	4.5	traces	traces	5.8	4.50	4.25	6.00	6.00	48.25	37.75	25.75	8.25	16.75	29.50
Organic C %	1.83	1.10	0.37	0.49	7.51	6.30	3.43	1.61	0.85	0.71	0.70	1.45	0.91	0.65	3.33	3.05	1.92
Organic matter %	3.14	1.88	0.64	0.84	12.92	10.84	5.9	2.76	1.47	1.22	1.21	2.50	1.57	1.12	5.73	5.24	3.31
Ca^{++}	4465	3080	1835	3485	12480	10400	8560	4760	3930	3530	3285	3740	2845	2410	9400	8260	4860
Mg^{++}	119	134	75	82	266	112	74	126	90	74	74	155	98	84	443	251	164
K^{+}	153	88	25	59	390	212	181	310	214	230	63	142	200	201	575	452	225
Na^{+}	151	148	144	204	208	164	170	143	178	176	210	406	498	314	324	236	266
C.E.C. me/100g	27.85	22.72	13.15	19.87	64.29	58.32	49.25	29.5	23.74	22.46	20.26	16.15	10.99	10.66	40.68	33.45	27.2
Total acidity %	4.06	3.75	2.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Base saturation %	87.28	76.32	79.57	96.14	100	92.72	90.41	88.83	91.29	87.16	89.22	100	100	100	100	100	100

Table 3: Summary of laboratory data.

SAMPLING PLOTS	PARENT MATERIAL	PHYSIOGRAPHIC POSITION SLOPE - EXPOSURE	SOIL COVER	SOIL	HUMUS
P1	Glacis of the ancient Quaternary	Foot of slope 20% - N 350°	Coppice with predominance of Quercus ilex	fine, mixed, thermic Typic Rhodoxeralf	Mullmoder
P2	Recent slope debris	Karst depression (doline within) 25% - N 20°	High forest chiefly of Quercus ilex	loamy-skeletal, mixed, thermic Typic Xerochrept	Mullmoder
P3	Wurmian unconsolidated calcareous debris	Valley floor	Semi-abandoned olive grove	loamy-skeletal, mixed (calcareous), thermic Typic Xerorthent	-
P4	Compact limestones of the Cretaceous	Top of slope 10% - N 65°	Scrubchiefly of Juniperus oxycedrus	very fine, mixed, thermic Lithic Haploxeralf	-
P5	Breccia and conglomerates containing calcareous and crystalline rock fragments of the Eocene-Oligocene	Foot of slope 12% - N 240°	Arable land alternating with grazing land	fine-loamy, mixed, thermic Fluventic Xerochrept	-
P6	Breccia and conglomerates containing calcareous and crystalline rock fragments of the Eocene-Oligocene	Midslope 35% - N 300°	Coppice chiefly of Quercus ilex	fine, mixed, thermic Haplic Palexeroll	Mullmoder
P7	Compact limestones of the Cretaceous	Top of slope >40% - N 320°	Thermoxerophilious macchia, mainly Phillyrea latifolia and Pistacia lentiscus	fine-loamy, mixed (calcareous), thermic Lithic Xerorthent	-
P8	Breccia and conglomerates containing calcareous and crystalline rock fragments of the Eocene-Oligocene	Midslope 30% - N 310°	Area cleared for grazing	fine-loamy, mixed, thermic Mollic Palexeralf	-
P9	Breccia and conglomerates containing calcareous and crystalline rock fragments of the Eocene-Oligocene	Valley floor <1%	Arable land alternating with grazing land	loamy-skeletal, mixed (calcareous), thermic Typic Xerorthent	-
P10	Breccia and conglomerates containing calcareous and crystalline rock fragments of the Eocene-Oligocene	Edge of terrace 10% - N 130°	Riparian vegetation with Alnus glutinosa and ruderal species (Rubus)	fine-loamy, mixed (calcareous), shallow, thermic Typic Xerofluvent	-
P11	Glacis of the ancient Quaternary	Valley floor	Arable land alternating with grazing land	clayey-skeletal, mixed, thermic Typic Xerochrept	-
P12	Plio-Pleistocene fluvial-lacustrine deposits	Terrace scarp 10% - N 170°	Degraded macchia chiefly Cistus monspeliensis	fine-loamy, mixed (calcareous), shallow, thermic Typic Xerorthent	-
P13	Breccia and conglomerates containing calcareous and crystalline rock fragments of the Eocene-Oligocene	Valley floor	Arable land bordered with moderately developed macchia	fine-loamy, mixed (non-acid), thermic Typic Xerorthent	-
P14	Wurmian unconsolidated calcareous debris	Valley floor	Garrigue of Helichrysum microphyllum	loamy-skeletal, mixed (calcareous), thermic Typic Xerorthent	-
P15	Recent fluvial deposits	River bank 25% - N 90°	Riparian vegetation with Nerium oleander	sandy-skeletal, mixed, thermic Typic Xerofluvent	-
P16	Glacis of the ancient Quaternary	Foot of slope 60% - N 110°	Coppice chiefly of Quercus ilex	sandy-skeletal, mixed, thermic Typic Xerochrept	Leptomoder
P17	Recent slope debris	Midslope 50% - N 110°	Coppice chiefly of Quercus ilex	clayey-skeletal, mixed, thermic Typic Xerochrept	Mullmoder
P18	Compact limestones of the Jurassic	Midslope 30% - N 150°	Scrub of Juniperus oxycedrus and Quercus ilex	fine, mixed, thermic Lithic Rhodoxeralf	-
P19	Compact limestones of the Jurassic	Top of slope 70% - N 320°	Coppice chiefly of Quercus ilex	very fine, mixed, thermic Lithic Haploxeralf	-

Tab 4: Summary of the environmental aspects of the sampling stations (Lanaitto Valley).

Sampling Plots	Parent Material	Physiographic Position Slope - Exposure	Soil Cover	Soil	Humus
P20	Detritus slope deposits with Jurassic calcareous-dolomitic rock fragments	Midslope 35% - 110°	High forests of holm oaks with undergrowth chiefly of strawberry trees	loamy-skeletal, mixed, thermic Typic Xerumbrept	Mormoder
P21	"	Slope bottom 30% - 290°	Young Aleppo pine afforestation	sandy-skeletal, mixed, non-acid, thermic Lithic Xerorthent	Absent
P22	"	Slope bottom 75% - 190°	High forests of holm oak	clayey (very-fine), mixed, thermic Typic Palexeralf	Absent
P23	Dolomite and dolomitic limestones of the Dolomie e limestones Dorgali Formation, Jurassic	Doline bottom - / -	Rough grazing land with thyme, , santolina corsica, rosemary, dog rose, helichrysum, Juniperus oxicedrus, prunus, sparse yews (relict of the forest	fine-loamy, mixed, non-acid, thermic Lithic Xerorthent	Absent
P24	Detritus slope deposits with Jurassic calcareous-dolomitic rock fragments	Top of slope 25% - 260°	high forest of holm oaks, sparse	sandy-skeletal, mixed, calcareous, thermic Lithic Xerorthent	Absent
P25	"	Midslope 70% - 170°	high forest of holm oaks, sparse	fine-loamy, mixed, thermic Pachic Haploxeroll	Mullmoder
P26	"	Midslope 35% - 10°	high forest of holm oaks	coarse-loamy, mixed, non-acid, thermic Lithic Xerorthent	Turbic Mullmoder
P27	"	Midslope 25% - 28°	Garrigues with santolina (juniper burned in 1985)	coarse-loamy, mixed, non-acid, thermic Lithic Xerorthent	Absent
P28	"	Depression (polje) - / -	Meadow of asphodel	very-fine, mixed, thermic Typic Palexeralf	Rhizomull
P29	Detritus slope deposits with Jurassic calcareous-dolomitic rock fragments mixed with rock fragments of the crystalline Paleozoic basement	Slope bottom <2% - 150°	High forest of holm oak	fine, mixed, thermic Typic Palexeralf	Mullmoder
P30	"	"	High forest of holm oak	fine, mixed, thermic Typic Palexeralf	Mineric Lignic Mormoder
P31	"	"	High forest of holm oak	fine, mixed, thermic Lithic Haploxeralf	Mullmoder
P32	Dolomite and dolomitic limestones of the Dorgali Formation, Jurassic	karst depression level	Garrigues with santolina (natural pastures)	very-fine, mixed, thermic Lithic-Ruptic Xerochreptic Haploxeralf	Absent
P33	"	gently sloping depression 2% - 70°	Meadow of santolina (natural pastures)	fine, mixed, thermic Typic Palexeralf	Absent
P34	Detritus slope deposits with Jurassic calcareous-dolomitic rock fragments mixed with rock fragments of the crystalline Paleozoic basement	sub gently sloping depression 15% - 120°	young holm oak wood with heather, ferns, lavander, cistus	clayey-skeletal, mixed, thermic Typic Xerochrept	Absent
P35	Dolomie e dolomitic limestones of the Dorgali Formation, Jurassic	gently sloping terrace 360°	High forest of holm oak	not classified	Lignic Mullmoder
P36	"	"	"	not classified	Mullmoder
P37	"	"	"	not classified	Turbic Mullmoder

Tab 5: Summary of the environmental aspects of the sampling stations (Monte Corrasi and Montes Forests).

REMOTE SENSING APPLICATIONS TO LAND RESOURCES AND DESERTIFICATION PROCESSES

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Abstract. Remote sensing and especially satellite remote sensing provides systematic measurements of surface parameters over large areas in a reproducible manner and at frequent rates; therefore it appears as a tool allowing to monitor land resources and their changes related to degradation processes. In this paper the main uses of remote sensing for monitoring desertification processes with high resolution and meteorological satellite data are reviewed and advantages and drawbacks of this technique are analysed.

Key words: Land resources, remote sensing, desertification processes.

Introduction

According to FAO (1976) "land is an area of the earth's surface, the characteristics of which embrace all reasonable stable or predictable cyclic, attributes of the biosphere vertically over and under this area, including those of the atmosphere, the soil and the underlying geology, the hydrology, the plant and animal populations, and the result of past and present human activity". Ecologically unbalanced exploitation of land resources as a result of population growth and inadequate land use practices (excessive grazing, fuelwood collection, uncontrolled fires) are placing ever increasing pressure on the environment. Nations need to make the best choices among options for the use of land in order to support development without hazard of land degradation which lessens the current and/or potential capability of soil to produce goods and services (FAO et al., 1979). When effects of degradation become irreversible, desertification occurs (Giordano, 1998) causing not only the reduction of soil productivity, but also widespread poverty, vegetation damages, reduction of the land's resilience to natural climate variability, undermining of food production (UNCCD, 1992).
In the framework of efforts against desertification and drought the Rio Earth Summit (1992) assumed the "strengthening of the knowledge base and developing information and monitoring systems for regions prone to desertification and drought" as one of the programme areas. To this end the use of remote sensing proves and has proved to be a valuable instrument to evaluate and monitor land degradation and desertification processes. Furthermore the United Nations Convention to Combat Desertification (1994) regards remote sensing as one of the modern tools that can help to combat desertification.
This paper deals particularly with the contribution of Earth observing satellites to the study of changes occurring at the land surface and indicating land degradation and desertification. First, some brief notes on remote sensing principles are given.

Fundamentals of remote sensing

Remote sensing is generally defined as sensing an object or phenomenon without actually coming into contact with it. Its principle aim is to utilise radiation to measure physical parameters of surfaces and to give images from electromagnetic energy beyond the range of human eye. A remote sensing system may be used to detect and measure three types of energy: the first is the reflected solar energy from a surface, whether it is water, a leaf, a roof or a cloud. This will in principle encompass the whole wavelength range of solar energy, but in practice the atmosphere absorbs so much of some energy bands that little can be detected. Between these absorption bands are windows where energy passes through the atmosphere relatively easily, and these are the preferred bands for remote sensing purposes. Secondly sensors may detect energy radiated from the surface and this is principally the thermal infrared wavelength. These two are the passive sensors and dominate because they do not require a source of energy other than the sun, or the radiation coming from the earth's surface; thus thermal infrared may be measured at night. Active sensors involve an energy source on the spacecraft that is directed at Earth and part of the energy scattered at the surface is then measured back at the satellite; the main method uses radar wavelengths.

Remote sensing imagery obtained from aircraft or satellites allows rapid and repeated mapping of large areas, thus permitting a broad range of environmentally important but transient phenomena to be monitored. Moreover remote sensing offers the advantage of a wide spectral coverage: the huge quantity of spectral information contained in multispectral imagery allows features with very subtly different spectral responses or signatures to be differentiated.

Selecting an appropriate source of remote sensing data requires understanding how the resolution of the system will affect the ability to measure the biophysical landscape features that are of interest. There are four types of resolution: spectral, spatial, temporal and radiometric. The spectral resolution refers to the dimension and number of wavelength regions in the electromagnetic spectrum to which the sensor is sensitive; the spatial resolution is the minimum size of terrain features that can be distinguished from the background or whose dimensions can be measured. The resolution element is called pixel and its radiometric value is the average of the values coming from every part of the pixel; generally a good spatial resolution involves a small pixel, but at the same type a small amount of energy is collected so a broad band is required. The temporal resolution is a measure of how often a sensor obtains imagery of a particular area and this is a very important parameter because the timing of image acquisition plays an important role in the possibility of detecting, identifying and analysing the processes of interest. Finally, the radiometric resolution is a measure of the sensitivity of a sensor to differences in the intensity of the radiant flux reflected or emitted from features on the ground; increasing radiometric resolution of a sensor system requires that the difference between one brightness level and the next is greater than the noise level of the system.

Contribution of satellite remote sensing to desertification studies

Remote sensing and particularly satellite remote sensing is the only available system performing systematic measurements of surface parameters over large areas, in a reproducible manner

and at frequent rates; therefore, it appears as a tool allowing to monitor desertification spatially and temporally. Seen as a process, not as a final state, desertification can not be assessed by occasional inspection of the landscape (Bolle, 1994). It is rather necessary to follow with high precision changes of parameters able to provide information about the interaction between the atmosphere and the surface during the sequence of the vegetation cycle and interannually. Therefore one of the problems remote sensing has to face, relates to the different time scales at which changes and observations might occur. The need for appropriate time sequences to document changes in the vegetation cycles in different years rules out the use of high resolution imagery (Landsat TM, SPOT, etc) for global studies since the frequency of cloudfree observations is too low in many parts of the world and the amount of data to be analysed would be too large. Medium resolution data as offered presently by meteorological satellites (NOAA/AVHRR, METEOSAT) causes however other interpretation problems because of the mixture of surface types present in the pixel sizes of 1.1km x 1.1km. Therefore, the study of desertification requires a twofold approach: the use of medium resolution satellite data for frequent overviews and high resolution satellite data to zoom into critical and vulnerable areas (Bolle, 1994).

It has to be realised from the beginning that measurements from space can not replace local investigations at the ground to study the complex process of desertification such as the substitution of vegetation species by more resistant ones, the thinning out of the vegetation cover, the loss of biomass, the loss of soil by erosion, the increasing extent of the unsaturated zone in soils, demineralisation, salinisation and the related change of the soil-vegetation-atmosphere transfer of water and energy. Remote sensing measurements can pick up indicators of the change of land-surface characteristics, which are related to parameters governing the desertification process (Hill et al., 1994). However, although is agreed that remote sensing provides a convenient source of information, the problem is that raw measurements such as the surface radiance in a specific wavelength has not particular meaning for the ecologist or pedologist and cannot be used as it is. For this reason more usable indices can be derived from satellite images, having the advantage of being a fast and easy first step of data processing, which is not strongly alterating the original information content of data, while eliminating some of the noise due to differences in atmosphere and instrument calibration between dates (Escadefal, 1994).

Three types of indices can be obtained by linear combination of measurements in the spectral domains of red (0.4-0.5 μm), green (0.5-0.6 μm) and near infrared (0.7-2.5 μm) bands: Brightness index, Redness index and Vegetation index.

Several brightness indices can be found in literature, but the following general formulation can be used:

$$BI=\sqrt{G^2 + R^2 + IR^2}$$

As an example, a decrease in brightness can be due either to the wetting of soil surface after rainfall , to an increase in plant cover or in soil roughness. With simple ground information it is easy to discriminate among these possible causes. If the brightness change is determined to be due to a higher plant cover, then the change measured from space has been translated into ecological terms of significance for land degradation study.

Colour indices by definition are limited to the visible spectral range, i.e. the two red and green bands. Globally soil surface colour changes are due to the presence of more or less reddish

soil materials (Escadefal et al., 1989). The simple normalised difference between the two bands expresses the redness of the surface (Escadefal and Huete, 1991):

$$\text{RI}=\frac{R-G}{R+G}$$

A decrease in the Redness Index generally corresponds to the thinning of the surficial sandy soil layer (Escadefal et al., 1993). In this case this leads to a lowering of water intake and seeding emergence capabilities of the soil, indicating undergoing desertification. In the case of higher Redness Index values, the interpretation might be just opposite: erosion of the organic topsoil exposing the lower layers of a red soil.

More used are the vegetation indices: the most widespread is the Normalised Difference Vegetation Index (NDVI). It is based on measurements of the reflection in the two spectral channels of red (R) and near infrared (NIR):

$$\text{NDVI}=\frac{IR-R}{IR+R}$$

In desertification studies this index can only be used to indicate vulnerable areas and to assess in a qualitative way changes of land surface characteristics (Bolle, 1994). In fact, although NDVI was developed to normalise canopy spectral responses from soil and illumination contributions (Rosema and Roozekrans, 1994), it has been shown that there are soil-induced influences on the vegetation index in areas showing sparse vegetation (Meliá, 1994). To minimise soil brightness influences, Huete (1991) proposed the Soil Adjusted Vegetation Index (SAVI):

$$\text{SAVI}=\frac{IR-R}{IR+R+0.5}\cdot(1+0.5)$$

An abundant literature describes the relationships between the vegetation indices and plant cover, biomass, LAI (Leaf Area Index). However, vegetation index changes must be interpreted with care, according to local conditions. As an example, in certain situations an increase in vegetation index does not necessarily mean an improvement of the soil surface condition. When this corresponds to the replacement of perennial shrubs by annual plants, it is rather an impoverishment of the biological potential. In the other hand, a low and steady vegetation index does not necessarily corresponds to unchanging vegetation. In arid areas shrubs are often photosynthetically inactive and the vegetation cover affects only the brightness index (Escadefal, 1994).

All the indices described above for detecting soil and vegetation degradation are generally derived from high resolution satellite data (Landsat TM and Spot), with the only exception of NDVI. Another important approach for characterising desertification is based on the monitoring of energy and water balance of the earth surface at national to regional scale by meteorological satellites, such as NOAA and METEOSAT. In table 1 the main characteristics and applications in desertification studies of all the mentioned satellites are summarised.

METEOSAT can provide information on rainfall, net radiation and actual evapotranspiration. NOAA cannot provide the rainfall information, but instead is used for deriving NDVI. Rainfall and net radiation data, as derived from METEOSAT satellite, can also be used to derive the aridity index that is the ratio between the incoming net radiation and the energy required to evaporate the rainfall. An analogue index is the Desert Index (Rosema and Roozekrans, 1994) which is given by the ratio between net radiation and evapotranspiration.

	LANDSAT	SPOT	METEOSAT	NOAA
Spatial resolution	30 m	10 m	5 km	1 km
Time resolution	16 days	26 days	½h	6 h
Image width	185 km	60 km	Earth disk	2500 km
Spectral bands:				
visible	3	2	1	1
near Infrared	3	2		1
thermal Infrared	1		2	3
Application:				
soil degradation	+	+		
vegetation cover	+	+		+
net radiation			+	+
evapotranspiration			+	+
rainfall			+	

Table 1: Overview of the characteristics and applications of the main operational satellite systems

Conclusions

Land degradation and desertification are caused by an ecologically unbalanced exploitation of land resources and inadequate land use practices. Remote sensing is regarded as one important tool for monitoring land resources and their changes indicating the advancement of desertification processes. Two are the possible approaches: the first relates to the derivation of indices of soil and vegetation degradation, the second to the monitoring of energy and water balance of the earth surface. High resolution images offer a higher spatial and spectral resolution but a lower temporal one; meteorological data at the contrary have a low spatial resolution but a very high temporal frequency. Therefore the integration of the two types of data is necessary. Finally, it must be emphasised the importance of a retrospective analysis of Earth observation satellite images which are available for almost 20 years. The integration of these data, available climatic records and ground measurements may help to understand the causes of degradation and desertification processes.

References

Bolle H.J. (1994). Remote Sensing in desertification studies. In Desertification in a European context - Physical and socio-economic aspects. Report EUR 15415 EN.

Earth Summit - Agenda 21 – The United Nations Programme of Action from Rio (1992). Final text of the United Nations Conference on Environment and Development (UNCED), 3-14 June, Rio de Janeiro, Brasil

Escadefal R., Girard M.C., Courault D. (1989). Munsell soil color and soil reflectance in the visible spectral bands of Landsat data (MSS and TM). *Remote Sensing of Environment*, **27**: 37-46.

Escadefal R. and Huete A.R. (1991). Improvement in remote sensing of low vegetation cover in arid regions by correcting vegetation indices for soil noise. C.R. Acad. Sc. Paris, 312, Sér. II: 1385-1391.

Escadefal R., Pontanier R., Belghith A. (1993). Propriétés spectrales des surfaces et télédétection de variations spatiales et temporelles de l'infiltrabilité de sols arides (Menzel Habib, Tunisie). In Actes des Journées de Télédétection de l'AUPELF, December 1993, Tunis.

Escadefal R. (1994). Simple remotely sensed land surface parameters: a rationale for land degradation monitoring in arid Mediterranean areas. In The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin. Experts workshop - State of the art and future research, 13-15 June 1994, Valencia, Spain.

FAO (1976). A framework for land evaluation. *Soil Bulletin*, **52.**

FAO/UNEP/UNESCO (1979). A provisional methodology for soil degradation assessment. Roma.

Giordano A. 1998. Soil and soil conservation with focus on remote sensing. Relazioni e monografie agrarie tropicali e subtropicali, nuova serie no. 116, Studio Editoriale Fiorentino, Firenze.

Hill J., Sommer S., Mehl W., Mégier J. (1995). Land degradation, soil erosion and desertification monitoring in Mediterranean ecosystems. *Remote Sensing Reviews*, **12**:107-130.

Huete A.R. (1988). A soil adjusted vegetation index (SAVI). *Remote Sensing of Environment*, **25**: 295-309.

Meliá J.(1994). Use of soil and rock spectral signatures for natural vegetation cover estimation. In The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin - State of the art and future research. Expert workshop, 13-15 June 1994, Valencia, Spain.

Rosema A., Roozekrans H. (1994). Practical approaches to desertification monitoring using meteorological satellite data. In The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin - State of the art and future research. Expert workshop, 13-15 June 1994, Valencia, Spain.

UNCCD United Nations Convention to Combat Desertification (1994). UNEP/IUC, C.P. 356, Geneva Executive Center, 1219 Châtelaine, Switzerland.

INTEGRATING UNIVERSAL SOIL LOSS EQUATION AND DIGITAL ELEVATION MODEL TO EVALUATE SOIL EROSION RISK AT THE WATERSHED LEVEL. THE CASE STUDY OF KOCABA RIVER BASIN (CZECK REPUBLIC)

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Abstract. This work has been completed during 1998 as final degree thesis in Environmental Sciences, Faculty of Sciences, University of Milan, in collaboration with the Chair of Physical Geography and Geoecology, Faculty of Sciences, Prague Charles University. Main goal of the study has been the estimation of the erosion produced in a watershed situated in Central Bohemia (Czeck Republic). On that area, during the years 1995-1997, has been made by the Chair of Physical Geography an Geoecology and by the Chair of Social and Regional Geography of the Charles University a multidisciplinary research project called "Project for the development of the upper Kocaba river basin region", which had as main aim, the identification of a development strategy of the region, which was at the same time environmentally sustainable and economically feasible. In this context appeared interesting evaluate the level of the erosion of the river catchment. For this purpose has been choose a soil erosion model, the Universal Soil Loss Equation. The main aim was determine the areas where the erosion was significant and where would be necessary intervene with minimization strategies. To do that has been integrated the soil erosion estimated by the model with the maximum soil loss tolerance to produce a soil erosion risk map, a first, important tool for the policy makers.

Key words: Universal Soil Loss Equation (USLE), maximum soil loss tolerance, soil erosion risk.

Introduction

Erosion is a process by which soil is moved from one area to another. At present, the main natural agents of erosion are wind and water. Erosion occurs naturally on cropland, forested land, and in urban areas, but this process can be accelerated by human activity (such as agriculture, forestry, and urban development) to levels that cause environmental and economic problems.
Erosion removes organic matter from the soil and contributes to the breakdown of soil structure. These losses in turn affect soil fertility, the movement of water into and from the soil surface, and crop yields. Yields from severely eroded soils may be 50-100% lower than those from stable soil in the same field.
In this context appears fundamental have tools able to predict the entity of soil erosion to evaluate the real risk of soil loss in determinate areas. Soil erosion models are a important instrument to do that; in particular the Universal Soil Loss Equation can be useful because of the relatively few data that needs, in comparison with others models,

more difficult to apply. A second advantage is its perfect integrability with geographical information system technique. In fact, the multiplicative structure of the equation fits good to be reproduced in a multilayer raster framework, typical of G.I.S. application. Each factor of erosion forms an informative layer in Arc/Info Grid extension; the product between the single factors provides a result in terms of soil loss per time unit [ton/ha year]. For that reasons USLE was chosen as soil erosion model for this work.

The study area

The study area is the Upper Kocaba River Basin, located in Central Bohemia (Czeck Republic), 50 Km far from Prague (fig. 1). It consists of approximately 118 Km^2. The maximum altitude is 625 meters on sea level, the minimum 360 meters, the average 454; the maximum slope is 17°, the minimum 0°, the average 2.9°. The land is covered by agricultural land, forests, water ponds and urban (tab. 1)

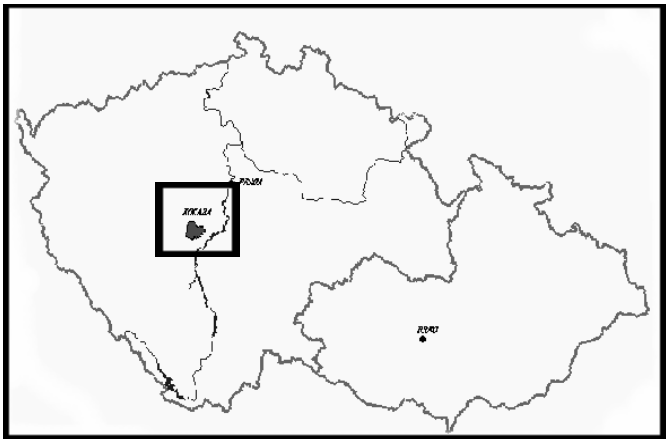


Figure 1: The study area.

Land use typologies	Surface (ha)	Percentage (%)
Arable crops	5223.2	43.97
Permanent grass	1279.1	10.77
Forest	4134.8	34.74
Water	151.1	1.27
Urban	822.0	8.22
Others	120.8	1.03

Table 1: Land use of the study area.

The land is mostly hilly and is characterized by slowly slopes, tilled by maize, wheat and barley, interrupted by little forests, ponds or permanent grass; the forests are placed in the most sloping areas at the edges of the basin, near the borders of the study area (fig. 2). The region is passed through by three little rivers, named Kocaba, Sykrosky and Kotencicky and by many tributary creeks giving a total hydrographic network length of

113.5 Km. The streams are often surrounded by permanent grass fields, consequent of the environmentally difficult conditions to grow culture.
The pedological processes that occur more frequently are:

- Zonal processes like liscivation and brunification, typical of temperate middle humid climate, where the morphology is mostly hilly and flat;
- Azonal processes, independent from the climatic belt, but present everywhere occur specific conditions like waterlogging, regular succession of flood events and low soil tickness.

The main typologies of soils that occur in the study area are therefore Cambisols (FAO, 1990), Albic Luvisols, Eutric Luvisols belonging to the first kind of processes, Gleysols, Planosols, Fluvisols and Leptosols, belonging to the second one.
The temperature and the precipitation data (tab. 2) come from the Czeck Institute of Agrometeorology of Prague. They are derived from daily measures at the meteorological station of Hostomice, situated near the north-western border, just outside the study area. The most of the rainfall falls during the late spring and the summer (65%).

Month	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rain.(mm)	28,7	30,2	35,3	42,9	67,5	75,8	67,3	59,3	45,6	30,2	36,1	27,8	546,7
T (C°)	-1,8	-0,5	3,3	7,8	12,7	15,8	17,6	16,9	13,4	8,5	3,5	-0,1	8.11

Table 2: Average monthly precipitation and temperature.

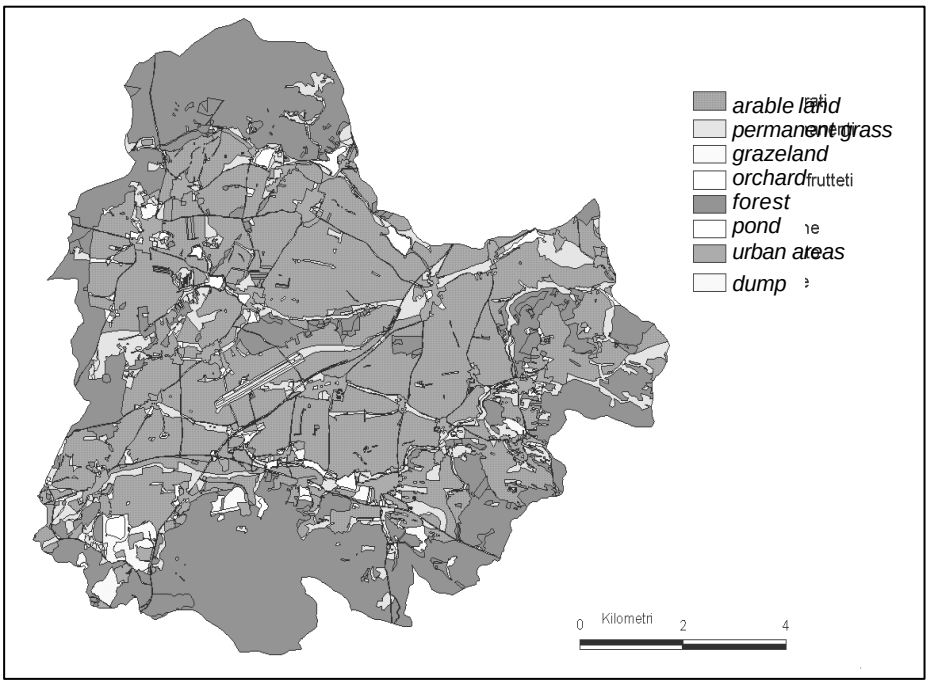


Figure 2: Land cover map of the study area.

The Universal Soil Loss Equation

The Universal Soil Loss Equation (Wishmeier et Smith, 1978), developed at the United States Agricultural Department (USDA) during the 50s, is the most used equation to determine the yearly average soil loss, depending on the pluviometric regime, on the soil characteristics, on the terrain morphology, on the land cover and on the conservative practices eventually adopted.
It doesn't predict the deposition and considers only the rill and interrill erosion, not the gully erosion. It can be used not only for agricultural, forest and grazeland, but even for areas subjected to urbanisation processes.
The equation has the following structure:

$$A = R\ K\ L\ S\ C\ P \quad [1]$$

where:

- A = yearly average soil loss per unit area [ton ha^{-1} $year^{-1}$]
- R = rain erosivity factor [MJ ha^{-1} mm h^{-1} year-^{1}]
- K = soil erodibility factor [ton MJ^{-1} mm^{-1} hour]
- L = length factor [adimensional]
- S = slope factor [adimensional]
- C = cover and management factor [adimensional]
- P = conservative practices factor [adimensional]

Each factor has been derived from elaboration on existing data collected during the project and represents a layer in a G.I.S. environment. The multiplicative overlay between the factors produces the final erosion result. In the next chapter will be shown the methodology used in the present work to calculate the erosion factors which appear in the equation.

Application of the USLE

The rain erosivity factor R describes the climate aggressiveness and, in this work, was furnished by the Czeck Institute of Agrometeorology and derives from 50 years rainfall records. The value in International System Unit was 200 MJ mm ha^{-1} h^{-1} $year^{-1}$ (Janecek, 1995).
The soil erodibility factor K reveals the soil particles attitude to be removed from an erosional agent, in this case water. It depends on the fine sand, silt and clay percentage, on the organic matter content and on judgement on the permeability and the structure of the topsoil. Having the digitalized soil map of the study area and 70 soil chemical analysis, has been possible to associate to each soil typology the necessary characteristics to determine the K factor (tab. 3).
The soils have a moderate erodibility because of the low content in organic matter (except Gleysols and Fluvisols) and the texture, mostly loam.
The length factor L and the slope factor S usually are united in a single factor called topographic factor LS. To calculate this factor has been used an algorithm developed ad the Institute of Agricultural Hydraulics of the Faculty of Agriculture of the University of Milan which differs a lot with the method indicated by Wishmeier and Smith in 1978. In fact, the authors consider the topographic factor function of the slope length and of the acclivity of a standard plot.

Soil	OM (%)	C (%)	S+fS(%)	Struct.	Perm.	K(S.I.)
Gleysols	4,08	23,0	43,7	2	5	0.029
Orthic Luvisols	1,77	16,0	48,6	1	3	0.036
Albic Luvisols	2,07	15,7	48,6	1	3	0.035
Fluvisols	3,89	18,4	55,4	1	4	0.032
Haplic Cambisols	1,96	10,4	48,3	1	2	0.036
Gleyic Cambisols	2,45	13,1	49,2	1	3	0.037
Dystric Planosols	2,21	17,4	46,4	2	3	0.032

Table 3: The K factor.

In case of watershed, that factor formulation falls because the land has irregular shape and can be considered formed by many slopes. For that reason, in the present work, in order to calculate the topographic factor have been used the tools furnished by G.I.S. techniques in general, and by Digital Elevation Model (D.E.M.) in particular.
A D.E.M. describes the earth surface in the three spatial dimensions, from a series of sample data referred to a reference surface. In this case, the D.E.M. has been generated using the Topogrid Arc/Info function from the 10 meters equidistance. It produced a Grid with cell size 20 m x 20 m, simulating the land surface irregularity. The D.E.M. quality has been evaluated from the comparison between the automatic stream network, derived from the D.E.M. and the real one, available as Arc/Info coverage.
The next step, in order to derive the topographic factor, was the application of the algorithm cited above. The algorithm uses the D.E.M. to determine the flow paths generated from each watershed cell to the final cell of the channel network. This procedure is used to determine the single flow direction from each cell to the one of the eight neighboring ones, according to a steepest slope criterion. The network that is obtained by following backward the flow direction, starting from the control section, is connected and space filling. The cells area so identified, contribute to the flow at the control section of the channel network and substitutes the slope length factor described by Wishmeier and Smith. The following expression defines, in mathematical terms, what above said:

$$L_j = \frac{\left[\left(a_j\right)^{m+1} - \left(a_j - d^2\right)^{m+1}\right]}{22{,}13^m \times d^{m+2}}$$

where:
Lj = L factor for the j cell
aj = contribuiting area to the j-esima cell
d = dimension of cell size in the grid
The last operation was the elimination of the channel network from the grid derived from the algorithm application because the L_j expression considers only the flow producted along the slope till a drainage network cell. At the end, each cell had a unique L value, depending on the area contribuiting to the flow.
For the Slope factor, the method was the same as shown by the authors in 1978.
The cover and management factor describes the protection offered by every land cover typology on the soil. In order to calculate it, has been associated to each land cover a

yearly coefficient which could change from 0 (total absence of protection) to 1 (total protection). In order to compute the C coefficient of the cultivation it has been necessary to divide the year in cropstage periods, each one characterized by cover and management effect approximately uniform, because of the change of effectiveness of plant cover during the year. For the other typologies of land cover it has been sufficient to give a unique yearly value of C because of the low cover changes in the course of the whole year. The final result was a Arc/Info coverage in which every land cover typology was associate to a single cover a management factor value.
The conservative practices, in the study area, are not taken; therefore has been given a unique value 1 to the whole region.
The factors Arc/Info coverage have been then converted in raster format to permit the multiplicative overlay between them.
The product of the USLE factor grids produced the final soil loss map. The result, in particular was a grid in which each cell had a soil loss value. In table form, these are the final results of the application of USLE to the study area with reference to the three main typologies of land use because it has been revealed as the control factor of the entity of the erosion in the study area. (tab. 4).

Erosion classes	Forest(%)	Permanent grass(%)	Arable land (%)
0-0.5 ton/ha year	97,6	95,7	6,5
0.5-1 ton/ha year	1,9	3,4	16,9
1-2 ton/ha year	0,5	0,8	25,5
2-4 ton/ha year	0.0	0.0	22,9
4-10 ton/ha year	0.0	0.0	20.8
> 10 ton/ha year	0.0	0.0	7,3
	100	100	100

Table 4: The erosion classes of the study area.

It appears clearly that forest and permanent grass belong to the first two classes and don't present erosional problem. The arable land belong uniformly to the different classes and present significant problems of soil erosion.
The final erosion data has been compared with plot measures of erosion made in a basin with morphological, climatic and environmental characteristics similar to the one studied located 30 Km far from Prague. Even if the result has only a indicative value, has been obtained a good accordance between the erosion estimation and the real field measures.

Definition of the Soil Erosion Risk

The comparison between the estimated erosion and the soil depth, main parameter to define the real erosion vulnerability, is useful to determinate the total surface in which the maximum acceptable soil loss is exceed, like defined by the Research Institute for Soil and Water Conservation (VUMOP) in Zbraslav. It depends in fact from the depth of soil; in detail, if the soil is < 30 cm thin, the threshold value is 1 ton/ha year, if the

soil depth is between 30 and 60 cm, it's 4 ton/ha year, if the soil is more than 60 cm depth, it's 10 ton/ha year (Janecek, 1996). When these threshold values are exceeded, are necessary measures able to minimise the erosional process like, for example, the introduction of new agronomic practices (rotation, minimum tillage). In this case, only for agricultural soil because of the lack of depth data for forest soils, has been possible to integrate the erosional class information with the soil depth class, to determine the percentage of the soils in which the maximum soil loss tolerance has been exceeded (tab. 5). In the Upper Kocaba River Basin, almost a quarter of the agricultural soils is in critical conditions.

Erosion classes (ton/ha year)	Depth classes (cm)	Area (Km^2)	%
1-2	< 30	1.0	1.6
2-4	< 30	1.0	1.6
4-10	< 30	3.9	6.4
	30-60	4.6	7.5
> 10	< 30	0.5	0.8
	30-60	1.9	3.1
	> 60	1.2	2.0
Total		14.1	23.0

Table 5 : Area and percentage of agricultural soils in which the maximum soil loss tolerance is exceeded.

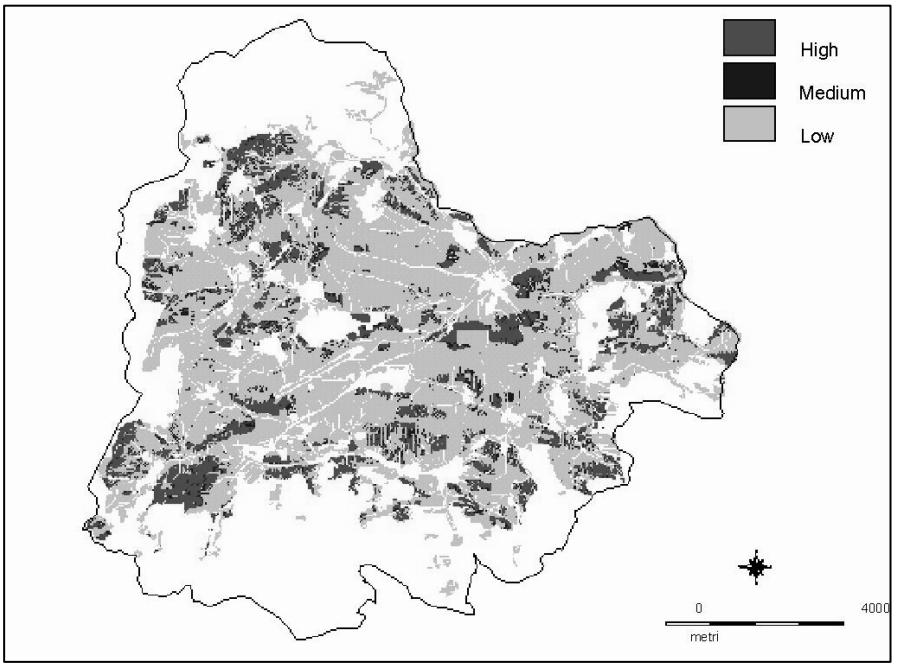


Figure 3: Soil Erosion Risk Map.

In figure 3 is reproduced the Erosion Risk Classes Map, defined by integration between the USLE erosion estimation and the depth class data. To the High Risk Class belong the soils in which has been exceeded the maximum soil loss tolerance. The risk of soil loss irreversibility and of the consequent productivity decrease is very high; on these areas it would be necessary to intervene in order to minimise the entity of erosion. The Medium Risk Class includes the soils which are close to the previous condition; in case of an erosion increase they would pass probably to the High Risk Class. The Low Risk Class, finally, is formed by soils which don't have any erosional problem, since the soil formation rate is higher than the soil removal rate.
The Soil Erosion Risk Map, derived from the application of an erosion model like the Universal Soil Loss Equation permits to evaluate the erosion level in an area subjected to soil degradation phenomenon and the Soil Loss Risk Map can be an instrument having important practical implication, being a decision support element for the policy makers. In fact, from the soil risk classes zonation is possible the identification of the more susceptible areas to erosion processes and in which mitigation measures would be necessary in order to reduce the problems connected to the soil loss.
In this application is appeared that some cultures, especially maize, don't offer sufficient protection to the soil and it would be important to have more information in order to intervene with proper mitigation measures.

Conclusion

The application of the U.S.L.E. on the Kocaba River Basin underlines that, even in areas characterized by uniform morfology and by low climate aggressiveness, the erosion level can be significant. The protection of the soil resource appears a important need because of the general medium fertility of the agricultural land. It could be inferred by correction in the land use practices, theme strictly related to the one studied in the present work. In particular the Soil Erosion Risk Map provides a first tool to identify the areas in which would be necessary intervene in order to reduce the probably reduction of agricultural productivity in the next years.
The use of an erosional model within G.I.S. permits to integrate informations, that come from different disciplinary fields maintaining a unitary and at the same time synthetic vision of the problem.
From a methodological point of view, the water flow, which produces the erosion and is contained in the LS USLE factor could be better simulate, considering even the obstacles which modify the flow along the slopes.

References

Bergsma (1996), Terminology for soil erosion and conservation; *ISSS, ITC, ISRIC*, pp 291.

Bicik I., Sefrna L., Perlin R. (1998), Harmonizace regionàlnìho rozvoje povodì Kocàby-Zàvèrecna zpràva ùkolu RE 5507; *Prìrodovèdeckà fakulta UK, katedra sociàlnì geografie a regionàlnìho rozvoje katedra fyzickè geografie a geoekologie*; pp 51+69+54.

Bischetti G. B, Gandolfi C., Whelan M. J. (1997), Valutazione distribuita della perdita di suolo in un bacino alpino mediante integrazione tra USLE e modello digitale del terreno; *Atti del convegno nazionale di ingegneria agraria, Università degli Studi di Ancona*, Vol 1, pp. 191-200.

FAO-UNESCO (1990), Soil Map of the World, Revised Legend, *FAO-UNESCO-ISRIC*, Roma.

Janecek M. (1995), The potential risk of water and wind erosion on the soils of the Czech Republic; *Scientia Agricolturae Bohemica*, no. 26, pp. 105-118.
Wischmeier W. H., Smith D. D. (1978), Predicting rainfall erosion losses. A guide for conservation planning*; U.S. Department of Agriculture, Agriculture Handbook* , no. 537.

PLANT SPECIES DIVERSITY AS INDICATOR OF RESTORATION QUALITY: THE CASE OF SOILS AMENDED WITH SEWAGE SLUDGE IN ABANDONED QUARRIES

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Abstract. The use of plant species diversity (including especies richness, diversity indices and evenness indices) and species composition as indicator of restoration quality is discussed in the context of ecological restoration. The application of these parameters to a case study of soil amendment with sewage sludge in abandoned quarries is presented. An accurate description of the methodology used according to the case-specific carachteristics is given. First results show that sewage sludge amendment has a clear effect on increasing plant cover and plant biomass in the first stages of secondary succession, although differences in plant cover have almost disappeared six years later. Plant species richness decreased in sewage-sludge-treated plots, while diversity and evenness indices were not related to treatment. Species composition, including exotic plants, was analysed in terms of similarity, but a clear relation to treatment is not found. These first results show that, although some diferences are detected in plant species richness, there are probably other factors (environmental factors, colonization, competition) that play an important role in plant species diversity, so more analysis are required in order to assess the utilization of plant species diversity as an indicator of restoration quality.

Key words : Restoration quality indicators, plant species diversity, abandoned quarries, sewage sludge amendment.

Introduction

Restoration ecology deals with the goal of the re-eestablishment of a lost or degenerated indigenous, historic ecosystem (National Reserach Council, 1992; Bakker et. al 1998). Although the achievement of this objective is extremely difficult given that a deep understanding of ecosystem structure and function at both spatial and temporal scale is required, ecological aspects are essential in restoration projects if we want to succeed in returning an ecosystem to the closest approximation of its condition before it was degraded. These aspects consist of the improvement of the abiotic (even biotic) conditions of the degraded ecosystem to facilitate the development of a self-organising process that will lead to the eestablishment of a sustainable ecological community in space and time, which results thus in a functional ecosystem.
Some indicators of the state of the restored ecosystem are required to assess the achievement of restoration project goals, which may range from returning the ecosystem to the predisturbance state to improving the whole or some of ecosystem functions

(Pastorok et al., 1997). Therefore, ecosystem diversity and functions represent key elements to evaluate the developement of this process through time.
From the view point of scientific knowledge, there is some degree of uncertainty about the way in which species diversity is related to the functioning of an ecosystem (Ehrlich, 1993). However, from the view point of conservation, indicators of both parameters can be used to assess the ecological health in restoration project monitoring (U.S. Environmental Protection Agency, 1990).
According to the definition of disturbance as 'a change in conditions which interferes with the normal functioning of a biological system' (van Andel et al., 1987), the work of van Andel (1998) concludes that an specific measure of species diversity, estimated as species richness, can be used as a criterion for normal ecosystem functioning as long as one evaluates a comparable range of ecosystems. Thus, plant species richness is applicable as indicator of ecosystem quality in cases of restoration towards a formerly existing ecosystem. Other plant diversity measures, such as similarity and dissimilarity indices based on species composition, can be used to quantify the comparisons.
Plant species richness as indicator of ecosystem quality is narrowly related to restoration projects dealing with nature conservation, but cannot be a target in restoration management on its own (Mortimer et al., 1998) because of conflicting goals with the conservation of other groups of organisms, e.g., insects. Thus, a proper definition of restoration goals is neccesary as a prerequisite for its evaluation (van Andel, 1998).
Many restoration projects of abandoned quarries, however, do not consider plant species diversity as a mesure of ecosystem quality, instead they are focused on aesthetical criteria, such as the reduction of visual impacts. Thus, in the context of ecological restoration, improving ecosystem quality should be incorporated as a major restoration goal and plant species diversity can be used to its estimation.

Case study: soil amended with sewage sludge in abandoned quarries

Here I show the use of plant species diversity as indicator of restoration quality in the application of urban sewage sludge to the rehabilitation of soils in abandoned quarries located in the north-east of Spain. The main objectives of these restoration projects were: first, to accelerate plant cover eestablishment and successional processes by soil amendment with sewage sludge, and second, explore new ways of sewage sludge removal as it is a major environmental problem in the region.
The utilization of sewage sludge in soil amendment is based on the fact that it is a source of organic matter and nutrients (specially N, P and trace elements) and it has a favourable effect on soil erosion reduction (Sort et Alcañiz, 1996) by enhancing soil physical properties (Epstein, et al., 1976; Morel et Gukert, 1981). However, the presence of organic pollutants, pathogenic organisms and heavy metals content, reduces its application as organomineral manure in order to avoid possible ecological damage.
Since 1990, this kind of rehabilitation of abandoned quarries (mostly limestone quarries) is being developed in the region, focusing, by now, mainly in two goals: soil physical and chemical improvement and dense plant cover eestablishment. But given that there is the aim to include this rehabilitation experiences in the context of ecological restoration, indicators of ecosystem structure and functioning are required.

In this paper I assess the utilization of plant species diversity, including species richness, diversity indices and eveness indices, besides plant community composition, as indicators of ecosystem state and, thus, of restoration quality.

Experimental Design, Materials and Methods

Given that experimental design was established after the applications of sewage sludge in the abandoned quarries, some limitations related to the presence of sinchronic control areas, seeding and non-equivalent doses were found. Figure 1 shows a general diagram of the process and details about each step.
Finally, six sites (Table 1) were selected from a total of 11 quarries treated with sewage sludge, and two plots (about fifty square meters) per site were established, one plot corresponding to the soil plus sewage sludge treated area (T: treatment) and other plot corresponding to the area treated only with soil (C: control).

Site no.	Name	Altitude (m.)	Latitude	Longitude	Rehabilitation Date	Mean annual temperature (C°)	Mean annual rainfall (mm.)
1	Rubau	210	42º02'10"N	02º49'02"E	12/1992	14,5	825
2	República	223	42º01'44"N	02º50'12"E	06/1994	14,5	825
3	Alfarràs	370	41º50'00"N	00º34'37"E	03/1995	13,5	475
4	Collserola	455	41º26'05"N	02º05'46"E	07/1995	14,5	575
5	Terrassa	270	41º34'47"N	02º02'18"E	09/1996	14,5	625
6	Alcover	712	41º17'23"N	01º06'55"E	03/1996	12,5	725

Table 1: Summary of site numbers, names, altitude, locations, ages, mean annual temperatures and mean annual rainfall .

Some studies about succession in abandoned quarries include monitoring vegetation establishment over several years in response to different treatments using permanent plots (Hambler et Dixon, 1986; Davis, Lakhani et Brown, 1993), but this method needs a considerably amount of time before obtaining old plots. Other studies analysed the revegetation of different sections of quarries that have been abandoned sequentially (Reiking 1979; Usher 1979), which implies to have this kind of abandonement process in the case study. Finally, other successional studies on gravel pits (Aarsen et Epp, 1990; Borgegard, 1990) and on clifs faces of limestone quarries (Ursik et *al.*1997) have used chronosequences as substitute for observation of vegetation change over time at a single site, assuming that spatial variation among sites of known ages will accurately reflect temporal changes (Whittaker, 1989).
According to the characteristiques of the case study, the cronosequence method was selected, although only six sites were available for the analysis, from one to five years old (samples were taken in June 1998). Ten transects (ten meters long) were established in each plot and vegetation contacts to a vertical stick were registered every twenty centimeters, including plant species identification. An associated area (ten square meters) to each transect was defined and plant species presence/absence data were

registered. Total and relative plant species cover, relative species abundance, Simpson (D) and Shannon (H) diversity indices and Simpson's (J) and Shannon's (E) evenness (for complete detail of the mathematical expressions see Magurran, 1989) were measured with the data from the transects and the associated areas (when possible). Rank abundance diagrams were represented for each treatment. Plant biomass was measured in each plot using ten circles (0.2 square meters) disposed randomly in the plots.

Highly disturbed areas, such as abandoned quarries, may be very vulnarable to plant invasions (Tilman, 1993), particularly to exotic species. As most plant invaders in the Mediterranean Basin are herbaceus (Quézel, 1985; Wacquant, 1990), this parameter is suitable to be applied in our case study in which herbaceous community is found. Thus, exotic species abundance and richness were measured in the same plots where soil and plant community parameters were established.

In order to assess the differences in species composition between the amended plots and the no amended ones, similarity coefficients, Jaccard (J) and Sorenson (S) (see Magurran, 1989) were used. Although these indices are quite simple to calculate, they do not incorporate the relative abundance of species, therefore each species has the same weight in the equation, independently if it is rare or abundant. To incorporate the values of relative abundance of each species a modified version of the quantitative Sorenson's index, the sumatory of the minimun relative abundances of each common species (Q) was used.

Soil physical and chemical parameters from both treated and control areas were measured using ten samples per plot form transect locations.

Results

Table 2 shows that only pH (H2O and KCl) and niquel content are statistically different when comparing soil characteristiques of treated plots with control plots. However, differences are found in individual analysis of each site in almost all parameters except those related to texture.

As shown in Table 3, plant cover and dry biomass were higher in treated plots than in control plots. However, plant species richness decreased in the trated plots. Diversity indices and evenness indices did not change due to the treatment. From data of species composition, four functional groups (herbs, grasses, legumes and woody plants) were established and significant differences were only found in legumes in terms of relative abundance.

Similarity measures (Figure 2) calculated from the data of the associated areas (presence/absence) showed a range of similarity between treated and control plots from 0.7 to 0.2, but without correlation to site age. Jaccard and Sorenson indices presented a similar behaviour for all sites, although lower similarities corresponded always to Jaccard index when compared to Sorenson values. Lowest similarity was found on site 3, which correspondes to the dryest one, but correlations betwen similarity values and environmental variables (as mean anual temperature or mean annual rainfall) were not found.

Plant species composition was determined using data from transects . Table 4 shows the main species found and their relative abundance in each site and plot, including main exotic species presence.

Exotic species number and relative abundance were determined using data from transects, and Shannon and Simpson diversity indices were calculated (Table 5). The number of exotic species was significantly higher in control plots than in the treated ones, although differences were not found in terms of relative proportion of exotic species reffering to the total number of species. Diversity indices calculated only for exotic species did not show significant differences between treated and control plots.

Parameter	T	C	P-value
pH (H2O)	7.75±0.30	8.27±0.23	0.0002
pH (KCl)	7.30±0.16	7.60±0.11	0.0156
CEC(μS/cm)	1598.7±1299.7	1157.3±860.9	0.4452
>2000 μm gravels (%)	72.8±10.8	66.7±10.31	0.1516
2000-200 μ m coarse sand (%)	22.8±12.29	24.2±14.36	0.7806
200-20 μ m fine sand (%)	27.8±8.13	22.3±11.76	0.4316
20-2 μ m silt (%)	22.3±5.40	25.3±5.92	0.1613
<2 μm clay (%)	27.0±7.0	28.2±5.0	0.3632
CaCO3 (%)	18.8±13.0	21.7±13.4	0.3917
Organic matter (%C)	2.4±1.7	1.0±1.2	0.1347
Total P (mgP/kg soil)	246.0±231.0	76.0±15.6	0.0510
Total Zn (mg kg^{-1})	81.3±41.8	179.0±115.6	0.1700
Total Pb (mg kg^{-1})	93.06±65.6	88.9±36.4	0.8110
Total Ni (mg kg^{-1})	37.42±26.4	47.2±31.1	0.0155
Total Cu (mg kg^{-1})	36.28±35.9	111.74±100.9	0.1690
Total Cr (mg kg^{-1})	26.64±11.4	44.12±25.74	0.1017

Table 2: Analytical characterization of the soil from treated (T) and control (C) plots (paired t-test; n=6).

Parameter	T	C	P-value
Plant cover (%)	96.1±4.6	78.2±16.0	0.0211
Dry biomass (kg/ha)	192.2±80.8	73.5±65.5	0.0061
S	30.8±9.5	41.5±14.2	0.0450
H	2.3±0.2	2.7±0.4	0.0842
D	6.6±1.1	9.2±4.1	0.2373
J	0.69±0.06	0.72±0.04	0.6112
E	0.23±0.09	0.22±0.06	0.8607
HE (%)	68.6±9.4	63.8±6.9	0.2845
G (%)	24.6±7.6	18.9±9.3	0.2618
LE (%)	3.5±4.7	13.5±4.4	0.0108
W (%)	3.3±0.8	3.9±2.8	0.6147

Table 3: Plant community parameters in sewage-sludge treated plots (T) and control plots(C). (S=species richness; H=Shannon index; D=Simpson index; E= Shannon evenness; J=Simpson evenness; HE: herbs; G: grasses; W: woody plants; LE: legumes). (Paired t-test; n=6).

A strong correlation between age and the quocient *control plant cover/treatment plant cover* was found (see Figure 3). After approximately six years, this quocient achieves a value of one aproximately, showing that differences have almost disappeared. Other correlations between age an different plant community parameters were done in order to detect possible temporal changes, but significant correlations were not found.

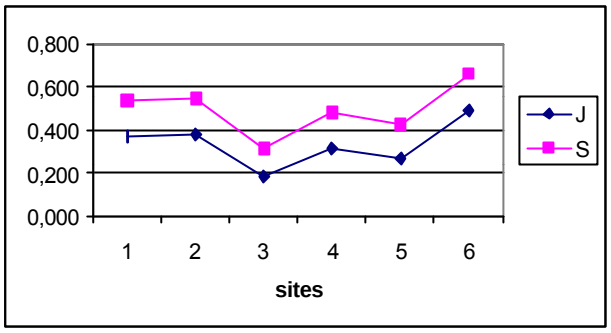


Figure 2: Similitude index among treated plots and control plots for each site, sorted by site age using data fron associated areas. (Jaccard: Cj=j/(a+b-j); Sorenson: Cs=2j/(a+b); a= number of species in plot T; b=number of species in plot C; j=number of common species).

	T	C	P-value
Exotic species number	2.2±1.2	3.8±1.2	0.0108
Exotic species/total species	0.068±0.026	0.099±0.036	0.1426
H (only exotic species)	1.3±0.3	2.0±0.9	0.0807
D (only exotic species)	6.2±2.3	6.9±1.9	0.0782

Table 5: Differences in exotic plant species diversity measures among treated (T) and control (C) plots using data from transects (paired t-test; n=6). (H:Shannon index; D:Simpson index). (Paired t-test; n=6).

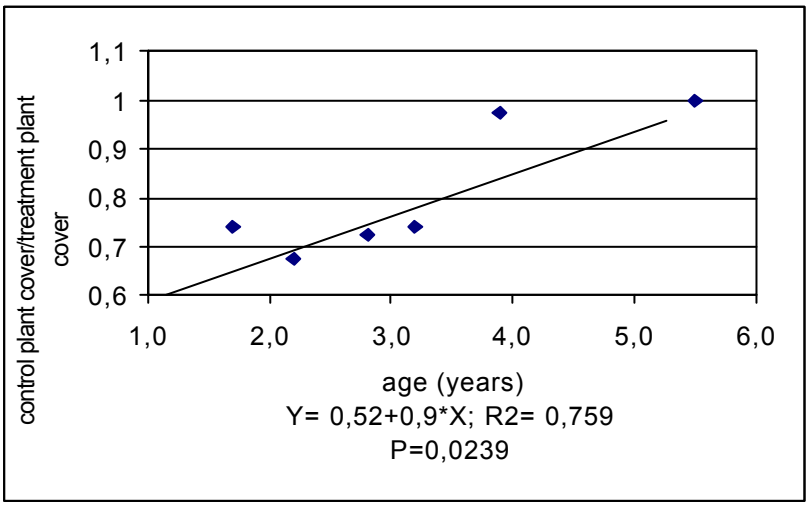


Figure 3: Correlation between site age and the quocient control plant cover/treatment plant cover.

Discussion

The case study chosen to explore the use of plant species diversity as indicator of restoration quality presents some problems related to site characteristiques which affect the results obtained. These problems are related to seeding, different doses of sewage sludge and different application techniques as well as different plant communities in the surroundings of treated and control plots. Soil analysis showed that, although general differences between treated and control plots were not found, strong differences appeared when analysing each site individually. Environmental variables also play an important role in the maintenance of plant species richness (Tilman & Paccala, 1993), so further analysis which incorporate these parameters are required, specially because climatic characteristiques of sites are highly variable in the case study.

The chronosequence methodology implies working with a considerable number of sites that only differ in terms of age. In the case study presented only six sites were selected and the period covered was six years approximately. Under these conditions, temporal changes in vegetation community could be difficult to establish. Differences in plant cover between treated and control plots (in terms of relative plant cover of control plots respect to treated plots) have almost disappear in six years, which shows that the initial effect of sewage sludge in this parameter decreases in time. Other correlations between plant community parameters such as dry biomass, species richness and similarity were not found. The existence of different environmental conditions in each site could influence this process given that the oldest site was also the most humid.

Plant species richness was higer in control plots when compared to treated plots with a paired t-test, which means that the treatment has an effect on this parameter, although a temporal correlation was not found. The functioning of this effect can not be established from our data, but disturbance mechanisms (Solbrig, 1993) and soil fertility (Marrs, 1993) could play an importan role. Other diversity measures, such as diversity indices or evenness indices did not showed this effect, probably because of the high variation of site conditions.

Given that disturbance and nutrient addition have a major role in the invasion of annual plants (Hobbs, 1988) we expected to find an higher number of exotic species in treated plots than in control plots, but the results obtained were the opposite. But if species richness related to the total number species per plot was compared, differences were not found. More analysis is required in order to determine if treated areas are more vulnerable to plant invasion and therefore, to the utilization of parameters related to exotic speciess diversity as restoration quality indicator.

Lower relative abundance of legumes in treated plots showed that sewage sludge affects plant community compossiton probably due to an effect on increasing soil nitrogen content. The establishment of other functional groups could detect other effects.

Conclusions

The utilization of plant species diversity to qualify the state of the ecosystem and, therefore, as restoration quality indicator represents a key element in the evaluation of the achievement of ecological restoration goals.

Plant species richness can be used as a measure of ecosystem quality in restoration towards a formerly existing ecosystem, as in the case of abandoned quarries. In the case

study analysed, this parameter represents an advantage compared to diversity and evenness indices given that they do not showed differences and their obtention implied a considerable amount of time. Plant community compossition and similarity measures can be used to compare different restoration practices, as the sewage sludge amendment.

References

Bakker J.P., van Andel J., van der Maarel E. (1998) Plant species diversity and restoration ecology: an introduction. *Applied Vegetation Science*, **1**: 5-9

Bolós O., Vigo J., Masalles R.M., Ninot J.M. (1993) Flora Manual dels Països Catalans. Pòrtic, Barcelona.

Davis B.N.K.., Lakhani K.H., Brown M.C. (1993) Experiments on the effects of fertilizer and rabbit grazing treatments upon the vegetation of a limestone quarry floor. *Journal of Applied Ecology*, **22**: 473-490

Ehlrich P.R. (1993) Biodiversity and Ecosystem Function: Need We Know More? In E.D. Schulze and H.A. Mooney [Eds] Biodiversity and Ecosystem Function. Springer-Verlag, Berlin, pp 7-11

Epstein E., Taylor J.M., Chaney R.L. (1976) Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. *Journal of Environmental Quality*, **5**: 422-426

Hambler DJ., Dixon JM. (1986) An experimental approach to the reclamation of a limestone quarry floor: the fourth to seven years. *Environmental Conservation*, **13**: 337-345

Hobs R.J., Atkins L. (1988) Effect of disturbance and nutrient addition on native and introduced annuals in plant communities in the western Australis wheatbelt. *Australian Journal of Ecology*, **13**: 171-179.

Magurran A.E. (1989) Diversidad ecológica y su medición. Ediciones Vedrà, Barcelona.

Marrs R.H. (1993) Soil Fertility and Nature Conservation in Europe: Theoretical Considerations and Practical Management Solutions in M. Begon and A.H. Fitter [Eds] Advances in Ecological Research, **24**: 242-300

Morel J.L., Guckert A. (1981) The influence of sewage sludge applicatiuon on physical and biological properties of soils. In G.Catroux, P.L'Hermite and E.Suess [Eds] Proceedings of a Seminar Organised Jointly by the Comission of the European Communities, Directorate–General for Science, Research and Development and the Bayerische Landdesanstalt für Bodenkutur und Pflanzènbau, Munich, pp 25-42.

Mortimer R.R., Hollier J.A., Brown V.K. (1997) Interactions between plant and insect diversity in the restoration of lowland calcareous grasslands in southern Britain, *Applied Vegetation Science*,**1**: 101-114.

National Research Council (1992) Restoring aquatic ecosystems: science, technology and public policy. National Research Council Comission on Geosciences, Environment and Resources. National Academy Press, Washington, DC.

Pastorok A.P., MacDonald A., Sampson J.R., Wilber P., Yozzo D.J., Titre J.P. (1997) An ecological decission framework for environmental restoration projects. *Ecological Engeneering*: **9**: 89-107

Quézel P. (1985) Definition of the Mediterranean region and origin of its flora. In Gómez-Campo C. [Eds] Plant conservation in the Mediterranean Area, Junk, Dordrecht, pp 9-24.

Solbrig O.T. (1993) Plant traits and adaptative strategies: their role in ecosystem function. In ED Schulze and HA Mooney [Eds] Biodiversity and Ecosystem Function. Springer-Verlag, Berlin, pp 97-116

Sort X. & Alcañiz J.M. (1996) Contribution of sewage sludge to erosion control in the rehabilitation of limestone quarries. *Land degradation & development*, **7**: 69-76

U.S. Environmental Protection Agency (1990) Environmental Monitoring and Assesment Program, Ecological Indicators, EPA/600/3-90/060. Hunsaker, C.T., Carpenter D.E. [Eds] U.S. Environmental Protection Agency, Ofice of Research and Development, Washington, DC.

Tilman D. (1993) Community Diversity and Succession: the Roles of Competition, Dispersal, and Habitat modification. In ED Schulze and HA Mooney [Eds] Biodiversity and Ecosystem Function. Springer-Verlag, Berlin, pp 327-344.

Tilman D., Paccala S. (1993) The Maintenance of Species Richness in Plant Comunities in R.E. Ricklefs and D.Schluter [Eds] Species Diversity in Ecological Comunities: historical and geographical perspectives. The University of Chicago Press, Chicago, IL, pp13-25.

van Andel J., Bakker J.P., Snydon R.W. [Eds] (1987) Disturbance in grasslands: causes, effects and processes. Junk, Dordrecht.

van Andel J. (1998) Two approaches towards the relationship between plant species diversity and ecosystem functioning. *Applied Vegetation Science*, **1**: 9-14.

Wacquant JP. (1990). Biogeografical and physiological aspects of the invasion by *Dittrichia* (*exInula*) *viscosa* W Greuter, a ruderal species in the Mediterranean Basin. In F di Castri, A Hansen and A Debussche [Eds] Biological invasions in Europe and the Medeterranean Basin. Kluwer, Dordrecht, pp 353-364.

Whittaker R H (1989) The vegetation of the Storbreen Gletschervorfeld Jotunheimen, Norway. III. Vegetation-environment relationships. Journal of Biogeography, **16**: 413-433

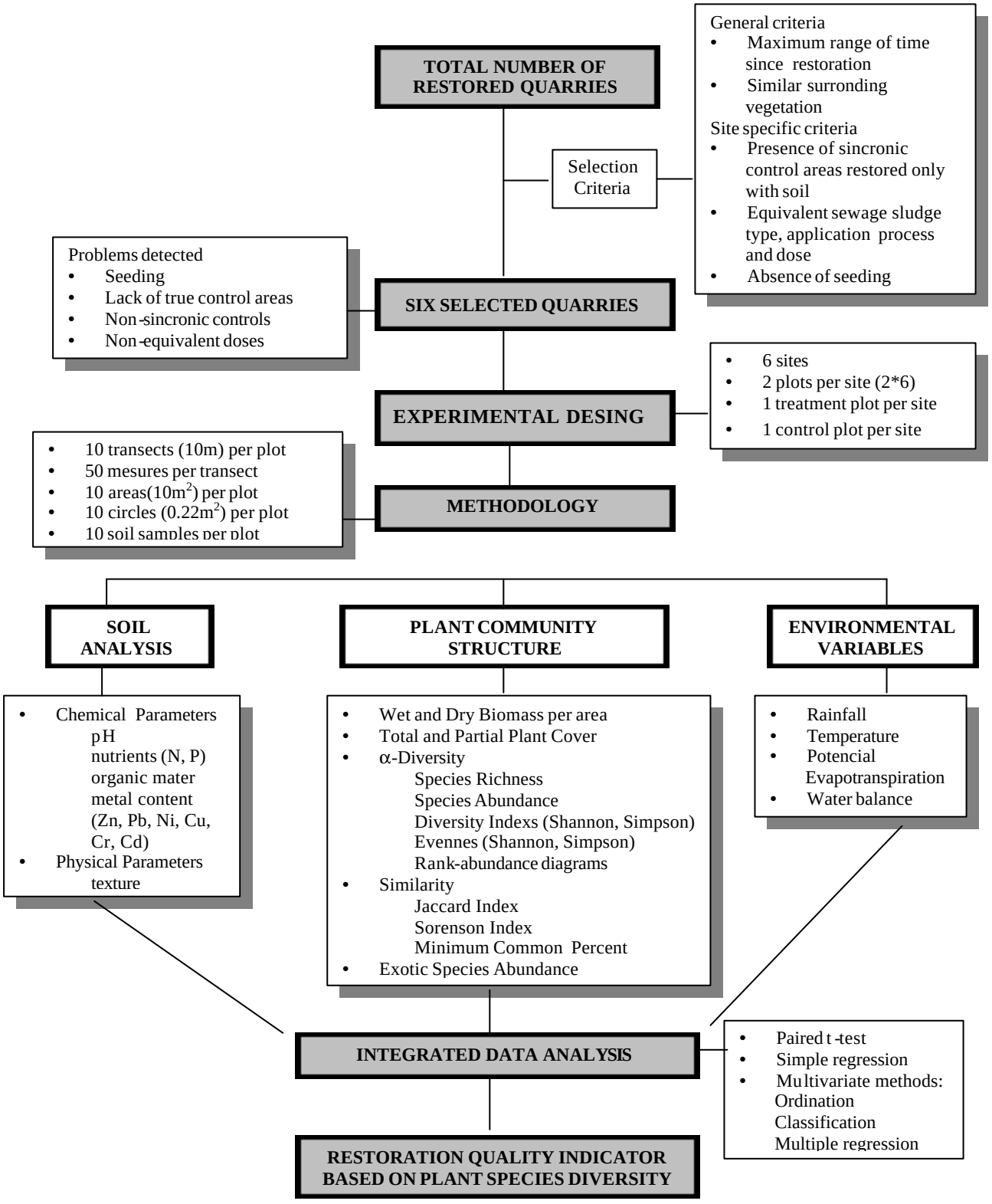


Figure 1: General study steps and case study details. Comments about each part are given in the text.

	Rubau		República		Alfarràs		Collserola		Terrassa		Alcover	
	T	C	T	C	T	C	T	C	T	C	T	C
Alopecurus myosuroides	-	-	-	-	-	4.33	-	-	-	-	-	-
Arrhenatherum elatius	-	0.80	8.04	20.73	-	-	-	-	-	-	-	-
*Aster squamatus**	-	-	-	-	0.26	0.78	2.41	7.31	-	0.43	0.08	0.14
Avena barbata	31.25	17.50	-	-	-	-	-	-	-	-	-	2.756
Avena sterilis	-	-	24.34	1.34	-	-	18.51	-	-	-	1.63	4.29
*Bromus catharticus**	-	1.16	10.05	-	-	0.98	-	-	-	-	1.88	7.70
Bromus rubens	0.41	-	-	-	1.44	30.31	3.89	-	-	3.69	6.44	4.88
Bromus sterilis	19.06	6.39	-	0.36	3.93	-	0.42	-	-	-	-	-
*Conyza bonariensis**	-	-	-	0.26	4.18	0.98	-	0.24	-	-	0.40	0.74
*Conyza sumatrensis**	-	-	0.10	0.71	-	-	-	1.70	1.13	7.39	-	-
Dactylis glomerata	5.42	10.84	7.73	7.47	-	0.39	-	-	0.19	-	2.94	16.72
Daucus carota	2.60	0.62	-	16.01	-	-	-	-	2.64	2.21	-	0.14
Echium vulgare	-	-	-	1.42	-	-	-	-	-	11.73	-	2.29
Erucastrum nasturtiifolium	-	0.17	0.63	1.51	2.88	1.37	16.93	9.02	20.43	1.73	-	7.98
Festuca arundinacea	-	0.17	-	-	6.15	-	20.92	-	-	-	-	-
Filago pyramidata	-	-	-	-	0.39	9.05	-	0.24	-	-	-	0.14
Hirschfeldia incana	-	-	-	-	-	-	-	14.87	-	-	35.67	-
Hordeum murinum	-	-	-	-	4.71	-	-	-	-	-	-	-
Inula viscosa	0.10	0.26	0.74	0.26	0.65	2.36	14.51	3.65	0.66	34.34	0.08	-
Koeleria phleoides	-	0.53	-	0.26	-	-	-	-	-	0.65	-	-
Lactuca serriola	-	-	0.74	0.08	1.44	0.19	-	-	10.69	-	-	-
Lolium perenne	12.71	8.80	-	-	-	-	-	-	10.41	1.09	21.80	-
Lolium rigidum	-	-	-	-	37.43	-	-	-	-	-	-	7.69
*Medicago sativa**	3.23	12.43	-	-	-	-	0.42	-	-	1.96	- 0.30	0.30
Melica ciliata	0.52	3.46	14.29	0.36	-	-	1.26	-	-	-	0.08	-
Orzopsys miliacea	13.65	23.98	15.87	0.71	-	5.70	6.41	36.09	-	-	10.28	2.36
Papaver rhoeas	0.41	0.17	-	10.94	0.26	0.19	-	-	-	0.43	0.32	2.95
Picris echioides	-	-	0.84	0.71	-	-	-	-	17.78	5.21	-	0.14
Picris hieracioides	-	0.8	0.52	9.16	-	-	-	-	-	-	-	0.14
Sonchus tenerrimus	0.93	0.44	-	1.24	2.48	-	0.42	1.70	16.84	1.30	2.93	4.29
Thymus vulgaris	-	-	-	-	-	5.11	-	-	-	-	-	-

Note: species followed by * are exotic plants; plant nomenclature from Bolós et al. 1993.

Table 4: Relative abundance of main species in treated (T) and control (C) plots at each site (data from transects).

INTEGRATION OF REMOTE SENSED IMAGES AND GIS FOR THE DETERMINATION OF ENVIRONMENTALLY SENSITIVE AREAS TO DESERTIFICATION IN MEDITERRANEAN ENVIRONMENT (EASTERN-CENTRAL SARDINIA)

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Abstract. The aim of this work is to determine the different grade of sensitivity to desertification of the different soils in the area of study. This aim has been achieved by means of the integration of different layers in a GIS; the use of remote sensing has allowed the determination of the layer of information related to vegetation cover.
The framework for the determination of the sensitivity to desertification, developed by Kosmas in Lesvos island in Greece (Kosmas, 1998), has been applied, in this work, to an area in the eastern coast of the Sardinia (Baronie), where former studies have provided information about soil, land use, climate and morphology.
The lack of information available about the vegetation of the area, has been overcome by means of the elaboration of remote sensed images (Landsat-TM), that have been used in the mapping of the differing cover of the study area. The great complexity of the mediterranean ecosystem has been resolved utilizing either maximum likelyhood classificator or spectral mixture analysis.
The implementation of this new layer into the GIS and the subsequent integration of the varied information have made possible the evaluation of the sensitivity of the soils to desertification.

Key words: Sensitivity to desertification, remote sensing.

Introduction

Among the main important factors that compound sensitivity of soil to desertification, differing human activities in the use of land must be considered fundamental (UNCCD, 1994). Knowledge of the territorial characteristics, either from environmental or human-use point of view, is of primary importance if the aim is to develop sustainable land management. The integrated use of remote sensed image elaboration and GIS, allows on one hand to obtain territorial information by means of satellite sensor and, by the other side, to make the procedures of implementation of different information layers automatic.
Remote sensing is here used not as an indipendent step in an environmental study, but as information input of a GIS, formerly built to manage data coming from other sources (field studies for soil map, digitalization for morphology, aerial photos for land use).

In this work, after determination of vegetation cover distribution by means of remote sensing, the framework for the evaluation of the soil's sensitivity to desertification has been applied as in the work of Kosmas in Greece under the EC-MEDALUS project. The fifteen parameters used permit the evaluation of sensitivity of soils; these values are then arranged in four groups; two of them are subdivided in three sub-classes to better represent the heterogeneity of the soil sensitivity to desertification.

Images and elaboration

Two images of August 96 and March 97 have been used. Their temporal closeness assures the vegetation cover to be unaltered, and, at the same time, to be in different and significant periods in the phenological cycle of mediterranean vegetation. In August, the driest month during the year, vegetation is in the phase of stasis. On the contrary, March is the period in which, as winter rains come to an end, vegetation is in the growing phase, with strong photosynthetic activity.
In this way it is possible to utilize the differing behaviour of vegetation during the different seasons to determine vegetation cover on the land. Multitemporality in images' elaboration allows to use these behaviours of the covers during seasons.
Image georeferentiation has been carried out by means of cartography of the IGM (scale of 1:25,000) and about 30 ground control points.
Two different kinds of elaboration have been applied in this work; first, a traditional maximum likelihood classification (MLC) to identify the more homogeneous covers (agricultural cover, bare soil and exposed rock, holm-oaks, coniferous forest), while the second (Spectral Mixture Analysis) allowed the analysis of the more complex covers: "macchia" and pasture.
The maximum likelihood classifier has been used on one cover at a time; by means of the appropriate bands (simple bands, principal components, bands ratios), it has been possible to determine the distribution of the cover under examination and then, after the evaluation of the accuracy of the classified, the cover has been masked and the classification has been carried out, with other appropriate bands, on other cover. The suitability of the bands has been evaluated considering their capacity to discriminate the cover to resolve, i.e. comparing the spectral behaviour of the covers in those bands. The more different is the behaviour of the examining cover, in a band, as regards that of other covers, the more useful is that band to discriminate the cover (Figure 1).
Each classification phase has been carried out with a threshold of the 90%; it means that to be classified as coniferous forest, for example, a pixel must have the same (at the 90%) spectral behaviour of the training set of this class. Much higher is the threshold, much more selective (strict, severe, rigorous) is the procedure, so that only the pixel with a pure cover are classified in an homogeneous class. This procedure improves the not-classified, but it assures the homogeneity of the pixel belonging to a class. Therefore, each class identified by means of the MLC is an homogeneous and pure cover.
In this way, the following covers have been recognized: urban, cultivated areas, pine forests, holm oak forests, bare soils, water.
In all cases, the accuracy has reached the 90%.

The great heterogeneity of the structure and species of “macchia”, and its progressive shading into pasture areas, make these covers the most complex of mediterranean vegetation. The heterogeneity hinders the characterization of the cover “macchia” even using more than one training set.

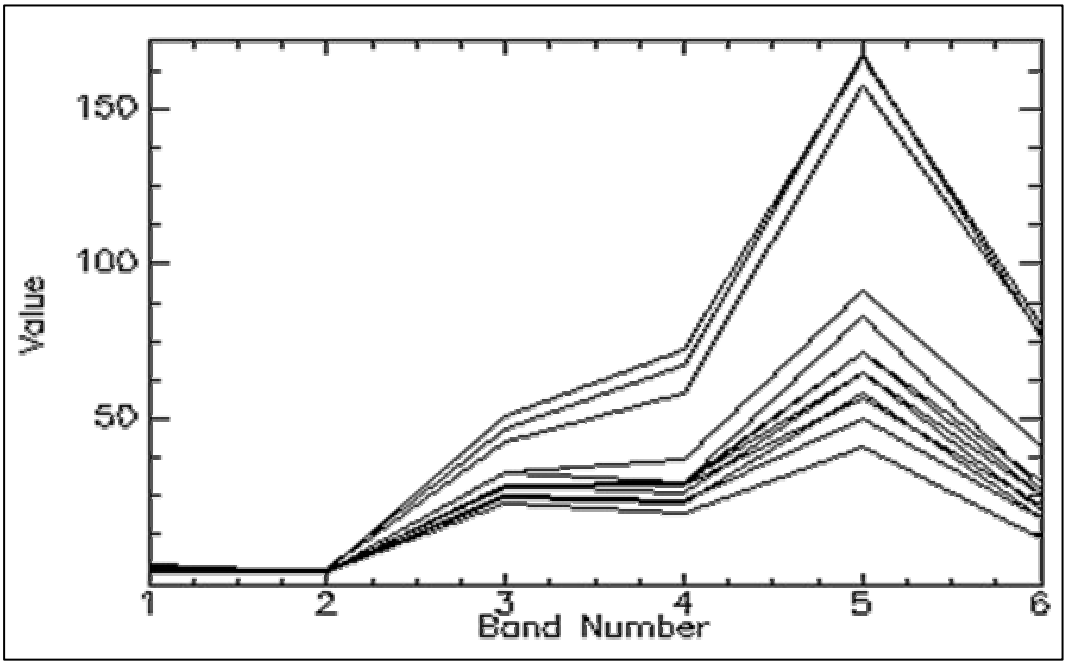


Figure 1: Choice of the best bands for MLC.

The SMA method is supported by the hypothesis that each pixel is composed by few cover in different percentages (Figure 2). The interpreter has to decide the covers compounding the whole pixel, and then to find these pure covers in the image to use them as reference. Each of these is called end-member (the extreme, pure member of which the pixel can be formed).
The SMA carries out the abundance of each cover in a pixel by means of the following equation, one for each band used in the classification:

$$T + \delta = \Sigma (F_j * \mu_j) \ , \quad \text{with} \quad j = 1 \ldots N,$$

where N is the number of endmembers that form the pixel, F_j is the fraction of the pixel occupied by the j-endmember, μ_j is the spectral answer of the j-endmember, δ is the error and T is the total signal at the sensor (Settle and Drake, 1993).
Considering N+1 bands (N+1 equation), it is possible to make a system whose resolution carries out the values of μ_j for every pixel. In this way, it is possible to determine the percentage of the pixel occupied by each endmember. The sum of the μ_j gives 1.
The SMA does not assign each pixel of the image to a informational class represented by a training set, but, for each pixel, it states the fraction of it occupied by a pure cover (the endmember). The sum of the fractions of pixel occupied by each cover gives the unity (100% of the pixel); the pixels considered in the SMA classifier are occupied, with differing

percentages, only by the endmember, because the other covers have already been identified and masked.
Therefore, once defined the endmember (in this case three endmembers have been defined: pasture, forest-macchia and *Cistus spp.*), the result of the spectral mixture analysis is, for each pixel, the percentage of it occupied by each endmember (Figure 3).

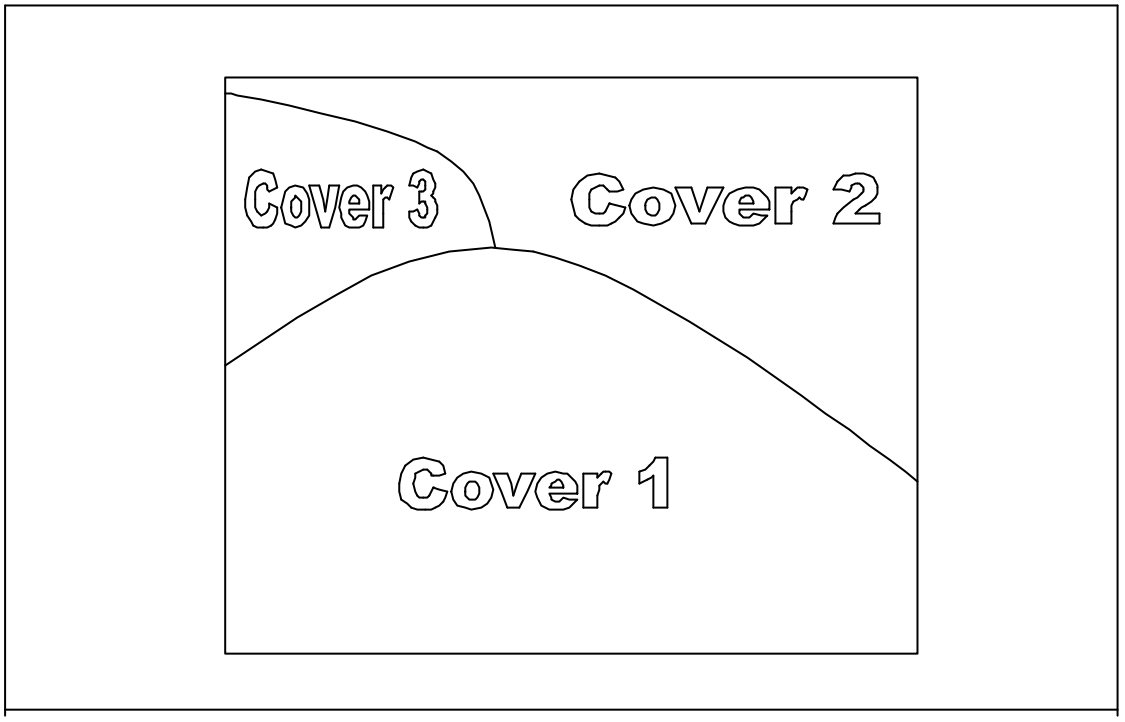


Figure 2: SMA: example of a pixel compounded by three different endmembers.

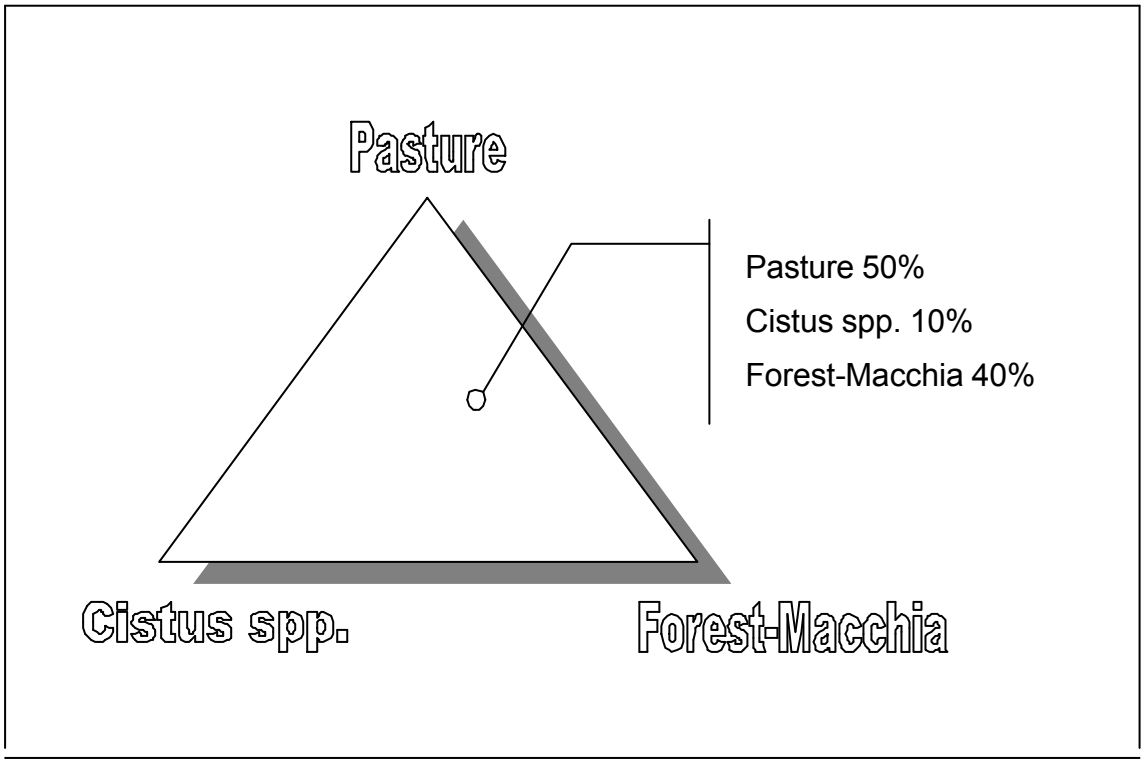


Figure 3: SMA: endmembers and example of the percentages of the different covers in a pixel.

The SMA produces three images, one for each endmember. Each image presents values of the pixels between 0 and 1. This value of the pixel can be considered the percentage of it occupied by the cover the image refers to (Figure I, at the end of text). For each pixel, there are three values, one for each endmember. The subsequent step is to determine the various classes (Figure 4) and to identify their distribution. In this way, it is not necessary to define the classes before the elaboration, but it is enough to determine the endmembers. The classes are defined as the mixture in each pixel of these endmembers.
Finally, it has been possible to characterize the cover of the area in the following classes: urban, water, bare soil, exposed rock, cultivated areas (irrigated and arboreous), coniferous forests, holm-oak forests (all determined with maximum likelihood) and cultivated pastures (class 7 in figure 4, with pasture at least 90%), grassland pastures (class 8, pasture between 80% and 90%, shrub at most 20%), shrub-pastures (class 9, as class 8 but with more developed shrub), macchia-pastures (class 10, pasture and Cistus predominant over forest macchia, at most 10%), low macchia (class 11, shrub component prevailing), macchia forests (class 12), all with spectral mixture analysis.

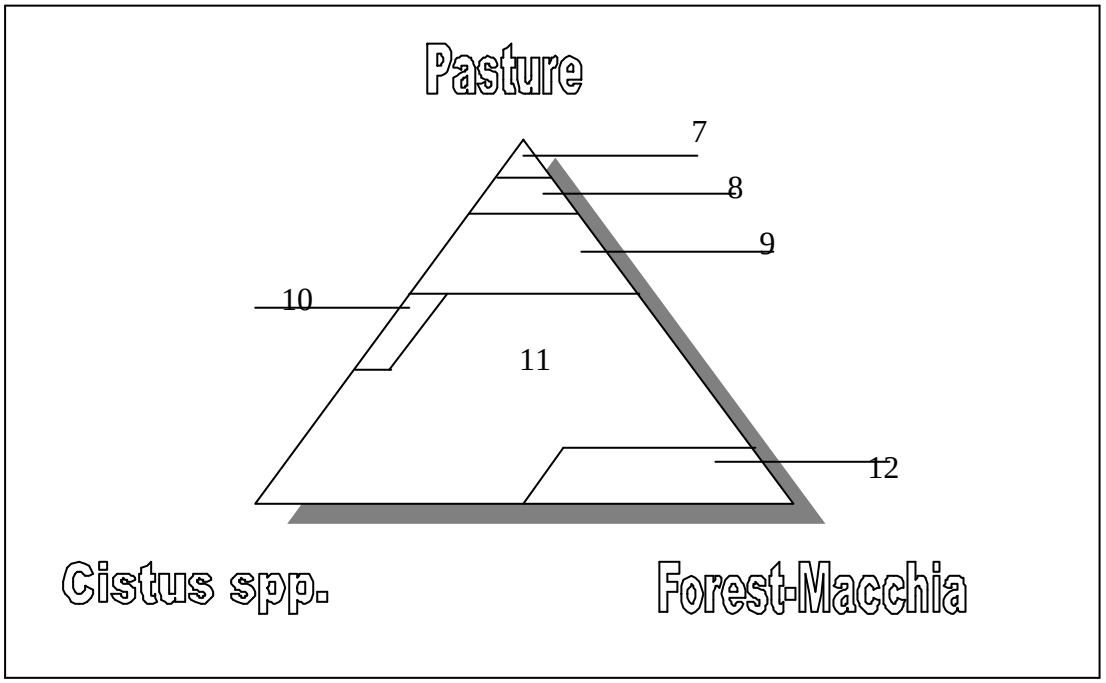


Figure 4: Definition of classes (SMA).

The ESAs (Environmentally Sensitive Areas to desertification)

The following scheme (Figure 5) shows the parameters utilized to value the sensitivity to desertification and the layers of the GIS providing them. This metodology considers either environmental or management data. Each of the parameters is connected to the processes of degradation of soils.
Vegetation, in particular, has a protecting function from the impact of the rain and from the runoff of the water on the soil surface. It can also improve the rate of infiltration of rain with a reduction of runoff water. The roots of the plants can increase the stability and the humus content of the soil, improving its quality.
For each characteristic, a table has been created to convert the absolute value of the parameter into an index that is comparable with the indexes of the other characteristics (Table 1).
At the end of this procedure, each pixel has as many values as the number of parameters. The integration of all these values gives the Environmentally Sensitive Areas Index (ESAI). By means of another table, it is possible to arrange in groups the values so that, finally, there are four different classes: critical ESAs, fragile ESAs, potential ESAs and areas not-threatened by desertification. The first ones are already highly degraded and present a threat to the environment of the surrounding areas. The fragile areas are characterized by delicate balance of natural and human activities and any change in this balance can cause desertification. The potential areas are threatened by desertification only under strong climatic change, while the not-threatened areas are considered not to be, in any case, under degradation processes.

Class	Description	Plant cover (%)	Index
1	High	> 40	1.0
2	Low	10 - 40	1.8
3	Very low	< 10	2.0

Table 1: Vegetation cover: conversion from absolute values to index.

For the vegetation cover, four parameters have been valued (Kosmas, 1998). Since the vegetation cover is fundamental in the protection of soil (from splash erosion and run-off, for development of a good quality soil), the four considered factors have the task of giving information on the presence of adequate cover, where “adequate” means useful in protecting soil from erosion (i.e. percentage cover, resistance to drought condition, capacity to recover burnt areas and protection from erosion, for the different classes of vegetation).
The set of parameters considered allows the determination of a quality index for soil, climate, vegetation cover and management. Each of these indexes is then arranged into three quality classes (high, moderate, low) (Table 2). The classes of quality allow the determination of which of the four major categories makes the area more sensitive to desertification. It is possible to determine which of them affects the result of sensitivity.

Vegetation Quality Index (VQI	Description	Range
1	High	1.0 to 1.6

2	Moderate	1.7 to 3.7
3	Low	3.8 to 16

*Table 2: Vegetation Quality Index = fire risk index * erosion protection index * drought resistance index * vegetation cover index.*

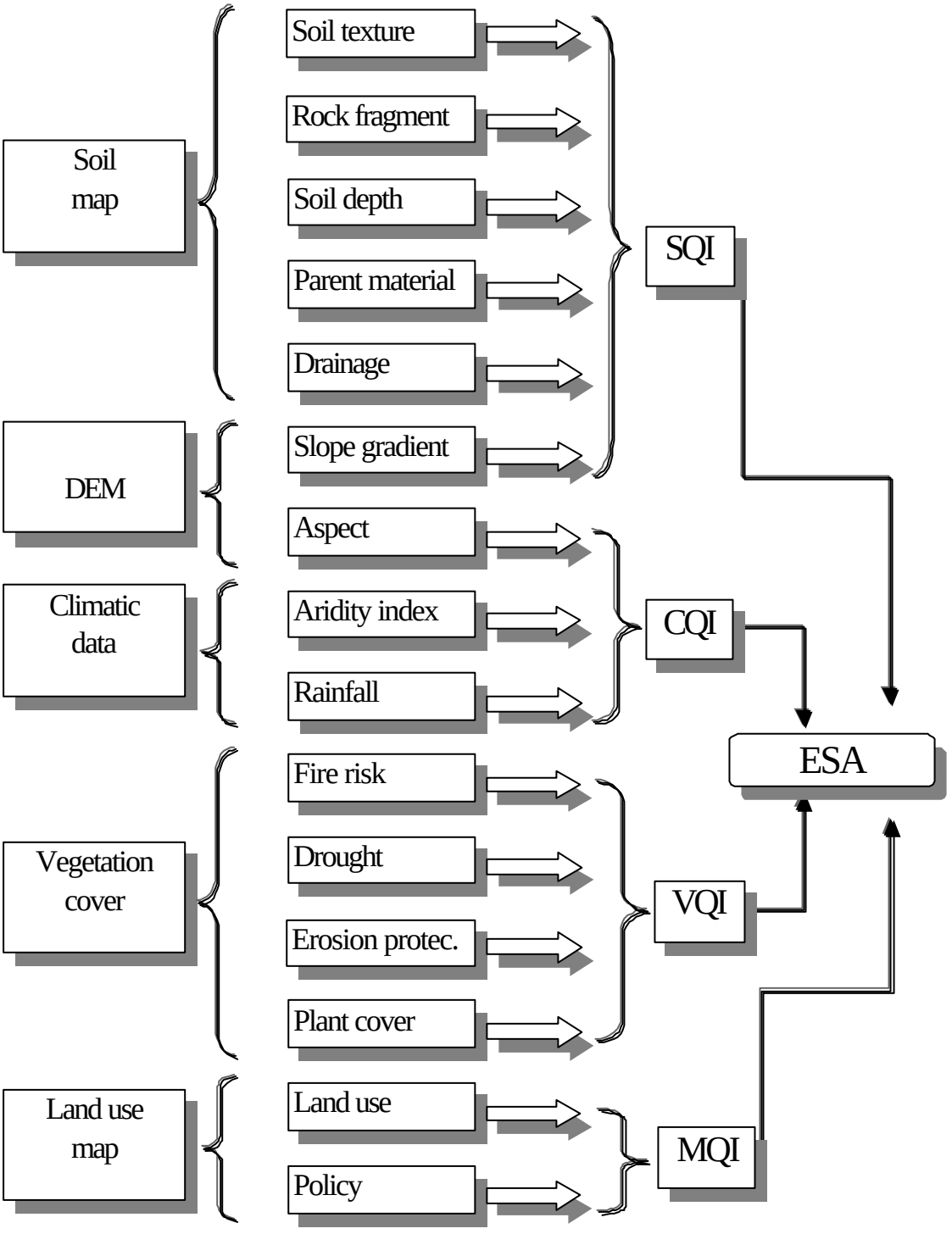


Figure 5: Scheme for the determination of the ESA (Kosmas, 1998).

The value of quality is obtained by means of multiplying together each of the single parameters considered. The ESAI is obtained in the same way, multiplying the quality indexes.

ESAI for the study area

The implementation of the new layer into the GIS produces the following values in the area of study of the sensitivity of the soils to desertification.

The data on soil, morphology and management has been derived from the soil map (NRD, 1997), the land use map (NRD, 1997), the DEM and other derived maps (Loda, 1998 and NRD, 1997). The climatic data refers only to the climatic station of Orosei. The data on the management of the area has also been obtained during the field surveys in the area.

The first step in this phase is to assign the correct value to each of the considered parameters and to derive the index for each pixel.

The second step is the calculation of the ESAI by means of the multiplication of all the indexes (Figure 6). The results obtained are here briefly discussed.

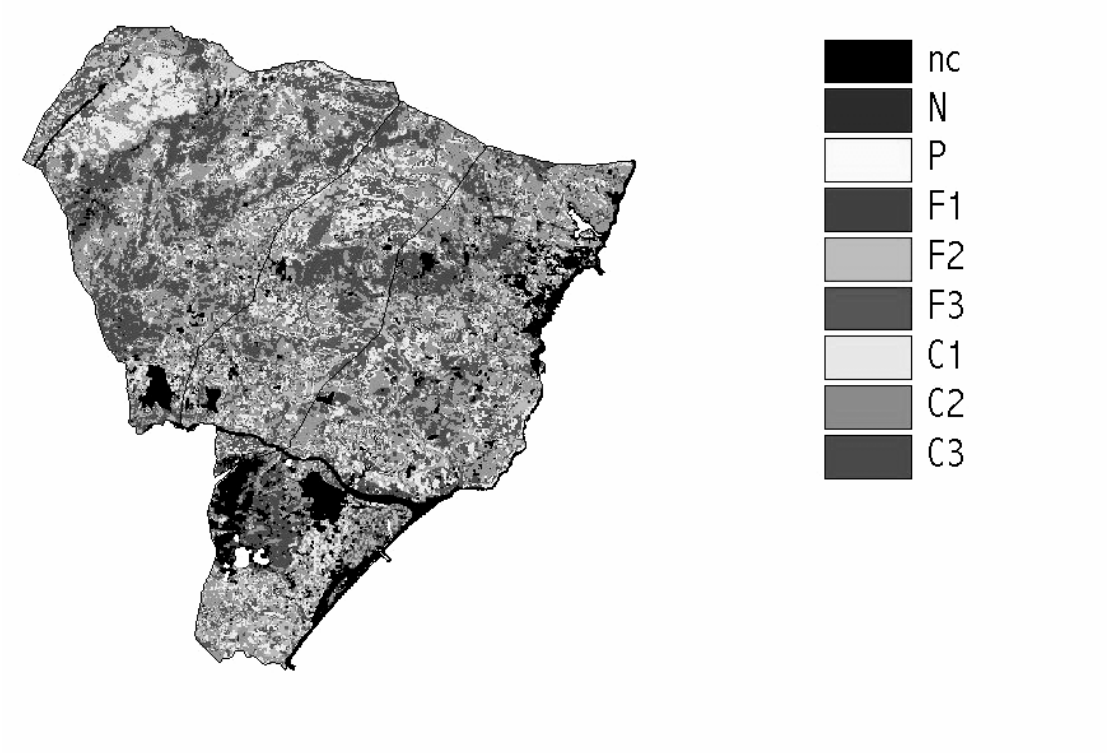


Figure 6: Map of ESAs.

First of all, the distribution of the different vegetation covers shows a clear predominance of low-macchia (31.65%) and pasture (39.15%) (classes number 7 to 10 in the Figure 4)

This means that the area is strongly affected by human activities and by other events (such as fire) resulting in underdeveloped vegetation cover. The homogeneous covers of *Quercus ilex*

and Pine are much less abundant (6.19% and 6.11% respectively). The same forest-macchia has a very limited extent (only the 4%). Future remote sensed images would be able to predict the development of the vegetation cover.
Table 3 shows the percentage of the different classes of sensitivity in the area of study. The predominance of the areas of the critical class (subdivided into the three sub-classes) is clear and it points out the degraded situation.

ESA classes	Percentage
Not considered	8,88
N	0,01
P	0,44
F1	1,70
F2	7,87
F3	12,64
C1	**16,71**
C2	**32,48**
C3	**19,27**

Table 3: Percentage of the ESAs.

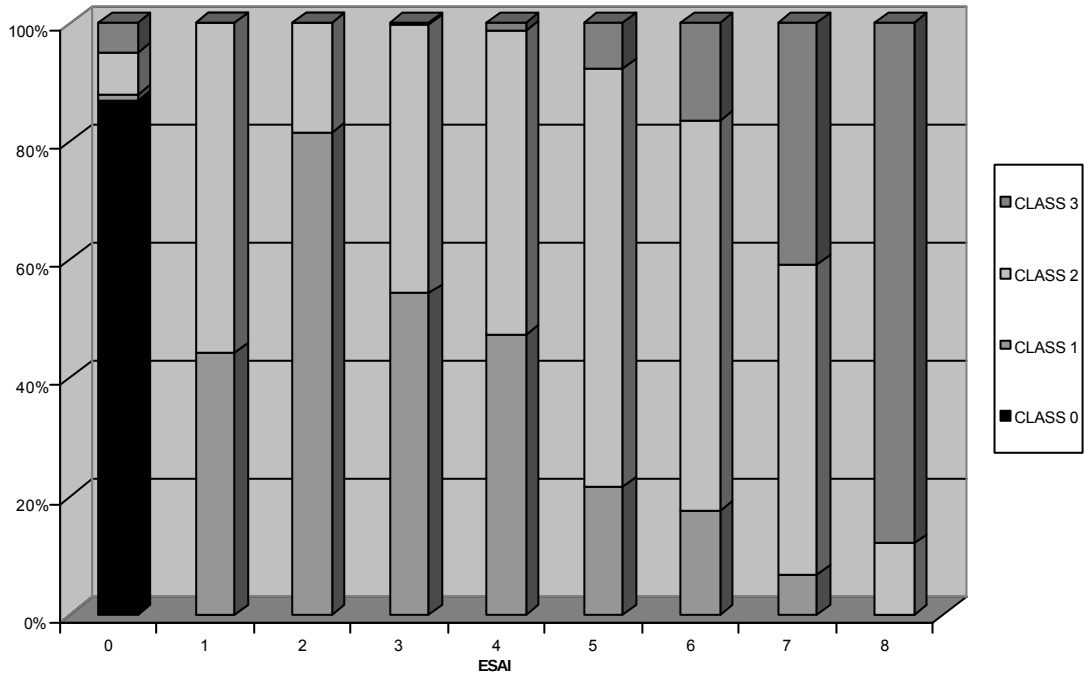
Figure 7 and table 4 show the distribution of the Vegetation Quality Index (VQI) classes into the different classes of sensitivity; this analysis is useful to understand the relationship between the ESAI and the quality of the vegetation cover.

ESAI	CLASS 0	CLASS 1	CLASS 2	CLASS 3
0	100.00	1,05	1,57	1,03
N	0.00	0,02	0,01	0,00
P	0.00	2,77	0,16	0,00
F1	0.00	5,32	1,13	0,01
F2	0.00	**24,13**	6,65	0,14
F3	0.00	**22,15**	18,53	1,90
C1	0.00	**23,33**	**22,40**	5,26
C2	0.00	**21,12**	**40,67**	**29,94**
C3	0.00	0,11	8,88	**61,70**

Table 4: Distribution of the classes of VQI into the different classes of ESAI (in percentage).

It is possible to say that the more sensitive class is characterized by a high value of Vegetation Quality Index (VQI) that means a low quality of the vegetation cover in protecting the soils from desertification. The 61.70% of the VQI "CLASS 3" falls under class C3; therefore a bad cover is typical of a class highly sensitive to desertification (C2 or C3).
The weight of the vegetation cover in the determination of the ESAI is less important then soil quality index. Looking at the distribution of the VQI class 1 (the same percentage from C2 to F2), it can be seen that a pixel with a high quality in vegetation cover does not necessarily fall into a class characterized by low sensitivity to desertification. If a pixel, with a good vegetation, belongs to a C2 or C1 class, it means that another parameter strongly influences the result (the soil).
This fact is due to the way the model has been set up. The SQI ranges from 1 to 128, while the VQI from 1 to 16. This means that a bad SQI puts the pixel into a class of high sensitivity, even if it has a good vegetation cover (as previously seen). The opposite is not always true, because a high VQI is not always enough to bring the pixel to high sensitivity, if it has a good soil quality.
Therefore, while it seems to be true that low VQI (high values) means high sensitivity to desertification, high VQI (low values) is not indicative of low sensitivity to desertification. In this case, other factors, such as the soil quality index, can give the land a high sensitivity.

Figure 7: Distribution of the VQI classes into the ESAI classes.



Conclusion

The aim of this work is to produce a map of different classes of soil sensitivity to desertification. It has been achieved using remote sensing in developing a vegetation cover map and GIS in integration of different informative layers.
The elaboration of images has allowed the determination of the distribution of different cover, although there are some problems like shadows, spectral behaviour of some cover classes, linearity in spectral mixture analysis, elaboration of the images deriving from SMA. All these items can be better analyzed, improving the accuracy of the classification and the capacity to resolve more vegetation cover. However, the resulting classification shows to be useful in applying the ESAs method.
For the ESAs method, it is necessary a field survey to gather information on the real sensitivity of the soil to desertification; that is, it must be given worth to the method by means of valuation of the conformity between the reality and the obtained result.
This valuation is the following step of the work and it can give an answer on the real usefulness of the method and on its capacity to describe the real sensitivity of the soil.

References

Garcia-Haro J., Gilabert M.A., Melia J. (1996) Linear spectral mixture modelling to estimate amount of vegetation from optical spectral data. *Int.Journal of remote sensing,* 17 (7): 3373-3400.

Kosmas C. (1998). Lesvos-Land degradation and desertification. Fourth Interim Report, MEDALUS Project.

Kosmas C. (1998). Comparative analysis of target areas. Fourth Interim Report, MEDALUS Project.

Kosmas C. (1998). Land degradation and desertification. Fifth Interim Report, MEDALUS Project.

Loda B. (1998). Contributo alla valutazione del degrado dei suoli in ambiente mediterraneo (Sardegna centro-orientale): implementazione di un modello di stima dell'erosione in un SIT. Tesi di Laurea, Corso di laurea in Scienze Ambientali.

Melia J. (1994). Use of soil and rock spectral signatures for natural vegetation cover estimation. In J. Hill and D.Peter [Eds] Proceedings, The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin, June 13-15, 1994, Valencia, Spain.

NRD (1997). Carta dell'uso del suolo del territorio dei Comuni di Orosei, Onifai e Irgoli e note illustrative. Manoscritto.

NRD (1997). Carta dei suoli del territorio dei Comuni di Orosei, Onifai e Irgoli e note illustrative. Manoscritto.

Settle J.J., Drake N.A. (1993). Linear mixing and the estimation of ground cover proportions. *Int.Journal of remote sensing,* 14 (6): 1159-1177.

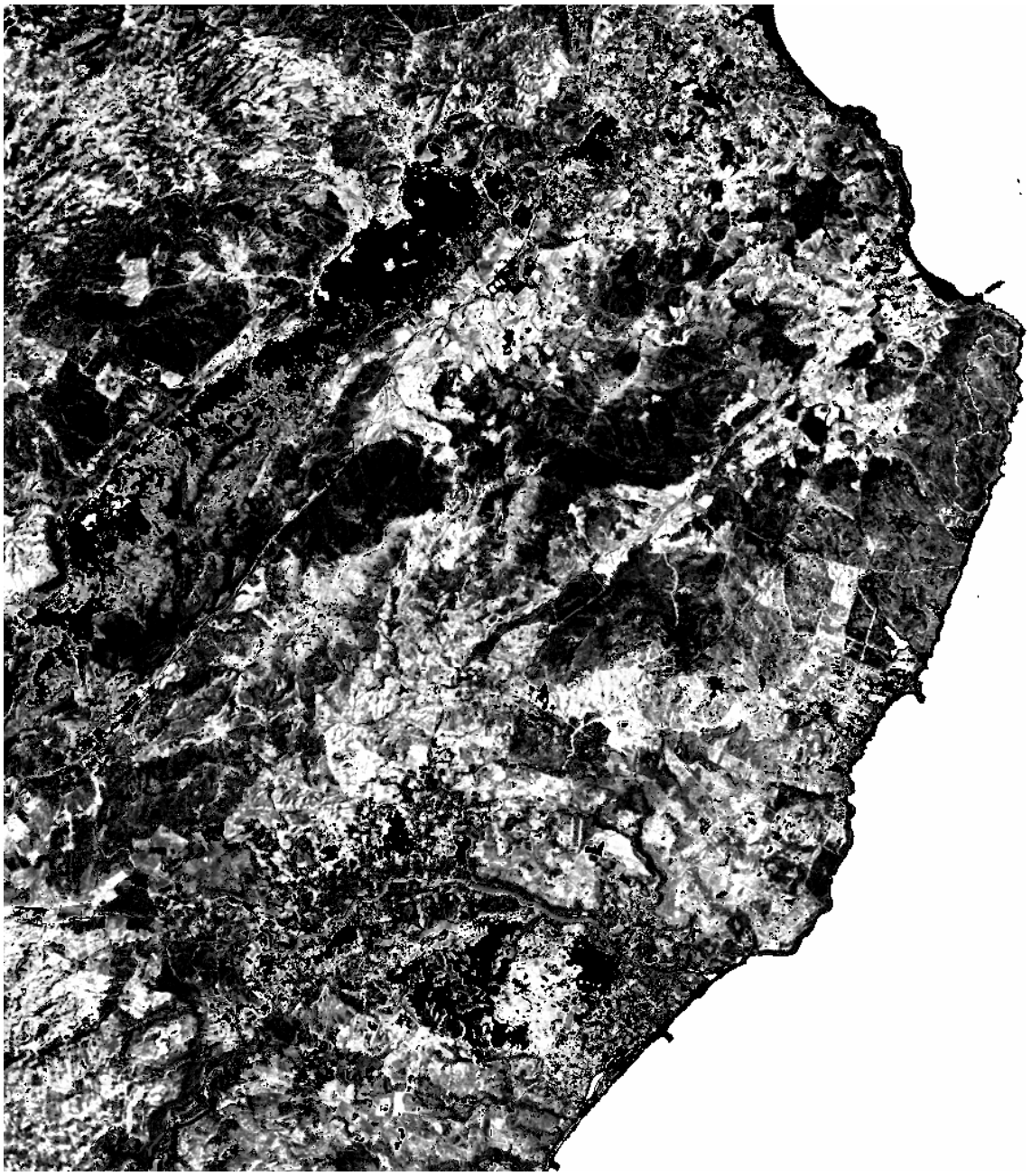


Figure I: Output image of SMA: the abundance of the endmember pasture in the area of study.

INTEGRATED APPROACHES OF LAND COVER CHANGES IN NORTHERN EUROPE

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Abstract. The arctic ecosystems are very fragile. Understanding the historical development of land cover changes in such landscapes might enable to forecast future trends of vegetation and soil degradation. In many parts of Iceland, highly active land degradation appears to be leading to complete desertification. Multiple factors exert stress on the fragile ecosystems that are believed to have resulted in a general desertification process affecting about 40% of the Icelandic surface. In order to maintain an ecological sustainability it is of great importance to increase the understanding of the critical factors that influence the maintenance of the ecological systems. A modelling framework for diagnosing the influencing factors that might lead to land cover changes in arctic environments is presented. Possible interaction between them is highlighted. The advantage of such a framework is the ability to visualise the complexity of a system in a simple way, and thus provide a deeper understanding of the root problem. The presented model performs a basis for a dynamic modelling that aims at clarifying the complex interaction between biotic and abiotic factors influencing land cover changes in arctic landscapes, especially issues regarding land use pressure and grazing potential of the ecosystem. This is important for the understanding of the land degradation processes and thus for the future sustainability.

Key words: Land cover changes, land degradation, integrated approaches, ecological sustainability, Iceland.

Introduction

Worldwide land cover changes occur repeatedly, mainly as a complex mixture of natural and athropogenic consequences. To be able to construct successful mitigation strategies for future sustainability it is of vital importance to understand how the different factors involved influence land cover changes, how the processes at the land surfaces change and why these changes occur.
In northern Europe there are no areas that have suffered as severe and extensive land degradation as Iceland. It is estimated that Iceland has lost over 50% of its vegetation cover, and over 90% of its woodland cover from the time of its settlement, 1100 years ago. The major cause is thought to be the settlers' alteration of the ecosystem and continuing human impact (Friðriksson, 1978; Þorsteinsson, 1973; Bjarnason, 1942, 1974; Þórarinsson, 1961; 1974; Arnalds, 1999). Several theories have been put forth to unravel the massive vegetation and soil degradation, mainly based upon tephrocronological studies, pollen analysis and historical sources, such as the Icelandic Sagas and annals. Fairly good databases on the current status on soil degradation have been established (Arnalds et al., 1997). However, very little work has been undertaken

on analysing the interaction between the natural and anthropogenic factors and how such interaction has contributed to land degradation. The complexity of the degradation processes requires a multi-disciplinary approach thorough integration of involving factors. Such approaches can describe more thoroughly the history of land cover changes, and thus contribute to a deeper understanding of the processes involved.

Integration requires alignment of models, which often is much harder than more straightforward formatting. The goal here is to provide a modelling framework for diagnosing the influencing factors that might lead to land cover changes with reference to processes that have taken place and still are taking place in Iceland, in terms of a conceptual model. Conceptual models have proved to be an effective approach for analysing and understanding a complex phenomenon. The purpose of such a model is to make it possible to learn things about reality by analysing the model instead of observing reality directly. Conceptual models help the user visualise the influencing factors and interacting processes in a complex system and thus facilitate the user's logical reasoning in his construction of a faithful representation of the application domain (Boman et al., 1992, 1993; Berztiss, 1993). In the case of modelling ecological economic systems, simple conceptual models provide a general understanding of the system behaviour, that later can be used as an elementary base for more detailed realistic applications aimed at evaluating specific policy proposals (Costanza et al., 1993). Further modelling aims at developing a methodology that can aid land use planners to create long-term sustainable solutions for integration of land use management and urbanisation demands (Ólafsdóttir and Haraldsson, 1999).

The model's evolutionary criteria

Ecosystem's responses

How an ecosystem responds to the different provocations is determined by a complex interaction of the critical factors involved, some leading to sustainability of the system while others may results in degradation. The Icelandic ecosystems, like other arctic ecosystems, are very fragile and sensitive to any changes. It seems that it only need a little wound in the vegetation insulation to give processes, like water and wind erosion, a chance to start their degradation process. The Icelandic land degradation is characterised by a complete removal of the vegetation and soil cover (Fig. 1).

The critical factors in the Icelandic model

The main critical factors on land cover changes are: geomorphology, hydrology, climate, land use, socio-economy/political management and farmers' perception (Fig. 2).

Geomorphological and hydrological factors in Iceland are determined of the country's location, i.e. on the middle of Atlantic Ocean Ridge in the middle of the north Atlantic Ocean. It extends from latitude 63°23′ to 66°32′ N and longitude 13°30′ to 24°32′ W. Geologically speaking, the country is very young and bears many signs of still being in the making. It appears on the whole roughly hewn, abrupt and jagged, without that softness that characterises a more mature landscape. Approximately 90% of the landmass is made up of volcanic rocks, mainly basalt, while the remaining landmass

is made up of lithified sedimentary interbeds from lacustrine, marine, eolian, fluvial and glacial deposits.



Fig. 1: The "desert" north of the large glacier Vatnajökull.

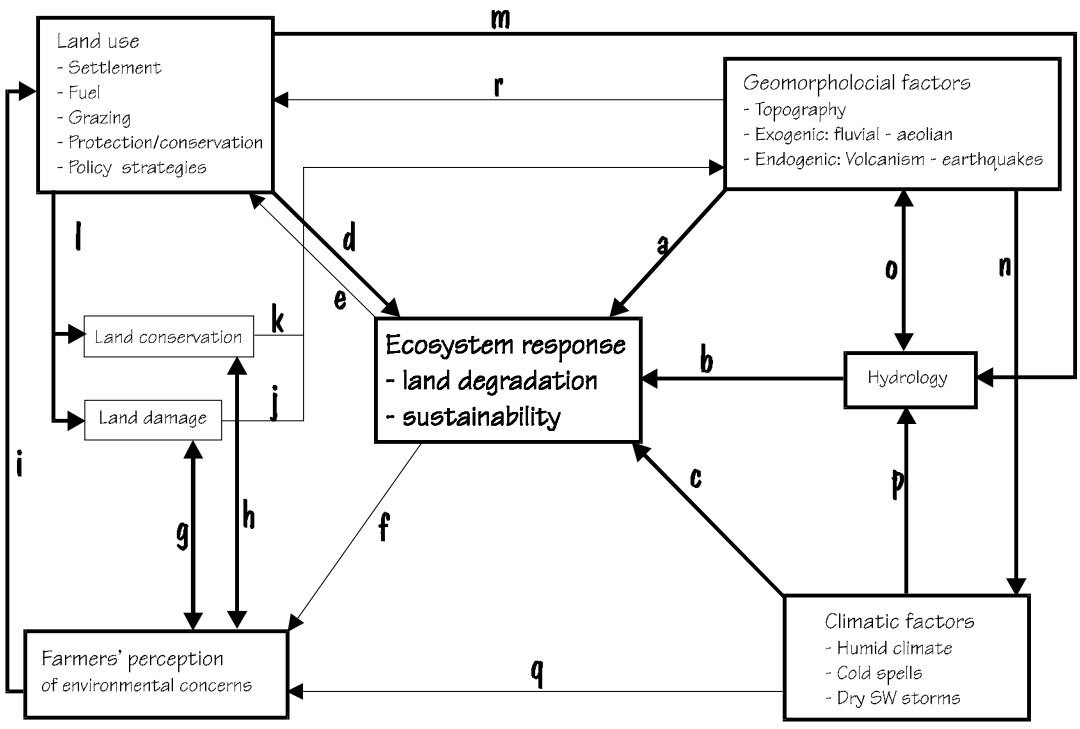


Fig. 2. A conceptual model of influencing factors and interacting processes on ecological sustainability in Iceland. The bold lines indicate the most important feedback processes of the system. It is referred to the letters (a-q) in the model description.

Climatic factors: Iceland lies at the junction of two climatic zones, i.e. the Temperate Zone and the arctic zone. Its climate may be characterised as cool-tempered oceanic, with cool summers and mild winters. The mild climate is a result of the strong influence exerted by the Gulf Stream. Shifts between frost and thaw are very common and storms are frequent. Annual mean temperature ranges from 2°C to 6°C in the lowlands. The temperature is considerably lower in the highlands. Annual rainfall averages 400 mm in the northeast and up to 3500 mm in the southeast (Einarsson, 1976; Bergþórsson, et al., 1987). The low temperature does not favour fast vegetation growth or resilience. Once the soil is deprived of its vegetation cover it easily becomes eroded by the strong wind and heavy run off during springtime, leaving completely barren landscapes behind (Fig. 1).

Land use factors and farmers' perception: The most extensive land use hitherto is sheep grazing. Only 1-2% of the land area is cultivated, mainly for hay production. The Icelandic highlands have basically only been utilised as pasture land for sheep and horse grazing. During the past decades they have, however, been growing in importance as a resource for tourist recreation. Ever since the earliest settlement (874 AD) livestock farming has been the main occupation in Iceland until the early 20th century. Dairy farming was mostly dependent upon hay production while the sheep and horses were expected to fend for themselves (Kristinsson, 1998). The custom has always been to let the sheep find their own pasture with limited winter feeding in former times.

An important factor in the model is the farmers' perception. How the local land users perceive environmental changes is often alternative from the scientific and political perspectives. Dahlberg (1996) demonstrates that studies with a focus on how the local people perceive the environmental changes may contribute to the understanding of the long-term effects of local land use practices and outside interferences. She claims that studies lacking this perspective have a tendency of describing all changes in the environment as detrimental, ignoring the fact that people are still living off these lands, utilising resources that scientists have described as completely degraded. Therefore, integration of top down and bottom up approaches are of vital importance.

Political factors include external decisions and management of land use. The historical dependence on sheep and cattle to sustain the land-based domestic economy is likely to have influenced the Icelandic policy, that from 1950 aimed at increasing the number of sheep and cultivating more land for hay crop production through protectionism and subsidies (Gísladóttir and Preston-White, 1998). Since 1979 the output of agricultural produce has been subject to quotas and in 1991 export subsidies were abolished (Icelandic Statutory Law Gazette, 1979, 1991). The total sheep stock has now been reduced to nearly 50%. On the other hand, the number of horses has increased over 60% during the last 30 years (The Icelandic Agricultural Information Service, 1997). General land use management is still lacking.

The models' feedback criteria

Feedback occurs when a portion of the output from the action of the system is added to the input and subsequently altering the output. The nature of the response can vary (positively or negatively) depending on the prevailing situation (Kangalawe, 1998).

The interacting processes in this model have been given the letters a-q, and are described below. The major feedback processes are expressed with bold lines (Fig.2).
The basic natural factors affecting the ecosystems' sustainability are geomorphology that comprises the nature of the underlying landscape attributes (a), hydrology controlled by the bedrock and soil drainage capabilities (b) and climatic variability (c).
The geomorphology is composed mainly of the volcanic bedrock and soils (Andosols), as well as of eolian, fluvial and glacial deposits. Volcanic and tectonic activities are common within the neo-volcanic zone that crosses Iceland from the southwest to the northeast. The active exogenic and endogenic processes influences the local climate (n) and hydrology (o). The hydrology is further influenced by climatic variability (p). Within the neo-volcanic zone, the bedrock is very porous resulting in low ground water level. Icelandic soils are very susceptible to water and wind erosion. They are very light (low bulk density) and can absorb large quantities of water. This high water holding capacity intensifies freezing effects that result in solifluction, debris flows, landslides, needle ice formation and the formation of thufur (Arnalds, 1990). The frequent shifts between frost and thaw makes cryogenic processes and periglacial phenomena very active. The basaltic lava and tuffs are also rich in cracks and pores, enabling rain to be lashed into the rock formations and running water to percolate into rocks, which further intensifies the frost processes. The Icelandic Andosols contain abundant amount of pumice and hyaloclastites (palagonite tuffs) (Sigbjarnarson, 1969; Guðbergsson, 1975; Arnalds, 1988), which have a major influence on physical and chemical properties of the soil and also on the soil resistance against erosion. Wind erosion causes abrasion of rocks and soils wherever loose sand can be swept away. Among the most important sources for wind transport are fluvial deposits (sandur plain) left by the glacial rivers, specially in the high altitudes north of the large glacier Vatnajökull. Real sand dunes are however uncommon in Iceland.
The vulnerability to land degradation is further intensified by the low temperature. Bergþórsson et al. (1987) consider temperature to be the most limiting climatic factor for vegetation growth in Iceland. The occurrence of frost/thaws is an important factor that may have an adverse effect on vegetation growth. If such condition persists for two or three months in late winter it can be very detrimental to the vegetation growth. The effects of cold winters also contribute to poor growth the following summer. Bergþórsson et al. (1987) and Dýrmundsson (1990) demonstrate that in high altitude regions vegetation growth, and consequently the grazing potential, is strongly influenced by the temperature. They assume that changes of each 1°C in annual mean temperature can lead to a 10-20% fluctuation of the grazing potential. It has also been shown that inappropriate anthropogenic land use, like heavy grazing, can result in large reduction in the Leaf Area Index and thus debilitate the plants' rooting dynamics (i.e. Svejcar and Christiansen, 1987; Archer and Tieszen, 1983), resulting in more vulnerable vegetation for degradation (d). Once the soil is deprived of its vegetation cover it easily becomes eroded by the strong wind and heavy run-off in the spring.
Iceland experienced a cold period (the Little Ice Age) from about 1200 to the beginning of the 1920´ies. Some of the coldest and most frequent cold spells during this period can be noted during the second half of the 18^{th} and 19^{th} centuries respectively. The annual temperature variation for the Stykkishólmur climate station in west Iceland is presented in Fig 3. The mean is based on the full length of the observation period 1823-1997. The plotted curve indicates the five years running mean. The annual precipitation for Stykkishólmur is also presented in Fig.4 indicating

strong negative rainfall anomalies during the cold spells of the second half of 1800. In general the period was about 1°C colder than the average and 15-20 % dryer.
The major anthropogenic factor affecting the sustainability of the ecosystem is land use. Consequently, the nature and the condition of the location are the factors, which determines the potential and nature of land use as well as setting the limitations for the expected future use (e). Before the Icelandic colonisation the environment had not at all been adjusted to herbivorous mammals. It is therefore believed that the human settlement caused a major shock to the natural ecosystem resulting in catastrophic land degradation (d). Archaeological studies (Einarsson, 1994) indicate that the proportion of cattle-sheep was 1:2 per farm at the time of the settlement. Historical studies (Júlíusson, 1995, 1998a, 1998b) show that this proportion changed significantly during the period of 1400-1700, from being 1:4 in the beginning of the 15th century to at least 1:10 in the beginning of the 18th century. It implies a corresponding increase in grazing pressure on the rangeland, especially the highlands, commonly used for sheep raising in summer.
The country's policy from World War II up to 1979 aimed to increase the number of sheep and cultivate more land for hay crop production, with close relationship between the policy makers and the farmers (Gísladóttir and Preston-Whyte, 1998). At the end of 1977 the total sheep population (winterfed sheep) peaked at almost 900.000 (The Icelandic Agricultural Information Service, 1997). This interruption in the land's resources might have caused heavy degradation in the most sensitive areas (j). The total sheep stock has now been reduced to 464.000 (The Icelandic Agricultural Information Service, 1997), after the major political changes in 1979 and 1991 (see section 2.2). On the other hand, since 1970 the number of horses have increased from 33.500 to 80.500 in 1996 (The Icelandic Agricultural Information Service, 1997) with corresponding increase in grazing pressure. Today horses are almost entirely raised for recreational purposes and in most cases grazed on farms. Cattle are only grazed on farms.
Consequences of the land use system are damage and/or conservation (l) that has feedback on the local geomorphological features (k, j). The Icelandic State Soil Conservation Service has been active in reclamation and conservation work from its foundation in 1907. Today there are numerous protected areas under its control. These areas are most often enclosed by reclamation fences and are in general small. Many farmers are of the opinion that the conservation fences change the behaviour of the sheep on the pastureland. The vegetation is often more desirable within the fences, so the sheep accumulate by the fences resulting in destruction of vegetation along the fences. Many farmers consider that conservation would improve in the long-range if co-operation with farmers at the decision stage would increase (Ólafsdóttir and Júlíusson, 1999).
When modelling ecological sustainability an important factor is the farmers' (the land users') perception towards their environment, and thus subsequently how they make use of their environment. How the farmers perceive the local land cover changes influences their ways of using the land (i). Moreover, the way land users understand the local climate (q) and the general ecological processes (f) modifies their practices and concern for their environment (g, h). This has a feedback effect on the land use system (l) and ultimately changes in land cover (d). Therefore, all aspects of land degradation should be taken into consideration in any land use decision making. The farmers' perception and knowledge may be viewed as an alternative approach to the

understanding of land cover changes and an important input into the development of appropriate land resource management policies which are readily acceptable by the farmers.

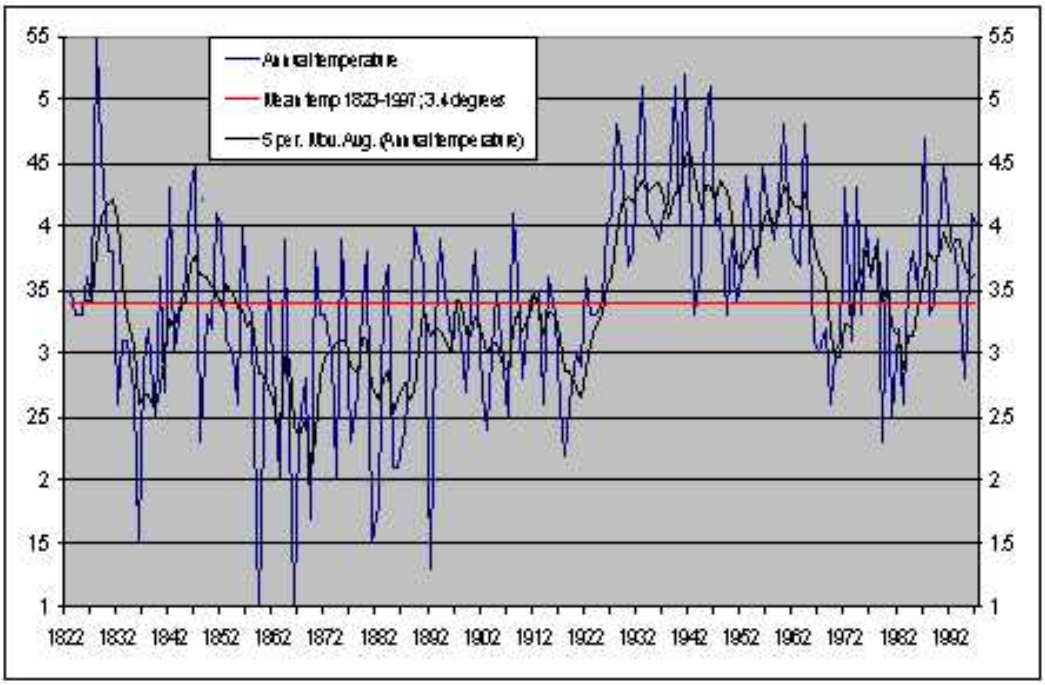


Fig. 3: Annual temperature, Stykkishólmur 1823 - 1997 (1823-1845 derived from Reykjavik).

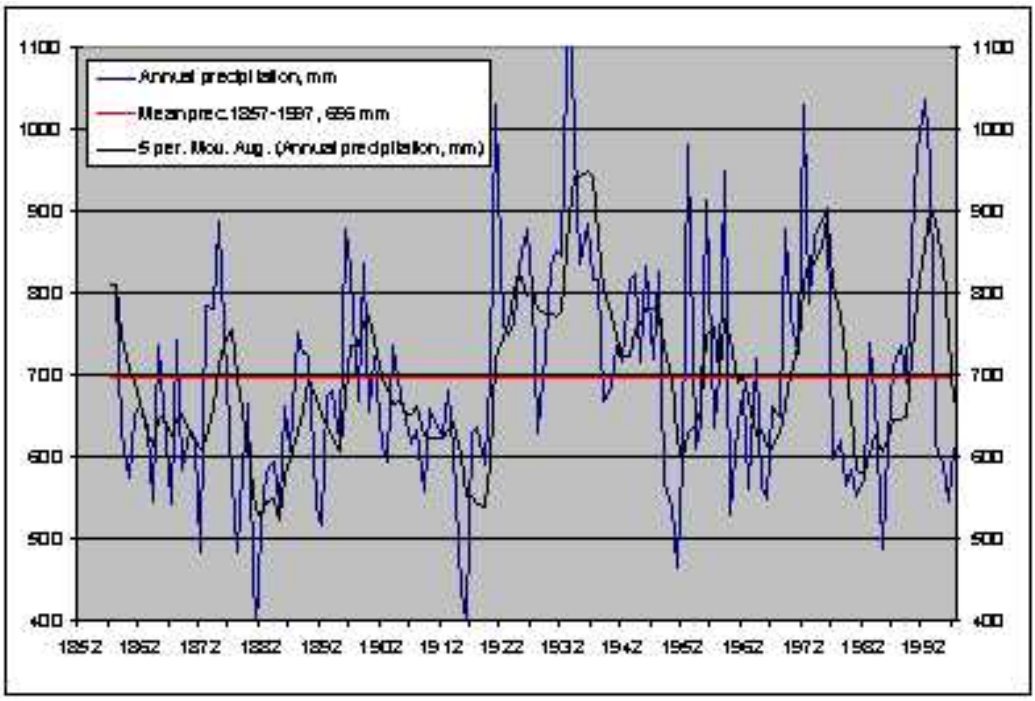


Fig. 4. Annual precipitation, Stykkishólmur 1857-1997.

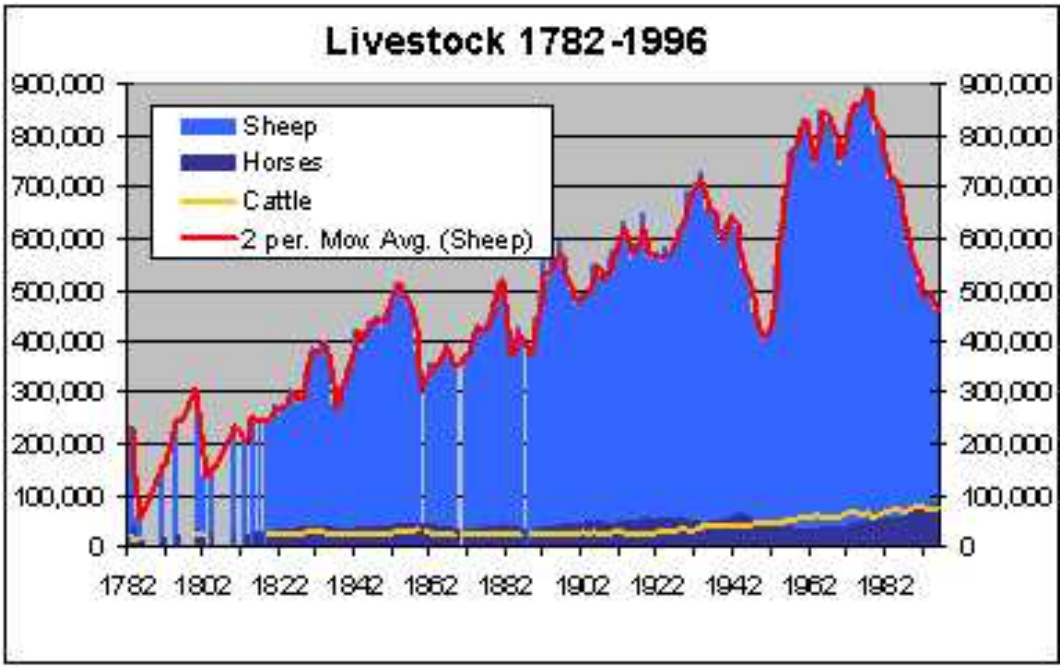


Fig. 5: Livestock evolution in Iceland from 1782-1996.

Discussion and conclusion

In order to be able to maintain ecological sustainability it is of great importance to increase the understanding of the critical factors that influence the maintenance of the ecological system. The advantage of a conceptual model as presented here is the ability to visualise the complexity of a system in a simple way, and thus provide a deeper understanding of the root problem. The presented model is a highly simplified version of reality. Many factors have been left out of the problem. However, the foregoing description has attempted to capture and explain some of the important factors and the nature of interactions that exist among them.

This preliminary study will serve as a basis for further inter-disciplinary studies on environmental impact of socio-economic processes in Iceland and in other fragile arctic ecosystems. It will be used to construct a dynamic model consisting of biotic and abiotic factors, which can be used to simulate and trace the effects of ancient natural climatic changes and historical anthropogenic effects on arctic ecosystems in terms of land cover changes. By using the historical data, it is possible to construct simulations that describe different forms of future land-use. It might enable land use planners to evaluate different land use scenarios and form the most cost effective and environmentally sound strategy. By enabling separation of natural factors from anthropogenic factors in the assessment of land cover changes, long-term land use planning can be understood much better and put into context with sustainable development.

Due to the sensitive nature and active erosion observed in Iceland, the country provides a grand opportunity to study all the stages of the processes in a holistic view. The experience gained from Iceland can be utilised when looking at other risk zones facing the problem of land degradation.

Acknowledgement

I would like to thank the course manager, Prof. Giuseppe Enne, and his team at Nucleo Ricerca Desertificazione, University of Sassari, for a fruitful course. I will also thank Sara Brogaard and Dr. Andrés Arnalds for their comments on this manuscript, and Andrea Nord for the English corrections.

References

Archer S. and Tieszen L.L. 1983: Effects of simulated grazing on foliage and root production and biomass allocation in an arctic tundra sedge. *Oecologia,* Vol. 58, pp. 92-102.

Arnalds, Ó. 1988: Jarðvegseyðing [Soil erosion]. *Græðum landið 1988*, Landgræðslan, pp.47-68.

Arnalds, Ó., Þórarinsdóttir, E.F., Metúsalemsson, S., Jónsson, A. Grétarsson, .E. and Árnason, A. 1997*: Jarðvegsrof á Íslandi [Soil Erosion in Iceland]*. State Soil Conservation Service & Agricultural Research Institute.

Arnalds Ó., 1999: Degradation of Icelandic Ecosystems. *http://www.RALA.is/desert/*

Bergþórsson, P., Björnsson, H., Dýrmundsson, Ó., Guðmundsson, B., Helgadóttir, Á. and Jónmundsson, J.V. 1987: The effects on Climatic Variations on Agriculture in Iceland pp. 387-444 *in* Parry M.L., Carter T.R. and Konijn N.T. (eds.). *The Impact of Climatic Variations on Agriculture. Vol. I: Assessment in Cool Temperate and Cool Regions*, IIASA and UNEP.

Berztiss A.T. 1993: *Imprecise queries and the quality of conceptual models*. Report series – Dept. of Computer & Systems Sciences; 93:18, Stockholm : Dept. of Computer and Systems Sciences.

Bjarnason, H. 1942: Ábúð og örtröð [Land use and overstocking]. *Ársrit Skógræktarfélags Ísl.*, pp. 8-40.

Bjarnason, H. 1974: Athugasemdir við sögu Íslendinga í sambandi við eyðingu skóglendis [The history of Iceland and woodland destruction]. *Ársrit Skógræktarfélags Íslands*, pp. 30-43.

Boman M., Bubenko, J. jr. and Johannesson, P. 1993: *Models, concepts and information : an introduction to conceptual models* [5. (rev.) ed.] Kista, 214 s.

Boman M., Bubenko, J. jr. and Johannesson, P 1992: Conceptual modelling. 4. rev. ed. Kista, 208 s.

Costanza R. et.al. 1993: Modeling complex ecological economic systems. Serie:Beijer reprint series ; 17, pp. 545-555, Stockholm : Beijer International Institute

Dahlberg, A. 1996: On interpreting environmental change: time, space and perception in the case of Kalakamate, North East district, Botswana, *in Interpretations of environmental change and diversity. A study from North East district Botswana.* Dissertation Series no 7. The Department of Physical Geography, Stockholm University dissertation series.

Dýrmundsson, Ó.R. 1990: Utilization of communal rangelands in Iceland. *NJF – seminar nr. 181. Jorderosion och fosforförluster i lantbruket. Laugarvatn, Island, 9.-13. August 1990.*

Einarsson, B. F. 1994: The settlement of Iceland; a critical approach, Granastaðir and the ecological heritage. *GOTARC. Series B. Gothenburg archaeological theses 4.* p. 202.

Einarsson, M.Á. 1976: *Veðurfar á Íslandi [Climate in Iceland]*. Iðunn, Reykjavík.

Friðriksson, S. 1978: The degradation of Icelandic ecosystems. In: Holdgate, M.W. and Woodman, M.J. (eds.) *The Breakdown and Restoration of Ecosystems*. Plenum press, N.Y., pp. 145-156.

Gísladóttir, G. and Preston-Whyte R. 1998: Policy changes in sheep farming in Iceland, *in Environmental characterisation and change in South-Western Iceland*. Dissertation series no 10. The Department of Physical Geography, Stockholm University dissertation series.

Guðbergsson, G. 1975: Myndun móajarðvegs í Skagafirði [Soil formation in Northern Iceland]. *Íslenskar landbúnaðarrannsóknir*, vol. 7, pp. 20-45.

The Icelandic Agricultural Information Service 1997: *Icelandic Agricultural Statistics*, 32 p.

Icelandic Statutory Law Gazette [Stjórnartíðindi B] 1979: Law no. 348/1979.

Icelandic Statutory Law Gazette [Stjórnartíðindi B] 1991: Law no. 313/1991.

Júlíusson, Á.D. 1995: *Bønder i pestens tid; landbrug, godsdrift of social konflikt i senmiddelalderens islandske bondesamfund [Farmers during epidemic times]*. Unpubl. Ph.D. thesis, Univ. of Copenhagen.

Júlíusson Á. D 1998a: Valkostir sögunnar. Um landbúnað fyrir 1700 og þjóðfélagsþróun á 14.-16. öld [The choice of the history. Agriculture before 1700 and social development in the 14th-16th centuries]. *Saga XXXVI* (1998), pp. 77-111.

Júlíusson Á. D 1998b: The environmental effects of Icelandic farming in the late middle ages and the early modern period. *International Congress on the History of the Arctic and Sub-Arctic Region. 18-21 June, 1998, Reykjavík, Iceland.*

Kangalawe R. 1998: Land-use and its impacts on the ecological sustainability – a conceptual model. In: *Moberg, A. (ed.) Modelling in Physical Geography. Project works 1998*. Dept. of Physical Geography, Research Report no. 106, pp. 37-41.

Kristinsson, A. 1998: Productivity and population in pre-industrial Iceland. *International Congress on the History of the Arctic and Sub-Arctic Region. 18-21 June, 1998, Reykjavík, Iceland.*

Ólafsdóttir R. and Júlíusson Á.D. 1999: Farmers' perception on land cover changes in NE Iceland. Submitted to Land degradation and development.

Ólafsdóttir R. and Haraldsson H. 1999: Modelling ecological sustainability in arctic landscapes. Proposal for project.

Sigbjarnarson, G. 1969: Áfok og uppblástur [The loessial soil formation and erosion on Haukadalsheiði]. *Náttúrufræðingurinn*, vol. 39, pp. 49-128.

Sigurðsson, S. 1977: Birki á Íslandi [Birch in Iceland], *in Skógarmál*. Reykjavík, pp. 146-172.

Svejcar T. and Christiansen S. 1987: The influence of grazing pressure on rooting dynamics of Caucasian Bluestem. *Journal of Range Management* Vol. 40, no. 3, pp. 224-227.

Þórarinsson, S. 1961: Uppblástur á Íslandi í ljósi öskulagarannsókna [Soil erosion in Iceland, a tephrocronological study]. *Ársrit Skógræktarfélags Íslands 1960-1961*. pp. 17-54.

Þórarinsson, Þ. 1974: Þjóðin lifði en skógurinn dó [The nation survived but the forest died]. *Ársrit Skógræktarfélags Íslands*, pp. 16-29.

Þorsteinsson, I. 1973: Gróður og landnýting [Vegetation and land use], in *Landnýting, Rit Landverndar*, pp. 26-37.

THE EFFECT OF ROCK FRAGMENTS ON POST FIRE EROSION CHARACTERISTICS.

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Abstract. The effects of different sizes, amounts, and positions of rock fragments on soil properties and erosion after a fire event were studied in experimental plots (10 treatments including bare soils ,with three replicates each) installed on a hillslope.

The largest amounts of runoff were from bare soil containing abundant rock fragments, either partially embedded on the surface or incorporated in the upper part of the soil. Stonelles soils give smaller amounts. Generally, large rock fragments, cobbles resulted in greater runoff than smaller fragments, coarse gravel.

Sediment yield loss was greater from soils with cobbles than from soils containing coarse gravel.

Keywords: Rock fragments, runoff, erosion, sediment yield.

Introduction

Wild fires are a very common phenomenon during the hot season in Greece as well as in the rest of the Mediterranean area. The impact of fire on soil is really very complex affecting not only the physic-chemical characteristics of but also the erodibility of a soil. They sometimes make worse the existing problem of soil loss from water erosion which is a main degrading factor for the soils. It is known worldwide that the fire as a rapidly acting modifier of the environment, resulting in events such as the destruction by combustion by the biomass and the modification of the physic-chemical parameters of the soil that are related to erodibility and fertility; producing global changes in the soil ecosystem.

In addition the rock fragments may have positive or negative effects on soil properties affecting runoff vegetation and erosion. It is stated that gravels (2 mm-7.5 cm in diameter) and stones (>7.5 cm in diameter) decrease exploitable soil volume and biomass production under normal climatic conditions but play an important role against desertification under dry weather conditions in the Mediterranean region. Kosmas et al. (1993) demonstrated that surface mulching with gravel and stones (7,6-29,9% by volume) decrease evaporation by a percent of 20-30% for soils on shoulders and footslope respectively.

The Laboratory of Soils and Agricultural Chemistry of the Agricultural University of Athens, has settled a field experiment since January 1993 in order to investigate the influence of rock fragments on soil properties and erosion. The influence of rock fragments was studied in especially designed experimental plots on the hillslope. Some time later this experimental site was burned and so the idea of this Msc thesis was born.

Materials and methods

The settlement of the experiment included the cautious structure of them concerning the rock fragments content of each one of them. So the coarse fragments (>15 mm) present in the upper 0,40 m of soil were completely removed. Then rock fragments of two sizes, classified as coarse gravel with 44 mm average diameter (range19-67 mm), and cobbles with 146 mm average diameter (range 94-189 mm), were either incorporated into the upper 0,15 m of soil or partially embedded into the soil surface. All of the plots as has already been mentioned were burned during the summer of 1998 and so were bare of any natural vegetation which was regenerated after the first rainfall events. The most dominant plant species were winter annual plants.

Each runoff plot was bounded and trenched around to lead away upslope runoff water. Consequently the runoff water from the plots was drained into troughs and then into large containers which were especially installed into the ground for this reason. For the purpose of the experiment the containers were periodically cleared of sediment and of water and of course after each rainfall event. The experiment was conducted for a five months period (from 27/11/98-2/4/99). There were ten studied treatment, depending on the percentage of the rock fragments and the vegetative cover.



Figure 1 The experimental site.

Description of the study site

The most important land and climate characteristics are the following:

The experimental site is located on a sloping site (slope 17%) 30 km in the east of Athens. The attitude from the sea level is 140m. It is consisted of 30 experimental plots each one 2m x 5m. The site is characterized by a thermo-mediterranean climate, with an average annual air temperature of 17.8 C and an annual precipitation of 496mm. The soil is well structured, dark,

stonycarcaleous clay loam, formed on marls interbedded with sand stone. It is classified as Typic Calcixerol according to the Soil Taxonomy.

Results and discussion

The data concluded from the experiment clearly indicate that the runoff and the sediment yield was higher when we were referring to plots containing cobbles than from those

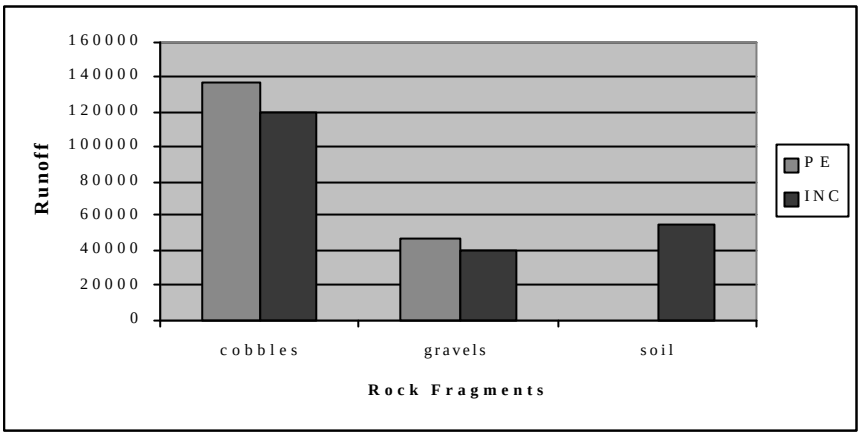


Figure 2 Runoff versus different treatments.

containing coarse gravels. It is very important to state that vegetation cover reduced sediment yield in all examples. Additionally sediment yield for the plots which had partially embedded cobbles of 10,45 was higher than that which had no rock fragments and further more the total sediment yield provided by this treatment from all the rainfall events was the highest one of all the treatments. As the cover increased till 17,8% sediment yield decreased(Fig 2).

Concerning the case of the partially embedded gravels of 17,9% cover of the soil surface the sediment yield was higher than the soil without gravels in all rainfall events and the highest in the total rainfall for all treatments. In Conclusion among the treatments with partially embedded rock fragments, gravels provided the lowest runoff and sediment yield.

The total sediment yield for these different treatments for the whole period of time in which the experiment was conducted is represented in figure 3.

However, in the soil with appreciable amount of coarse gravel on the surface of the soil under rainfall of long duration and low intensity the runoff is higher than in rainfall with greater intensities.

Moustakas & Kosmas (1995) reached to the conclusion that for rainfalls of low to medium intensities and duration coarse gravel and large cobbles on the soil surface induce similar or higher runoff than that from stoneless soil. However at greater intensities, even for short duration rainfalls, there is a protective effect of coarse gravel at the surface, that leads to reduced runoff.

Conclusions

In conclusion we could state that:
the partially embedded cobbles resulted in the highest total amounts of sediment yield and runoff, and they have definitely a most serious effect on the erosion characteristics than the gobbles, since the latter resulted lower runoff and sediment yield productions.
Generally large rocks fragments ,cobbles, can rresult in higher runoff than those of smaller rock fragments such as gravels.
The results from the field experiment showed that the more runoff was generated from the bare soil containing cobbles than from the bare stonefree soil.

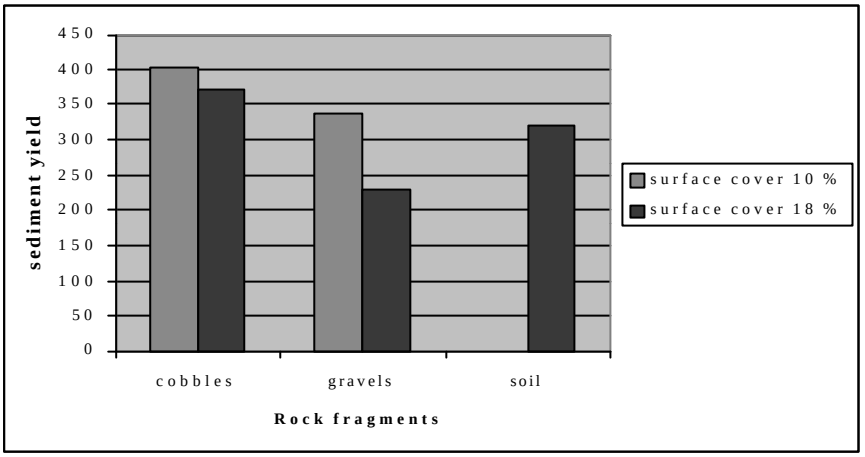


Figure 3 Sediment loss versus different percentages of surface cover of the rock fragments.

References

Brandt C.J. & Thornes J.B. (1996). Mediterranean Desertification and Land Use. John Wiley &Sons, Chichester, N.Y.

Danalatos N., Kosmas C., Gerontidis S., Marathianou M. (1998). The effect of land use on the degradation of the soil. 1st National Conference on Agricultural Mechanics 389-398.

Kosmas C., Moustakas N., Danalatos N., Yassoglou N. (1994). The effect of rock fragments on wheat biomass production under highly variable moisture conditions in Mediterranean environments. *Catena* **23:**191-198.

Kosmas C., Danalatos N., Cammeraat L.H. (1997). The effect of land use on runoff and soil erosion rates under Mediterranean conditions. *Catena*, **29:**45-59.

Kosmas C.S., Danalatos N. (1994). Climate change, desertification and the Mediterranean region. In: Rounsevell, M.D.A. & P.J. Loveland (Eds.), Soil Response to Climate Change, NATO ASI Series Vol I-23.Springer -Verlag, Berlin, Heildelberg, 25-38.

Moustakas N., Kosmas C., Danalatos N., Yassoglou N.(1995). Rock fragments I. Their effect on runoff, erosion and soil properties under field conditions. *Soil Use and Management* **11:**115-120.

DIGITAL ELEVATION MODELS IN PRECISION AGRICULTURE

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Abstract. Agriculture is strongly related to geography in local, regional and global scales. Applications and technical advances are developed towards site specific actions and measures. At the same time data are used in large information networks for decision making in national and international scale. In both micro and macro scale the tools used need a geographic component and a system to handle this, a Geographical Information System (GIS).
Water, that is one of the limiting growth factors, is of course essential in climates that are dry but also in sub humid areas. Other issues, as salt-water intrusion in ground water due to a large out take, are of importance for farming in these areas. With a system of precision irrigation help for different climates is provided.
Water that is irrigated or rains does travel over the surface that it hit, it also infiltrates and percolates and moves in the soil. This means water often ends up in plants in different places then where it first hit the ground. With distributed hydrological modeling the movements of water may be determined, both the run off and soil moisture movements in the unsaturated zone. Furthermore, the need for water in different parts of a field can be determined for specific or different crops. The water can then be irrigated with a system that receives data from the models and in connection with a GPS receiver (Global Positioning System) distributes the right amount of water to the right place. Water do then benefit the plants instead of evaporate unused that could be the case in a depression or on the other hand run off to other parts of a field if the case is a ridge.
For the research other data is used as well, this includes for example micrometeorological data which is used for evapotranspiration calculations and evaluation of models. Also, a large quantity of yield data from the investigated fields is collected. Preliminary results show that the technique enhances yield and reduces the water consumption.

Introduction

Agriculture is strongly related to geography in local, regional and global scales. Applications and technical advances are developed towards site specific actions and measures. At the same time data is used in large information networks for decision making in national and international scale. In both micro and macro scale the tools used need a geographic component and a system to handle this, a Geographical Information System (GIS).
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Water that is irrigated or rains does travel over the surface that it hit, it also infiltrates and percolates and moves in the soil. This means water often ends up in plants in

different places then where it first hit the ground. With distributed hydrological modeling the movements of water may be determined, both the run off and soil moisture movements in the unsaturated zone. Digital elevation models (DEM) are used for input data to the models. Furthermore, the need for water in different parts of a field can be determined for specific or different crops. The water can then be irrigated with a system that receives data from the models and in connection with a GPS receiver (Global Positioning System) distributes the right amount of water to the right place. Water do then benefit the plants instead of evaporate unused that could be the case in a depression or on the other hand run off to other parts of a field if the case is a ridge.
For the research other data is used as well, this includes for example micrometeorological data which is used for evapotranspiration calculations and evaluation of models. Also, a large quantity of yield data from the investigated fields is collected. Preliminary results show that the technique enhances yield and reduces the water consumption.
In the study, the first steps towards a system that includes hydrological models, is to make a DEM. The DEMs are useful tools in precision agriculture and are finding their ways into many different applications. Elevation models are a necessity for several topographic parameters that are used in hydrology and models connected to this. Parameters like this is slope (gradient), aspect, drainage area etc. If data is sampled in an inadequate way this will cause errors that affects the generation of for example run-off routines.

Background and aim

Digital Elevation Models (DEMs) are being used more and more frequently in precision agriculture. Topographic parameters, such as slope (gradient), aspect and absolute elevation are used both as input data for actions and other analysis. Actions can be guidance for machinery and an example of analysis can be deriving management zones from a DEM. Besides this, landforms, which are calculated from the former parameters, are used in a variety of applications. Examples of types of landforms are concave and convex slopes, up-, mid- and foot slope and examples of applications are soil management and hydrological modeling. In order to get models and data that are correct all steps need to have a good accuracy. This is not obtained if the interpolation carries on errors that arise during the sampling. The aims of this study were therefore to evaluate the influence of different sampling schemes, i.e. point density and point pattern, on the interpolated surface.

Errors that occur in interpolated surfaces as effects of sampling

One major problem in interpolating elevation data for the creation of gridded digital elevation models is the occurrence of striping artifacts. Striping, i.e. an effect of terracing of the elevation data in the DEM, is more or less apparent in the resulting DEM and is dependent on the type of interpolation algorithm used, the fine tuning of the parameters in this algorithm, and the distribution of the original elevation data that have been interpolated. Figure 1 illustrates a DEM with a pronounced striping effect as a result of the application of a sub-optimal interpolation algorithm to unevenly distributed elevation data.

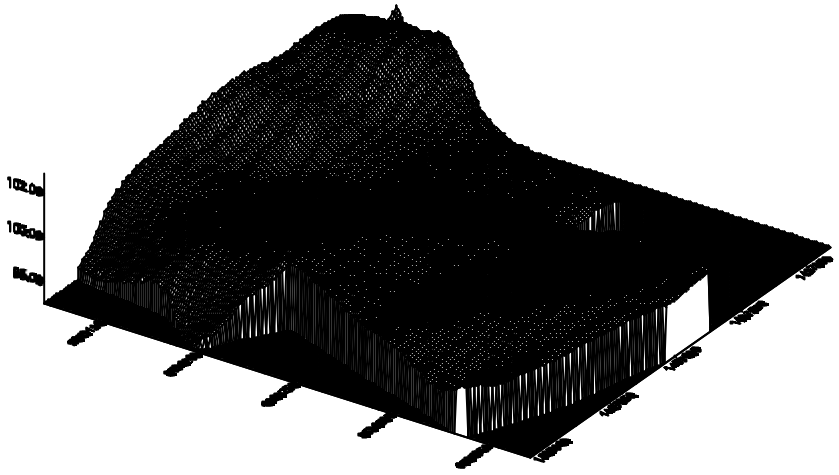


Figure 1: The striping, due to terraces in the terrain can be obvious when interpolating elevation data into a gridded digital elevation model.

Modeling the flow pattern over the terrain may reveal the problem, and present the resulting accumulated surface flow as an image (Figure 2). The algorithms used to estimate flow accumulation are presented in Pilesjö et. al (1999).
The striping must be explained before trying to eliminate the disturbing striping effect from the digital elevation model. A comparison of striping in Figure 1 and the representing elevation data points sampled in the field (Figure 4) indicates that the striping is concentrated parallel to the transects where the sampling has taken place. Figure 3 illustrates the lack of fit between the 'true' isolines in the field and the interpolated isolines extracted from the 'striped' DEM. The lack of fit may be obtained when the sampling has been carried out perpendicular to the isolines (i.e. when data is sampled 'up-down', see Figure 3.a) as well as when the sampling lines are parallel to the 'true' isolines (Figure 3.b).

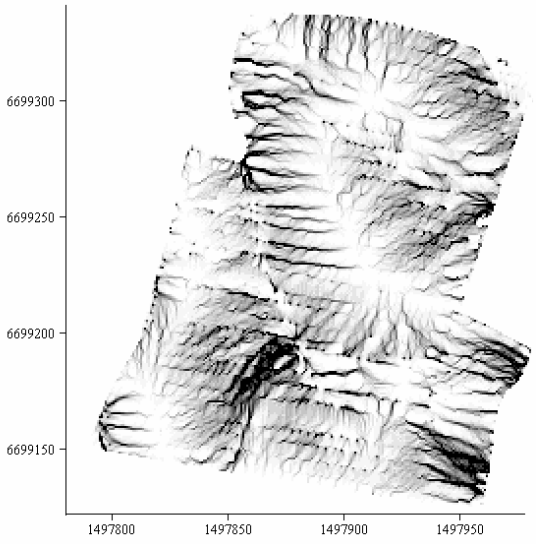


Figure 2: The accumulated theoretical flow pattern over a surface reveals anomalies in the form of striping.

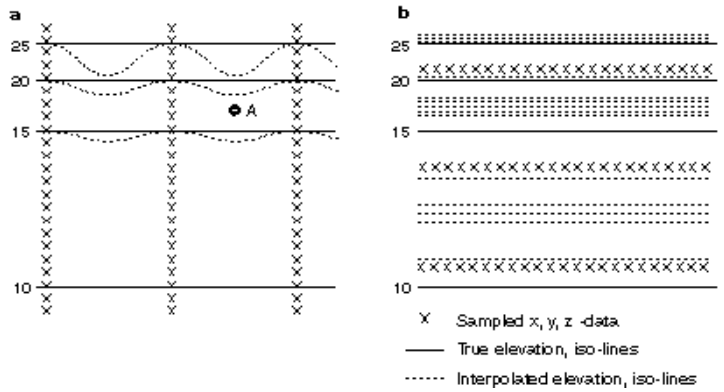


Figure 3 (a-b): There is a lack of fit between the 'true' iso-lines and the ones extracted from the interpolated DEM, independently if the sampling has been carried out perpendicular (a) or parallel (b) to the 'true' iso-lines.

In both cases, the anomalies depend on weighting a known input data point in relation to the distance of the unknown point. Interpolation entails the estimation of elevation based on the elevation value of existing, surrounding, data points. The anomaly produced by the sampling of data points perpendicular to the isolines is illustrated by Figure 3a. A is situated in a concave slope between two sample transects. The up-slope points are as important as the down-slope points in the interpolation. Since A is situated on a concave slope the differences in elevation are greater up-slope than down-slope. This yields an overestimation of A. The more concave the slope the greater the striping effect, especially in terms of the flow pattern over the DEM. If the slope were convex an underestimation would be the result. In Figure 3.b, the data points are sampled parallel to the isolines. The interpolation functions properly only when the slope is straight. The estimation of points in the vicinity of a sampled transects results in values close to the actual values, due to the fact that closer points are given more weight than distant points. This creates a "terrace" where steeper slopes are generated between the sampling transects.

The purpose of this study is to investigate the relative contributions of sample design vs. the interpolation algorithm on the resulting DEM.

Material, data and methods

Sampling scheme and data

Data sampling was carried out with an All Terrain Vehicle (ATV). The antenna was mounted above one of the wheels in the front so that sampling was possible in corners and along sides of ditches. Points along transects separated by 6 m in between were sampled over the study area, as shown in Figure 4. The sampling density was 1point every 1.5m within the transects as determined by the GPS-frequency and the speed of the ATV set this. This satisfied the need for both input data for interpolation and for evaluation data. The data was split in two halves; every second sampled point for an interpolation data set, and every second data point for an evaluation data set.

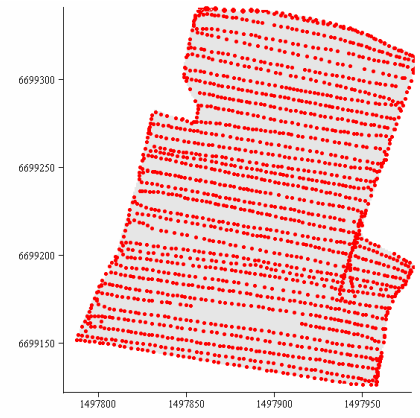


Figure 4: Data sampled with the ATV-mounted GPS.

In order to investigate the influence of the distribution of the sampling points on striping, different scenarios were tested. A standard inverse distance interpolation algorithm, available in ArcView (ESRI, 1999) and SURFER (Golden Software, 1999) were used. The data consisted of:

- All points from the interpolation data set (here called "the full data set")
- Every third data point along the transects of sampled points

These data sets were also used for the comparison between different interpolation algorithms. It is worth stressing that the evaluation data set differed completely (in space) from the data used for interpolation.

Interpolation algorithms

Two different interpolation algorithms were used and evaluated in this study; Inverse distance and kriging. Inverse distance uses a factor that represents a value that weights distance to a sampled point. A known data point that is closer to a point that is to be interpolated has a greater influence than a point further away (Burrough and McDonnell, 1998). Kriging uses a geostatistical approach. By using regionalized variable theory the local variation in spatial dependence is determined. This variation is determined with a semivariogram. In the semivariogram, all points are compared to all other points in the data set, yielding the spatial autocorrelation. Points close to each other have values that are closer to one another then points separated by greater distances. In the semivariogram, it is possible to find the distance where no spatial correlation. This distance is then used in the interpolation. Another variable derived from the semivariogram is the nugget, which describes a random, but spatially dependent error that has to be included in the interpolation (Burrough and McDonnell, 1998).

Interpolations with the two different algorithms were performed on both the full data set and on the data set with every third point.

Results

Surfaces interpolated on complete and partial data sets

The accumulated surface flow on the surface interpolated with the complete data set shows a pronounced striping effect (see Figure 2). Conversely, the accumulated surface flow that was calculated from the partial data set shows marked differences in flow pattern. Figure 5a shows the flow for an Inverse distance interpolated surface, using every third data point sampled in the field. The same data structure was used for Figure 5b derived with kriging.

Discussion

The generation of a continuous surface from the interpoalation of point data is complicated. The DEM must not contain significant errors if it will be used as input data for further study. An example is the flow accumulation. The computation of accumulated flow may be used as a diagnostic for investigating errors (i.e. striping) in the DEM (see Figures 2 and 5). When the sampled data is thinned out and interpolated the striping less apparent and a more representative flow pattern results. We tried different degrees of thinning on the data sets and found that every third data point gave the best result in lien of both surface representation and flow patterns. This degree of thinning also yields the most uniform distribution.

It is recommended that the data to be thinned out along the transects to produce evenly distributed data. As a rule of thumb, the distance between the sampling transects should be equal to the mean distance between sampling points along the transect.

However, when sampling in field, dense sampling is encouraged in order to facilitate an evaluation of DEMs.

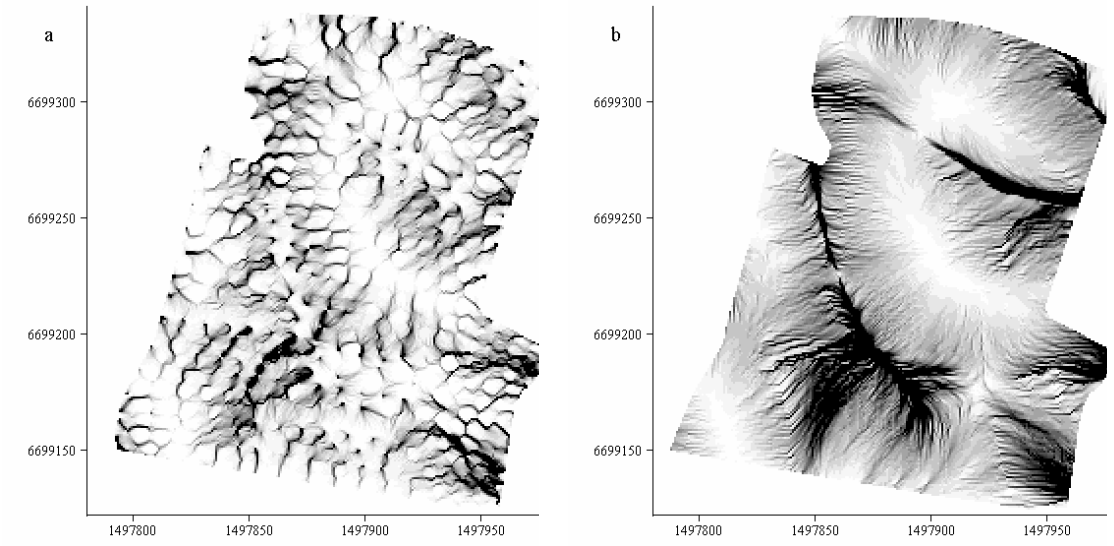


Figure 5: The accumulated flow in two DEMs interpolated with thinned out data by every third point. a) Inverse distance interpolation algorithm was used. b) The kriging interpolation algorithm was used.

References

P. Pilesjö, Q. Zhou, L. Harrie, 1999. “Estimating Flow Distribution over Digital Elevation Models Using a Form-Based Algorithm”, *Journal of Geographical Information* Science, 13p., In press.

ESRI, 1999, ArcView GIS 3.0

Golden Software Inc., 1999, Surfer for Windows, Version 6.

Burrough, P. A., McDonnell, R. A., 1998. Principles of geographic information systems, Oxford University Press, Oxford.

THE ROLE OF NATIVE AND ALIEN SPECIES IN THE RECOVERY FROM DESERTIFICATION OF St HELENA ISLAND

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Abstract. St Helena is a very isolated island refuge of international importance for its biodiversity. Over 450 years of degradation and desertification has been followed by a few decades of colonisation by a range of alien species. What role will these aliens play in the future of the island? Are they the latest in a series of threats to endemic species, or the means by which the wastes can begin a process of recovery and transition to sustainable use? Alien species can never be eradicated from St Helena. There is a need to determine impacts and functional behaviour rather than rely on simplistic evaluation.

Key words: Restoration, desertification, conservation, invasive species

Desertification on St Helena

Saint Helena Island is a British Dependent Territory. It is situated mid-Atlantic and is one of the most remote islands in the world. The story of how mis-management of natural resources lead to the degradation and erosion of large areas of land within the more arid climate zones, now called the Crown wastes, was one of the first documented, human-instigated, environmental disasters.

The island was originally discovered by the Portuguese in 1502. The loss and fragmentation of the natural vegetation began even before the island was settled. Goats were released in 1533, to supply meat for passing ships. The lack of predators or management of these herds allowed the population to grow dramatically. By 1588, flocks 'near a mile long' were noted. Trees were also cut for timber, fruits and vegetables were also planted and other livestock was released, including sheep and pigs each probably having its own impact on the vegetation.

Today the majority of the original vegetation cover and ecosystems of St Helena has been almost entirely destroyed. Wastelands of bare soil and sparse, mostly exotic scrub, cover over 60% of the island. Indigenous semi-natural forest covers less than one per cent of the country, occurring only in isolated remnants. The earliest pictorial view of the island approaches (reprinted in Gosse, 1938) shows cliffs which are, if anything, more barren than today. Certainly by the mid-19th century, the Crown Wastes were recorded as almost entirely desertified (Cronk, 1989).

Biotic Changes

Isolated from evolutionary change and shifts in plant and animal species, the island was a refuge for various endemic species. The term refuge seems appropriate as it is believed that many of the plants are relicts of a primitive flora that was once widespread and that colonised the island perhaps 10 million years ago (Cronk, 1989).

The native flora of St Helena consisted of about 70 species of flowering plants and ferns, 60 of which are endemic in 10 endemic genera. This makes it one of the most important islands for unique biodiversity in the world. However over 50% of the plant types described by Melliss (1875) have since been lost to the island. At present the endemic species cling on to tiny remnants of their former habitats, restricted to steep cliffs, wastelands or sheltered in *ex-situ* care. A number of species thought to be extinct have survived on remote and steep cliffs. Plants such as the Ebony, St Helena Olive *(Nesiota elliptica)*, False Gumwood *(Commidendrum spurium)* and Bastard Gumwood *(Commidendrum rotundifolium)* have all been rediscovered in recent times (Spooner, Upson, Kendle and Drucker, 1993). One dying plant of St Helena boxwood (*Mellissia begonifolia*) was rediscovered in 1999 and attempts are underway to propagate it.

However in parallel with this decline, introductions of economically important plants have increased the number of species significantly together with an increase in invertebrate pests. Strong altitudinal impact on climate meant that the inner one third of the island did not lose vegetation cover, but a series of waves of colonisation, associated with periods of strategic importance, such as acting as Napoleon's prison, meant that the interior underwent many land use changes. The flora now consists of about 320 species, of which some 260 (86%) are naturalized aliens.

The island's population is now around 5000. The 'productive' core of the island is currently far from self-sufficient. There is very little flat land suitable for large scale crop production. Common grazing land at the fringes of wastes are eroding. Many smallholders face problems arising from a suite of introduced plant pests and diseases that make it difficult to grow many crops (Spooner, Upson, Kendle and Drucker, 1993).

The Challenges of Ecosystem Recovery

In many parts of the world research into desertification and its remediation has to focus on the ways to slow current degenerative pressures. Technically valid solutions often founder because of social problems. However in St Helena many of the human pressures on the Crown Wastes have disappeared as the land become degraded; social and economic structures have adapted to a period of low involvement with the Wastes. Few people have expectations from it. This situation is of course partly a consequence of the fact that the early colonisers of St Helena were ahead of their time in pioneering landscape destruction. Current generations are living with the consequences of unsustainable resource use by their ancestors. However it does mean that there are few social barriers to revegetation.

It is often believed that the formation of deserts and the process of land degradation are effectively irreversible but in many areas this assessment is made without evidence, since the processes that first caused degradation have not been adequately halted. Irreversible decline will only occur when certain thresholds of degradation have been passed. In the most fragile

areas these thresholds may be easily attained and there will be no perceivable recovery from degradation for decades. The boundaries and limits of such an irreversible zone are not clear although Hourou (1979) identifies the 200mm annual rainfall limit as a critical point below which degradation is very difficult to reverse. Most of St Helena is above a 300mm isohyet. On climatic grounds therefore much of the St Helena Wastes is unlikely to be irreversibly degraded.

Irreversible desertification is sometimes attributed to internally generated climate change, e.g. where changing soil albedo affects rainfall patterns. Mathieson (1990) finds no evidence for changing macro-climate on St Helena in response to deforestation but water capture into the ecosystem was almost certainly higher than currently achieved as a result of mist precipitation onto the vegetation. Many St Helena native plants seem well adapted for mist capture (Spooner, Upson, Kendle and Drucker, 1993).

Permanent environmental decline may also occur where soil depth is reduced below critical amounts above impenetrable layers. The issues of land degradation on St Helena have inevitably been dominated by the huge and persistently visible effects of soil erosion. Estimates of soil loss in some catchments range from 60-1000 Ha^{-1} yr^{-1} which it is estimated could be reduced to 1 tonne Ha^{-1} yr^{-1} by appropriate revegetation (Anon 1991). However erosion control is expensive and complex, and it is already clear that the island cannot fund huge initiatives for rapid resolution of this problem. The areas of poorly vegetated Waste land in St Helena represents at least 50% of the total land area of 12100 Ha and rapidly gulleying 'badlands' represent about 7%. Revegetation initiatives have only managed to address 100 Ha since the 1950's (Kendle, 1995).

Loss of soil has been dramatic. What is less clear is whether, in the short to medium term, there will be a continual degradation of the land use options and potential for the island. The very definitions of soil degradation are open to debate. Young (1989) argues that the most significant process is the loss of productivity caused above all by the disappearance of organic matter from the soil surface. By this yardstick the St Helena Wastes are fully degraded and could get no worse. A second important concept is loss of 'recovery potential'. If irreversible change is a measure, then most of the St Helena Wastes may not yet be desertified. The processes of loss of 'soil' may still be many decades from being halted or even significantly slowed but in many areas the depth of potential soil forming material is still great and the risk of short term loss of land potential is not extreme.

Clearly it is essential that priorities are set and that expensive control measures are targeted with precision at the areas where consequent damage arising from neglect will be highest. Localised erosion control measures are critically important in areas where threats of encroachment onto productive land (either through soil loss or through soil deposition) are real, or where substantial areas of potentially productive land may become permanently degraded through loss of loose soil above rock. However whilst such initiatives are progressing the wider problem of wind and rain erosion will be gradually influenced by natural revegetation. Historically the areas of St Helena now regarded as Wastes were vegetated from bare volcanic rock. If this was possible once with the limited range of plants that were present, it must be even more likely now with a wider genetic base available.

On St Helena the first effective action to halt the uncontrolled grazing of goats was taken in 1940, linked to re-afforestation, a pasture fencing programme and a control on numbers. At

the end of 1955, there was a phased withdrawal of the goat ranges and the last animals were shot in the 1960s (Cronk, 1986). The regeneration of vegetation on the barren areas is now clearly progressing. Areas described as being devoid of trees just twenty years ago now show a developing covering of sparse scrub. In some places the processes are not so gradual but are proceeding rapidly. However the opportunities and trends now presented are complex. A careful analysis is required of whether the revegetation can be influenced by intervention, the nature of the species and communities that are developing, and the ways in which sustainable use can be made of the new land use opportunities.

International experience of successful dryland rehabilitation is far more limited than that of land degradation and the options and consequences are less well researched. Even less certain are the best approaches in circumstances where the biodiversity resource is of unique and great significance, or in areas where the flora is hugely dominated by introduced species and where the ability of the native plants and animals to compete is far from proven. Is it possible that the recovery from desertification is as big a threat to St Helena than the original degradation was?

The Potential Consequences of Unmanaged Rehabilitation

The key colonists on the regenerating scrublands are:

St Helena common name	**Scientific name**
Prickly pear	*Opuntia vulgaris*
Wild current	*Lantana camara*
Wild mango	*Schinus terebinthifolius*
Wild coffee	*Chrysanthemoides monilifera*
Cedar	*Juniperus bermudiana*
Aloe	*Furcraea gigantica*
Pine	*Pinus pinaster*
Spoor	*Pittosporum viridiflorum*
Creeper	*Carpobrotus edulis*
Yellow Pops	*Tecoma stans*
Willow	*Acacia longifolia*

This list includes useful species, neutral species and also some that have an international reputation as highly invasive weeds. To be able to make a realistic assessment of the weed threat it is necessary to address the issue of what the concept of 'weed' really means in the heavily degraded environment of the St Helena Wastes. The frequently quoted maxim that a weed is a plant in the wrong place is in many ways unhelpful and misleading since it could focus attention on species that are not really significant threats. These plants may be fulfilling an important functional role in substrate development and soil stabilisation, or they may simply represent a temporary successional phase that will help initiate recovery towards a more balanced system. For a plant to be a real weed there has to be a target for it to impact against,

it needs to be expected to cause significant harm and it needs to be a species for which eradication or control is a substantial rather than a trivial task.
The following potential threats may result through the growth of undesirable shrubs:

- Soil quality degradation
  Some species, because of their strategies for resource capture in hostile lands, may actually be capable of inhibiting recovery
- Excessive water use
  The endemic species of St Helena have a reputation of being good at water harvesting through mist precipitation. The islanders have some concern that introduced species, especially *Eucalyptus*, may lead to excessive water loss.
- Weed threat to endemic plant refuges
- Weed threat to pasture land
- Weed threat to forestry land
- Human health effects
  Schinus terebinthifolius in particular has been linked to respiratory diseases.
- Livestock health effects
  This could arise through the spread of poisonous plants or less seriously through the spread of species that would cause diet imbalances if used for browsing.
- Honey spoiling
- Fire risk
  The development of dryland forest will increase the fire risk on the island.

The one that has international as well as local significance is the threat to the endemic plant refuges. Many survived by finding cliff refuges that were inaccessible to grazing animals - there could be no such refuges that guarantee protection from invading plants. Since the endemics of St Helena are believed to be characteristics of a type of flora that has been almost completely driven to extinction in other countries, the likelihood is strong that they will prove to be uncompetitive against the ranks of some of the most stress tolerant arid-land species known in the world.

Management Options

The island's response to invasive species in the past has been to exploit biological controls on a case by case basis, wherever these are available, or using more direct methods of removal and control where they are not. These additional costs of production undermine attempts at developing the farming economy of the island. A more strategic approach would be to fully identify the role the wastes could play in strengthening the island's economy. The wastes currently provide a reservoir of opportunity for weeds, rather than being seen as an opportunity for the island. Ideally it would be possible to identify the opportunities for pre-emptive productive land use that would generate income as well as providing incentives for weed management.
The history of St Helena shows graphically how difficult the sustained exploitation of fragile arid habitats can be. At this stage, the true capacities of the Crown Wastes are yet unclear but globally there are many areas of comparable rainfall that do provide some benefits to local

populations. For example the Wastes could aid the protection of existing productive land by providing a fodder reserve. The commons pasturelands of St Helena tend to be found on the low productivity fringes of the island (Atkins, 1991), grading into scrub and 'badlands'. These areas are very fragile systems and are in crisis from overgrazing leading to localised soil degradation. Fodder supply in the season of peak stress plays an important role in influencing the extent to which the grasslands are overgrazed (Anon, 1992). 'Spoor' *(Pittosporum viridflorum)* has a wide ecological distribution and is one of the primary colonising species across much of the island Wastes. This species is used as fodder supply plant when young.

The opportunity also exists to consider a planned and more rapid expansion of the useful land base if suitable extensive intervention techniques can be identified. Priority areas would be the trialling of high value dryland forestry species or honey production. Savill (1989) recommended several species that may be suitable for the waste lands including *Casuarina* and *Prosopis* species. *Casuarina equisitifolia* is currently being grown in trials on the island. Its combination of salt tolerance and nitrogen fixing ability could give it great potential.

The rehabilitation programmes that have been targeted at the Wastes have focused on introducing more plants to the island which are adapted to adverse climatic and soil conditions. However there is clearly an important concern that further introduction may lead to further weeds and it is important to review the potential balance between desirable and undesirable properties for new species.

Very many invasive plants have tough physiology that makes them suitable for use in degraded lands. Such plants have been widely introduced by governments and international aid agencies around the world and the consequences can be undesirable where species have got out of hand. Even Vetiver grass, widely promoted for use in aridlands, has been prohibited in some countries who see it as a possible weed. It is said to grow in rainfall ranging from 200-6000mm and in almost any soil regardless of fertility. This wide range underlies its advantages as a species for use in restoration but also illustrates the nature of its threat (Sivamohan, Scott and WaIter, 1993).

Plants that are good colonists of degraded hostile soils need certain characteristics:

- they need to have efficient methods of reproduction as the likelihood of seed survival is low
- they benefit from mechanisms which make them efficient at resource capture in conditions where resources are in short supply
- they need a wide physiological range in order to allow them to tolerate variations in the environment which are magnified in arid lands
- they often need rapid growth to allow them to exploit temporary periods when conditions are favourable
- they need to have high levels of tolerance of periods of extreme stress.

This list can be compared to that prepared by Carter (1994) who attempted to determine the factors that indicate likely 'weed' status based on behaviour of *Acacia nilotica*:

- seedlings and young trees are grazing resistant because of thorns
- long distance dispersal mechanisms
- large seed production
- long lived seeds
- young plants grow rapidly

- tolerant of grazing, drought, fire and salinity (nutrient deficiency can also be added to this list)
- presence of an open, fire-free habitat to invade
- long lived adults
- growth possible over an extensive climatic range
- the plant has useful characteristics (this confuses those who may otherwise have introduced control measures)

Research workers increasingly feel that there has to be some control over the introduction of potentially invasive plants into countries. The intent of course is not to stop rehabilitation work but to try to identify species that have a value but which do not have an invasive ecology. The conflicts of interest between the valuable utilisation of a species in one land use system, and its harmful impacts in another, mean that species management decisions are complicated by complex social and political ambiguities (Harding and Bate, 1991). On St Helena there are many advantages that could be obtained from continuing the import and trialling of economically valuable alien species but each of these could present another risk to the ecology of the island.

Is it Possible to Identify Potential Weeds Before They Are Introduced?

Carter (1994) recommends that screening should be done in the native homeland of the plant and in other areas where it has been introduced to measure:

- seed production and longevity
- methods of seed dispersal
- susceptibility to grazing (this is of course irrelevant in a non-grassland habitat such as forestry areas
- climatic and soil preferences
- investigation of the effects of insect predators, diseases and fire
- investigation of practical methods of biological and chemical control

Inevitably there are numerous difficulties when screening plants in this way and he highlights:

- unpredictable behaviour away from native pathogens, insects and browse animals
- unpredictable behaviour under new climatic, soil and fire regimes
- genetic drift and hybridisatron which can change the character of the plant introduced

To this list can be added:

- unpredictable behaviour in absence of native pollinators and seed dispersal agents
- difficulty of predicting response to competition from established vegetation in the target country.

When attempts were made in Australia to identify variables for species likely to become pests, no indicators were found which consistently identified weed status in non-food crop weeds (Scott and Panetta, 1993). *Acacia nilotica* was introduced to Australia in the late 1890's but it was not perceived as a threat until the 1950's when a series of wet years lead to a spectacular increase in tree density after which it was declared a noxious weed. Ecological problems can arise from extreme or atypical events that do not characterise the normal growing environment of a plant (Harding and Bate, 1991). In the absence of appropriate

dispersal species, plants which are aggressive 'weeds' in other situations may remain very much more restrained. Conversely in the absence of predatory species or other natural competitors a species which is not aggressive in one setting may become a serious weed in another. Simberloff (1990) also concludes that there are no rules for forecasting the ecological impacts of an introduced species and cites the introduction into the USA of the ecologically similar house and tree sparrows, one of which has become a pest throughout most of the continent whilst the other has remained in one location.
To a certain extent therefore the reproductive ecology of different plant species can only be determined in a St Helena context. Part of the challenge of restoration management involves the need to develop strategies for ecosystems which are only partly functioning because they lack key processes. The prediction of long term effects, looking to a time when much of the Crown Wastes have recovered and when some new types of land use, such as rangeland grazing, may have become important is therefore even more difficult.

The role of Natives and Aliens on St Helena

The extent to which plant invasions pose threats to biodiversity and cause damage is becoming a very high priority research topic worldwide (e.g Luken and Thieret, 1998; Pysek, Prach, Rejmanek and Wade, 1995). However there has been a tendency to presume that 'aliens' are undesirable within ecosystems (e.g. Pysek, 1995) when in fact the situation is more complex. Most aliens are not weeds, whilst some natives are.
Williams (1997) argues that possible functional benefits of non-natives in natural habitats include:

- structural diversification and niche creation
- food supply
- facilitation of regeneration of natives (nurse species)
- modification of disturbance (e.g. reducing erosion or fires)
- compensating for the loss of a native that was important for ecosystem function.

Non-natives may also represent a resource of genetic diversity that has been lost or suffered massive depletion in its country of origin. On St Helena the Bermuda Cedar (*Juniperus bermudiana*) is a self regenerating timber tree but is a threatened species in Bermuda itself (Spooner, Upson, Kendle and Drucker, 1993).
If aliens have any unique capability to be weeds, it is because out of those that can reproduce, some of them may lack local pests or pathogens that would put constraints on their reproductive ability in their places of origin. However the disappearance of constraints can also happen to natives, for example if a predator goes extinct (Garrott, White and Vanderbilt White, 1993). On reflection, the invasive ability of natives is not surprising. These are plants that have proven reproductive ability within their climatic range and they are often very able to exploit opportunities created by excessive habitat degradation. In many cases in restoration work using afforestation techniques it is therefore the very absence of reproductive capability in some exotic species taken outside of their natural range, which obviously can not be guaranteed for natives, that makes them potentially useful.

Luken (1994) argues that the recent growth in concern about the global spread of non-natives does not reflect a growing problem, since the 'problem' has existed for centuries. Instead it represents an evolution of value judgements. Last century was a period when non-natives were studied, but seen as interesting rather than condemned. Luken (1994) also suggests that given that the spread of non-native plants is inevitable, the perceived conflict is actually being aggravated by the processes of nature preservation that define impossible boundaries, conceptual as well as physical, to species movement. The paradox of how conservationists increasingly pour resources and management effort into sites to keep them 'natural' is explored by various authors (Duffey, 1974; Peterken, 1996).

There is a great temptation to see the dominance of non-native species on St Helena as a problem in itself that needs to be tackled, but this would do little more than present the people of the island with an impossible challenge. The future ecology of the island will be based on a combination of natives and non-natives. Alien species can not be rejected out of hand, rather a functional classification of the effects and behaviour of a species is required and would inspire a clearer focus. This in itself will be a difficult enough research challenge, since it requires an assessment of potential impacts on land uses that do not yet exist. It is this research challenge that will be tackled in the coming years.

References

Anon (1991). Environmental Conservation Project. Proposal for funding to ODA. Agricultural and Forestry Department, St Helena. 27pp.

Anon (1992). A Strategy for Agricultural and Forestry Development in St. Helena, 1993-1998. Agricultural and Forestry Department, St Helena.

Atkins, W.S. International Ltd. (1991). Agricultural Sector Study, St. Helena Draft Report. Report by Overseas Development Administration, Department of Agriculture and Natural Resources and W.S. Atkins International Ltd.

Carter J.O. (1994) *Acacia nilotica* - a browse tree out of control. In R.C. Gutteridge and H.M. Shelton (Eds) Forage Tree Legumes in Tropical Agriculture. 338-351. CAB International, Wallingford. pp 338-351

Cronk, Q.C.B. (1986) Conservation of the St. Helena Endemic Flora. Report of WWF (UK) Project No.118/86. 22pp. Cambridge.

Cronk, Q.C.B. (1989). The past and present vegetation of St Helena. *Journal of Biogeography* **16** 47-64.

Duffey E. (1974) Nature Reserves and Wildlife. Heinemann Educational Books, London. 134pp.

Garrott R.A., White P.J. and Vanderbilt White C.A. (1993) Overabundance: an issue for conservation biologists? *Conservation Biology* 5 283-296

Gosse, P. (1938). St. Helena 1502-1938. Cassell, London.

Harding G.B. and Bate G.C., (1991) The occurrence of invasive Prosopis species in the north-western Cape, South Africa. *South African Journal of Science* 87 (5) pp 188-192

Kendle, A.D. (1995) Soil Conservation and Restoration on St Helena Island. St. Helena: The Overseas Development Administration for the Government of St Helena, l27pp

Hourou L. (1979) Long term dynamics in arid land vegetation and ecosystems of North Africa. In D.W. Goodall and R.A. Perry (Eds) Arid Land Ecosystems - Structure, Functioning and Management. Cambridge University Press, Cambridge.

Luken J.O. (1994) Valuing plants in natural areas. *Natural Areas Journal* **14**: 295-299.

Luken J.O and Thieret J.W. (Eds) (1998) Assessment and Management of Plant Invasions. Springer, New York.

Mathieson l.K. (1990) The Agricultural Climate of St Helena. W.S. Atkins, Cambridge.

Melliss, J.C. (1875). St. Helena; a Physical, Historical, and Topographical Description of the Island Including its Geology, Fauna, Flora, and Meteorology. Reeve, London. .

Peterken (1996) Natural Woodlands. Cambridge University Press, Cambridge.
Pysek P. (1995) On the terminology used in plant invasion studies. In P. Pysek, K.Prach, M. Rejmanek and M. Wade (Eds) Plant Invasions – General Aspects and Special Problems. SPB Academic Publishing, Amsterdam. pp 71-81.
Pysek, P., Prach K., Rejmanek, M. Wade, M. (Eds) (1995) Plant Invasions – General Aspects and Special Problems. SPB Academic Publishing, Amsterdam.
Savill P.S. (1989). A Review of Silvicultural Practices and Forestry Research on St Helena. Oxford Forestry lnstitute. St Helena A&F Dept Internal Report.
Scott J.K. and Panetta F.D. (1993) Predicting the Australian weed status of southern African plants. *Journal of Biogeography* **20** (1) 87-93.
Simberloff D. (1990) Community effects of biological introductions and their implications for restoration. In D.R. Towns, C.H, Daughtery and I.A.E. Atkinson (Eds) Ecological Restoration of New Zealand Islands. Conservation Sciences Publication No. 2. Department of Conservation, Wellington, NZ.
Sivamohan M.V.K., Scott A. and Walter M.F., (1993) Vetiver grass for soil and water conservation: prospects and problems. In D. Pimental (Ed) World Soil Erosion and Conservation. Cambridge University Press, Cambridge pp 293-209.
Spooner B., Upson T., Kendle A.D. and Drucker G. (1993) Environmental Profile of St. Helena. In M. Mander, B. Dala-Clayton and Bass A. Sustainable Environment and Development Strategy and Action Plan for St Helena. Vol 2. RBG Kew and the International Institute for Environmeent and Development. Government of St Helena, St Helena Island.
Young A. (1989) Agroforestry for Soil Conservation. CAB International, Wallingford.
Williams C.E. (1997) Potential valuable ecological functions of non-indigenous plants. In J.O. Luken and J.W. Thieret (Eds) Assessment and Management of Plant Invasions. Springer, New York. 26-34

THE CAUSES OF ENVIRONMENTAL DEGRADATION: AN ANALYSIS ON TROPICAL DEFORESTATION

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Abstract. The paper tries to shed light on the problem of tropical deforestation, through a quantitative analysis of some potential causes. On the basis of national data referred to 28 tropical countries in different periods, several regressions are carried out by using the weighted least squared method. With deforestation rate as dependent variable the relevance of various factors (demography, domestic socioeconomic situation, agricultural technology, ecological conditions and international economic relations) is examined. The results show that three variables constantly play a statistically significant role: fertiliser use per hectare, rural population density and trade openness.

Keywords: Tropical deforestation, empirical modelling, socioeconomic causes

Introduction: theories on the causes of environmental degradation

Though there are relevant regional differences in the processes of environmental degradation, an analysis of this problem from a global point of view is appropriate for at least two reasons: 1) the comprehension of its causes can hardly abstract from international factors; 2) the global effects of ecosystem deterioration are increasing, so that the consequent changes in climate, natural resources' availability and quality and economic equilibrium concern all the world. Tropical deforestation is one of the main topics and the necessity of studying it and of promoting appropriate interventions is of immediate urgency. The damages, both at the local and the global level, are so huge that soil protection, biodiversity and dimate cycles are in danger[1]. However the explanation of environmental degradation and, in particular, of tropical deforestation is a controversial issue: the various theories that are present in the literature focus on different causes and, consequently, they suggest political actions that are not compatible one another.

According to a diffuse line of thinking population growth is the fundamental cause of tropical deforestation, with poor peasants as the main agents of environmental destruction. The basis of this theory is a neo-Malthusian view, where demographic growth puts more and more pressure on limited resources, which can't increase as speedy as population. The result is not only an expanded misery but also a progressive destruction of the environment, which, being

[1] Scientists are more and more concerned about the impact of tropical deforestation on the climate of temperate zones, through an increase of greenhouse gases emissions and a reduction of the circulation of rain clouds towards the higher latitude regions (Bunyard, 1999).

an open access resource[2], is exploited by individuals at a rate above the one that would be optimal for the whole society.

The term "carrying capacity" is used to indicate the number limit of people above which an ecosystem is no more able to permit a sustainable development. In many parts of the tropics this threshold would have been exceeded; so that traditional methods of production, like shifting cultivation, have become a main cause of deforestation (Barney, 1980; Myers, 1980), in combination with migration of poor farmers towards the forest. International organizations, such as the World Bank (1992), generally agree with this explanation of the problem. The poor are considered, at the same time, as agents and victims of environmental degradation: the daily problems of survival and the lack of resources (technology, credit, etc.) would compel them to a short period view, even at the cost of destroying the ecosystem where they live.

Another aspect that is frequently discussed and that is not in contrast with the above line of thinking refers to market and policy failures. Some authors maintain that open access to natural resources and market distortions introduced by public policies have a central role in explaining environmental destruction and, in particular, deforestation. The theoretic basis of this view often includes neoclassical assumptions, according to which perfect competition assures the optimal use of resources and the efficiency of the system. The uncontrolled degradation of the environment would then derive from the existence of situations where this mechanism doesn't work. This often happens because of the absence of private property rights (either for practical difficulties or political will) and of alterations in economic indicators caused by State intervention in the economic sphere.

In this approach the lack of property rights, and hence of the inherent limits to the use of goods and factors, drives to a non-optimal solution, since the social costs associated to the depletion of a resource are not entirely paid by the one who provokes it. Researchers' attention has focused on land property, even if other open access goods (air, water, etc.) are involved. Some studies show how, in several countries, the activity of deforestation is a pre-requisite to obtain property rights on a certain area (Binswanger, 1991; Boado, 1988; Gillis, 1988b) and how the system of government concessions for logging provokes resources degradation in the long run (Gillis, 1988a). Other analyses censure the incentives to deforest caused by State distortions of market economy, both in the forest sector and in macroeconomic indicators (Repetto, 1988).

Another line of thinking looks at the problem of environmental degradation from a different point of view and finds its causes in the socioeconomic structure of tropical countries, eventually linking it to the international relations that characterize the world economic system. The emphasis on population growth is considered as a scapegoat that, by concentrating attention on a biological explanation, hides more controllable causes of social kind. There is not usually a real scarcity of natural resources, but an incapacity of most people to have access to them.

In this view the attribution of the responsibility of tropical deforestation to the poor is revised and criticized. First, it's observed that a part of tropical poor consists of tribal populations,

[2] Some authors use the term "common property" to indicate this situation (*cfr*. Hardin, 1968), but, since it is characterized by a lack of property rights, it's more correct to define it "open access", to avoid confusion with the cases of collective property.

which live in the best protected forests of the world (Hildyard, 1987). Second, rootless peasants, who have little incentives to natural resources conservation, must be distinguished from other little farmers, who usually produce in a sustainable way (Annis, 1992). Finally, the poor are often positive actors, since they participate in grassroots ecology movements.
In any case, even if the poor are sometimes direct agents of deforestation, the real responsibility should be attributed to the short-sightedness and the greed of the mighty (Lutzenberger, 1982). So, the vicious circle of poverty and environmental degradation is "an incomplete characterization" (Lélé, 1991: 613), because the analysis must be revolved on the socioeconomic reasons of poverty and on the issues of social justice and wealth distribution. In this approach the importance of public policies is not denied, but it is linked to social relations: government interventions wouldn't be external perturbations of an optimal equilibrium, but expression of the most powerful classes.
Some researchers (Stonich, 1992; Plumwood et Routley, 1982) have carried out a socioeconomic analysis of this kind in an international context and have examined the effects of the growing integration of tropical areas in market economy. They argue that the international division of work, as it is now, causes changes in the productive structure of underdeveloped countries that determine higher pressure on forests. Their accuse is addressed to a development model based on private capital accumulation and monoculture for export, which enriches a restricted *élite* of big owners.
Of course different theories support different actions to contrast environmental degradation. On one side several authors think that economic growth in a free market economy, together with birth control, can limit the dimension of this phenomenon. The State should intervene to enforce basic laws and to correct market failures, instead of encouraging the destruction of natural resources. On the other side the authors that follow the last approach described above maintain that the protection of the ecosystem is possible only after deep changes in the socioeconomic structure and usually they are much more confident in the action at the grassroots. Therefore, given the incompatibility of the different solutions, a better comprehension of the causes of tropical deforestation is of primary importance to promote appropriate interventions.

Quantitative analyses of tropical deforestation

There are two main approaches to tropical deforestation modelling. The first one consists of elaborating analytical models, which indicate the system of interrelations among selected variables on the basis of given theoretical hypotheses. These models are useful to test the logical rigour of theories and the rationality of their implications. Since they use mathematical equations that don't derive from empirical data, their deductions are precise, but the evaluation of the correspondence between reality and theory is beyond their scope.
Instead, the second approach is directed to this problem, which it intends to face by building empirical models. Statistical methods are employed to estimate, on the basis of available data, the parameters of the equations and to test hypotheses about variables' influences. The present work gets into this direction of research, by regression analyses that try to individuate the importance at a global level of some potential crucial factors in tropical deforestation.

The quantitative works on this subject have already provided some important results, suggesting that deforestation tends to be greater in consequence of more accessible forests, higher agricultural prices, lower national wages and better opportunities for trade (Kaimowitz et Angelsen, 1998). However these results are based more on analytical models than on empirical ones, which often refer to particular territorial ambits. On the contrary macro-level models don't generally lead to univocal results, mainly because of the poor reliability of data. Though it is undeniable that there are regional variations in deforestation process, pan-tropical models are essential to examine the factors that operate on a world scale. I'll try to throw light on the role played by several variables, by using a restricted, but more reliable, database.

Methodology

The models presented below are estimated using weighted least squared regressions on national data, and analysing the indicators of how well the equation fits (t-test, F-test and adjusted R^2) and the χ^2-test for heteroskedasticity[3] (White, 1980). Data used to calculate the dependent variable (forest cover and total geographical area) are from national inventories gathered by the Food and Agriculture Organization, mainly for the FRA90 project. They refer to 28 tropical countries and 46 observations, which span from 1950 to 1994. I did not consider data originating from mathematical models like those formulated by FAO (1993), since those ones interfere with the cause-effect relations under exam. Data concerning the independent variables, except for those about the population before 1960 (United Nations, 1966), are from the World Bank (1995) and span from 1960 to 1993, including estimates for year 1994.
When only partial data were available, I normally approximated, provided that no more than half of the data were missing. Since this procedure makes the observation less reliable, I analysed the influence of each approximated observation on the results of the regression, and I excluded it when the possibility to alter them was too high[4].

Dependent variable

To avoid the problem of the lack of data accuracy, several authors carried out the regression analysis using as dependent variable the percentage of forest cover on the total surface (Palo et al., 1987; Palo et Lehto, 1996a; Palo et Lehto 1996b; Palo et al., 1996) or on the sum of forest, cropland and pasture (Rock, 1996), instead of the deforestation rate. However, in my opinion, models using a *proxy* for deforestation may lead to wrong conclusions. For instance,

[3] The problem of multicollinearity was analysed too, but, not to make heavy the presentation of results, the indexes calculated for that are not exposed here.
[4] Units were excluded when their influence is above prefixed limits for two indicators: a) scaled measure of the change in the predicted value when an observation is eliminated; b) scaled measures of the change in each parameter estimate deriving from excluding a certain observation. These indicators are described in Belsey et al. (1980).

the use of forest cover as dependent variable does not represent the deforestation occurred in recent years. In fact, it derives from the original extension of the forest and from the changes cumulated during the centuries, elements depending on different natural and social factors, normally excluded from the analysis.
For this reason, the present work is carried out using the average rate of deforestation as the dependent variable:

$$DEF = -\left[\sqrt[n]{\frac{F_n/G_n}{F_0/G_0}} - 1\right] \times 100 \quad (1)$$

where the average rate of deforestation (*DEF*) represents the average decrease rate of the ratio between the total forest cover (*F*) and the total surface (*G*). The subscripts *n* and *0* indicate, respectively, the values of the variable at the end and the beginning of the period considered[5].
However, the dependent variable described above does not consider the relative magnitude of the units analysed, which are representative of countries whose forest extensions differ considerably one another (from Brazil, which includes almost a third of world tropical forests, to small countries such as Bermuda and Cayman Islands). To avoid this problem it was necessary to weight each single observation so that its contribution to the results was proportional to its importance in the global extension of tropical forests. The weighting was performed using the variable W1, which represents forest cover at time 0, and W2, which relates W1 with the number of years of available data[6].

Independent variables

Demography

Demographic pressure is frequently cited in the explanation of deforestation and a lot of models emphasize it. The prevailing idea is that the environment is able to sustain only a limited amount of population, beyond which resource conservation becomes impossible. A deviation respect to a population level, fixed for each country on the basis of ecological elements, should be analysed, but the difficulty of calculating it compels to examine other indicators, in particular the ratio inhabitants/surface and its variation.

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[5] The total surface is introduced in the formula to reduce the inexactness in the measurement of forest cover. A direct relation between the mistakes made for the two variables is supposed.

[6] The formula used in the calculation of W2 to transform the number of years included in the period of reference is:

$$f(x) = e^{-4/x} \quad (2)$$

where x is the number of years and e is equal to 2.718282. It's a function that, for $x>0$, varies between 0 and 1, in correspondence respectively of $x=0$ and $x=\infty$. Its elasticity is decreasing and reaches a value of 1 for $x=4$; beyond that limit the resulting W2 ($= W1 \times f(x)$) increases less than proportionally respect to the years. Therefore I supposed that: a) the longer a period is, the more reliable a relation; b) 4 years is an optimal period for the evaluation of the relations examined.

For instance, Cropper et Griffiths (1994) find a positive relation between rural population density and deforestation rate, which indicates the importance of demographic factors. However their results are significant only for Africa, but not for Latin America and especially for Asia, where the coefficient is negative. Studies carried out by Palo et al. (1996) and Palo et Lehto (1996b) on these last two continents lead to different results. They use subnational data too, but in their models population density both at local and at national level is often significant. On the contrary, in conformity with models by Cropper et Griffiths, population growth rate is not negatively related to forest cover[7]. It has been observed (Kummer et Sham, 1994), however, that, if forest cover is used as dependent variable, it's probable to find a negative relation between it and population density. This may happen just because human settlements in forests are not many and vice versa, but it doesn't mean that demographic factors cause deforestation.

In any case it can be argued that the population density variable doesn't consider the possibility that the carrying capacity varies according to the territorial characteristics of each unit and so it doesn't precisely indicate the deviation from that limit. Besides, in works based on subnational areas, the local demographic density depends not only on birth-rate and mortality, but also on the concentration of people in given zones. Since in these areas there is freedom to move, population density depends on income opportunities and on other external forces that induce a part of the population to migrate[8].

The change respect to a base situation, as expressed by population growth, lets differences of units' starting points be held in due consideration; but these differences are linked to socioeconomic factors, besides ecological elements. For instance, a positive relation between the increase of inhabitants and deforestation doesn't necessarily indicate that population has exceeded sustainability limits. It could mean that demographic pressure becomes relevant, but only in relation to a starting point characterized by a certain structure of property and a certain level of economic development.

A more specific index for the analysis of the consequences of population growth on forests is the ratio between rural population and agricultural area. In fact it's cultivable land scarcity with respect to potential workers that can directly create a pressure on marginal zones, even if urban population contributes to the demand for primary products. However also this variable depends on migrations and, hence, on non-biological factors.

Domestic socioeconomic situation

Besides demography, one of the most frequently used factors in deforestation modelling is income per capita or its change. It's generally thought that deforestation increases during the first stages of economic development and subsequently decreases, following a so-called environmental Kuznets curve (*cfr.* Palo et Lehto, 1996a). At the beginning the rising demand for forest and agricultural products would lead towards a conversion of forests to productive uses. But, when a superior stage of development is reached, the demand for primary goods

[7] It has been noted (Sabatini, 1998: 87) that these studies use data built by FAO through a model that comprises population density as independent variable: so there is a danger of circular explanation.

[8] To consider this possibility Southgate et al. (1991) have built a two-stage model, where the population variable is endogenous in the first equation and exogenous in the second one.

increases more slowly, industrialization creates alternative employment opportunities and modern techniques can make the agriculture more intensive and permit the substitution of other energy sources for charcoal. Besides, environmental goods could become more important in the public opinion and be the object of stronger protection policies.

In the present work the possibility that the effects of this variable depend on the development level is examined through the subdivision of units into two groups of equal size, on the basis of GNP per capita in constant dollars at the beginning of the period: upper income and lower income units. I made separate regressions using as independent variables initial income per capita (average income would be influenced by deforestation itself) and its trend growth. While the latter doesn't give relevant results, initial GNP per capita is positively related to deforestation only for lower income units, while the relation is opposite for upper income ones[9] (tables 1 and 2).

However the use of this result for forecasts and political programs is not straightforward. In fact, international specialization usually involves a relative increase of secondary and tertiary production for developed countries, while underdeveloped ones tend towards primary activity. If the increase of income above a certain level favours a reduction of natural inputs' domestic use, the same factor may transfer the pressure on environment in other countries, through an expanded demand for imports of primary products. Therefore, even if a significant negative relation between income and deforestation is estimated, the increase of income could accelerate forest conversion abroad. So it might be wrong to maintain that economic growth in tropical countries lessens deforestation at a global level.

In general models presented below (table 4) another factor is preferred to express domestic socioeconomic situation: primary value added as percentage of GDP. This variable is referred to the beginning of the period, to avoid that the results reflect causal relations in the opposite direction, given the relevant effects of deforestation on total primary production.

Since economic growth is usually accompanied by a structural change towards industrial and tertiary production, this variable is negatively correlated with income per capita[10]. But, with respect to simple economic growth, the analysis of the consequences of this factor contains some more aspects. For a country whose economy is biased towards agriculture the alternatives to an expansion into the forest are less. In fact industrial development, besides requiring appropriate socioeconomic conditions, involves considerable costs for workers migration from rural areas to urban ones and for building the necessary infrastructure to be competitive. Exploiting natural resources is easier, to satisfy people needs and to put low cost merchandise in the international market. On the contrary industrialized countries have already overcome most problems of transition: they are more able to specialize in non-agricultural productions and to employ excess labour force in the country.

Agricultural technology

The role of agricultural techniques and of technological progress is not univocal: on one side the increase of inputs' productivity permits to use less resources to obtain the same

[9] Other works arrive at an analogue conclusion, by using different methods (*cfr.* Cropper et Griffiths, 1994; Palo et al., 1996).

[10] That is confirmed by a correlation coefficient equal to -0,75 for units under exam.

production; on the other side it can make profitable the cultivation of marginal lands, including those deforested. The final effect on deforestation depends on the geographic extension of change, on the characteristics of the demand for primary goods and on the bias of technological progress. If some countries acquire a technological advantage that makes them increase their share in international markets, it's probable that they specialize in primary production, with more pressure on their forests, while the situation is opposite abroad. If, on the contrary, innovations are diffused at a global level, economic competition and the changes in the international division of labour don't have relevant consequences.

INDEPENDENT VARIABLES	COEFFICIENTS (prob.>|t|)			
	Lower income units	Upper income units	Lower income units	Upper income units
Intercept	-0.391998 (0.4646)	3.247315 (0.0003)	0.765718 (0.2192)	1.141965 (0.0032)
Initial GNP per capita	0.005050 (0.0044)	-0.001524 (0.0010)		
GNP per capita trend growth			0.120909 (0.4816)	0.255534 (0.0625)
Observations	22	21	22	16
Adjusted R^2	0.3066	0.4109	-0.0237	0.1711
Prob.>χ^2	0.7507	0.2449	0.3112	0.6179

Table 1: Deforestation and GNP per capita; models with W1 weights

INDEPENDENT VARIABLES	COEFFICIENTS (prob.>|t|)			
	Lower income units	Upper income units	Lower income units	Upper income units
Intercept	-0.267736 (0.5829)	4.536039 (0.0001)	0.491314 (0.3006)	0.338016 (0.1529)
Initial GNP per capita	0.004972 (0.0083)	-0.002233 (0.0001)		
GNP per capita trend growth			0.185143 (0.1884)	0.339952 (0.0549)
Observations	19	19	20	19
Adjusted R^2	0.3057	0.6162	0.0437	0.1530
Prob.>χ^2	0.3760	0.4977	0.3857	0.3676

Table 2: Deforestation and GNP per capita; models with W2 weights

In any case, thanks to the world levelling of profit rate, technological progress makes products' prices fall, which normally implies an increase of their demand. If the price elasticity of demand is high, the use of inputs is intensified by the change, notwithstanding the increase in their productivity. Besides, the consequences on deforestation are linked to how demand is distributed among the various merchandises, whose supply may involve different levels of pressure on natural resources.

For a fixed quantity and quality of goods demanded, the kind of production techniques and their variation are essential to determine the final effects on forests. In particular land-saving innovations make production intensification more profitable than the extension of cultivated area. On the contrary labour-saving technical progress, in addition to induce a more extensive production, expels workers, who may colonize the forest, especially if income opportunities in other sectors are scarce.

With reference to technology, I analysed three variables, expressed as mean values and trend change rates: 1) primary value added / agricultural area (1987 US dollars / km^2); 2) irrigated land, as percentage of agricultural area; 3) fertiliser use per hectare (kg/ha). The first one is a general index of productivity, which depends also on products' prices. The other ones express techniques usually associated to an intensive cultivation, even if their use is often connected to the diffusion of high yielding varieties, which may favour (Griffin, 1989) big farms, whose production per hectare is lower.

Ecological conditions

Ecological characteristics intervene in the process of deforestation in two ways: 1) they are indicators of forest resistance against alterations of the natural equilibrium; 2) they express the accessibility of the forest to human exploitation and settlements. The first element is evident in the long period, where the peculiar fragility of tropical moist forests' ecosystem can make human intervention more traumatic. In an analysis that uses recent available data on deforestation the second factor is probably more relevant. It represents the problem of accessibility under the point of view of natural conditions, while other studies have linked it to road construction.

The subdivision into ecological zones has been effectuated on the basis of annual precipitation and altitude. The variable that results more relevant is the share of total surface with more than 2,000 mm of annual precipitation and below 1,000 m of altitude[11].

International economic relations

A common shortcoming of models that focus on variables like population or GNP is to disregard the international dimension of the problem, in particular the economic relations of tropical countries with the rest of the world. Kahn et McDonald (1994), who put the external debt at the centre of their analysis, carry out an attempt in this direction. They suppose that decision makers try to maximize the present value of the future stream of consumption of the

[11] National data are obtained by calculating averages of local data, weighted by the extension of forests (initial+final) in each unit.

country, subject to the constraint of a minimum acceptable level of current consumption. A high external debt would lead to a myopic behaviour, since it makes it more difficult to satisfy basic needs in the short period. So, deforestation may be used to reach the minimum limit, to the detriment of future consumption[12].

In the present analysis external debt doesn't result statistically significant, while the main factor that has an impact on deforestation is trade openness. Since the usual measure of this variable (external exchanges / GDP) is too much linked to the economic and spatial dimension of the unit[13], an index of the specific bias to trade openness is built. I tried to exclude the effect on this variable of three factors, which constitute a multiplicative decomposition of GDP[14]:

1) surface: the bigger a country is, the farther foreign markets;
2) population density: the higher the number of inhabitants per km^2 is, the stronger internal market's attraction;
3) GDP per capita in constant dollars: wealth reduces the distance among markets, but the level of domestic prices can cause less foreseeable effects.

By using averages for the period examined, after operating a logarithmic transformation of annual data, the sum of exports and imports of goods and non-factorial services was regressed on the three variables described above. The parameters of the estimated equation define a growth path of external exchanges in relation to surface, population density and GDP per capita. For each country, trade openness is given by its standardized residual, i.e. by how much its situation differs from the estimated path.

The change of the terms of trade is another element that can influence the dynamic of deforestation. The relative variable was obtained by calculating the trend average change rate, expressed by the estimate of parameter m in the following equation:

$$\ln X = a + mt \quad (3)$$

where X is the level of the terms of trade and t the year[15]. So the level of each year contributes to the trend, which reflects not only the values at the extremes, but the total situation of the period.

Results

A number of models were confronted on the basis of adjusted R^2, F-test and t-tests: models presented here are the best ones according to these statistical indicators. The results of the

[12] Models by Kahn et McDonald include the ratio between total debt and export value, as independent variable. Its relation with deforestation is, as expected, positive and significant according to the t-test. However in these regressions, such as in many other ones elaborated by authors studying global tropical deforestation, the R^2 value is rather low, around 0.3.

[13] Supposing, for instance, that some countries unite to create a new entity, the trade openness index built in this way would result lower than the same index calculated for separate countries. In fact, though their economic structure isn't altered, the exchanges among them would no longer be registered as exports and imports, but as internal flows.

[14] I used the method described by Naudet (1994), with some differences in the procedure.

[15] For one-year periods the growth rate in the continuum was used: it is equal to the difference between the natural logarithms of final and initial levels.

present analysis suggest a relevant role in the deforestation process only for three variables: trade openness, fertiliser use per hectare and rural population density[16]. The first two ones are included in all presented models and are significant at 0.001 level; the third one usually shows the same statistical relevance, except in model IV (however significant at 5%) and in model V (table 4).

These results put trade openness as one of the main causes of deforestation. It's likely that an intensification of international exchanges makes most tropical countries increase primary goods production, which is often in competition with the conservation of forests, while an expansion in other sectors is more difficult because of a competition that can be hardly overcome. Besides, economic integration may favour a productive structure biased towards the concentration of property and large-scale production with labour-saving techniques.

GROUPS OF FACTORS	SINGLE VARIABLES
Demography	Population density
	Population growth rate
	Rural population density
	Rural population growth rate
Domestic socioeconomic situation	Initial GNP per capita
	GNP per capita growth rate
	Primary value added (% of GDP)
	Road construction / total surface
Agricultural technology	Primary value added / agricultural area
	Growth rate of primary value added / agricultural area
	Percentage of irrigated agricultural area
	Growth rate of the percentage of irrigated agricultural area
	Fertiliser use per hectare
	Growth rate of fertiliser use per hectare
Ecological conditions	Lowland very moist and wet zone
	Wet, very moist and moist zone, except alpine one
	Wet, very moist and moist zone, with alpine one
	Lowland zone
International economic relations	Trade openness
	Growth rate of the terms of trade
	Openness to international market of factors
	External debt / GNP

Table 3: Factors examined in the regression analysis

On the contrary the relation between fertiliser use and deforestation rate is negative. This result indicates the potentiality to obtain the amount of goods demanded on markets by using less land, but without saving labour. While this input assumes relevance, the other technological

[16] Estimated models are linear, except some logarithmic transformations; in fact, some attempts to perform non-linear regressions, particularly in exponential form, didn't give better results.

indicators are generally insignificant, except, in model V, the increase in the percentage of irrigated land, which seems to foster deforestation[17]. So, in the present analysis, technical progress seems to be able to restrain the destruction of forests, provided it's biased to land-saving innovations. Unfortunately more specific indexes of inputs relative use, such as the ratio agricultural workers / cultivated land, were not available.

INDEPENDENT VARIABLES	COEFFICIENTS (prob.>|t|)					
	W1 weighting			W2 weighting		
	Model I	Model II	Model III	Model IV	Model V	Model VI
Intercept	-2.08147 (0.0315)	-0.46423 (0.2707)	-0.67462 (0.0264)	-1.10610 (0.5159)	0.892335 (0.5777)	-0.80923 (0.2249)
Trade openness	0.856766 (0.0001)	0.882482 (0.0003)	1.002844 (0.0001)	0.914730 (0.0002)	0.969466 (0.0007)	1.001371 (0.0001)
Growth rate of the terms of trade		-0.05437 (0.1509)				
Primary value added (% of GDP) [a]	0.070878 (0.8699)					
Primary value added / agricultural area				0.000019 (0.4781)		
Growth rate of the percentage of irrigated agricultural area					0.236205 (0.0561)	
Fertiliser use per hectare	-0.08953 (0.0001)	-0.07712 (0.0001)	-0.06893 (0.0001)	-0.09054 (0.0003)	-0.07819 (0.0007)	-0.07025 (0.0004)
Population growth rate				-0.07658 (0.8804)		
Rural population density [a]	1.085933 (0.0002)	0.781819 (0.0001)	0.784691 (0.0001)	0.822715 (0.0321)	0.450264 (0.2018)	0.743413 (0.0002)
Lowland very moist and wet zone	0.791979 (0.1778)			0.817352 (0.3131)		0.829099 (0.2442)
Observations	29	32	34	28	25	31
Adjusted R^2	0.6398	0.6546	0.6166	0.5562	0.5533	0.5315
Prob.>F	0.0001	0.0001	0.0001	0.0005	0.0004	0.0001
Prob.>χ^2	0.8415	0.7826	0.6547	0.4209	0.5009	0.7299

[a] Natural logarithm.

[17] However, in this case many observations were excluded.

Table 4: Some global causes of tropical deforestation

The importance of the role of rural population density is confirmed by regressions' results. Probably this variable also reflects the action of factors included in the domestic socioeconomic situation, such as income per capita and the agricultural share of GDP; in fact, it's in a strict relation with them, which causes collinearity problems in model I. But the introduction of rural density in general equations implies a stronger role than other correlated variables: so demographic pressure has a non negligible importance in this ambit.

While the effects of these three variables is clear, in relation to available data, the other elements have not a decisive influence on the statistical explanation of deforestation, though they sometimes contribute to models with higher adjusted R^2. This doesn't mean that other variables, like income or road construction, can't be relevant in different models and that their alterations have no consequences on forests. In fact, besides the problem of data scarcity, it must be considered that they can act indirectly, i.e. by provoking changes in other factors, which appear more strictly linked to the dependent variable. For instance, economic growth can determine a reduction of rural density and an acceleration of technical progress, with considerable effects on tropical deforestation, even if other changes associated to it are insignificant.

A last consideration concerns the judgement on the quality of the estimate as a whole. Adjusted R^2 values go from 0.53 to 0.65 and F-test is always significant at 0.001 level. These indicators are good with respect to most models presented in literature that use a measure of deforestation as dependent variable. However it's not possible to say in general terms whether these values are high or low, unless they are confronted with regression analyses that use a procedure and a database similar to the present one. So, while the role of some variables appears well defined, the completeness of the individuation of deforestation causes is not valuable in absolute terms.

Conclusions

The statistical analysis presented here points out the socioeconomic character of the causes of tropical deforestation. The determinant factors must be searched for not in natural laws, or anyhow in forces beyond human control, but in social processes, which, as such, are not inevitable, since they depend on particular forms of socioeconomic organization and on the development of productive forces. Also demographic growth, considered by many authors the engine of forest destruction, assumes relevance only as rural density, which is linked, besides procreation and available means to reduce mortality, to the characteristics of the productive structure. The main weak point of the neo-Malthusian explanation seems to be a deterministic view of social process, as if the responsibility of deforestation resided in a biological law, which it's difficult to get out of. On the contrary the main obstacles to interventions in this field are not constituted by external mechanisms, but by powerful interests in environmental degradation.

The importance present models attribute to trade openness calls for an examination of the

issue of tropical deforestation at international level. Not only the effects of forest destruction in the tropics influence the ecological conditions of the whole Earth, but also the processes that cause it depend on transformations that involve, or have their origins in, other parts of the world. The positive and highly significant coefficient of the trade openness index seems to confirm the studies that relate deforestation to the integration of tropical areas in market economy. If we consider this result, the trend towards a reduction of legal and technological barriers to the free movement of merchandises and capitals brings about some worries. It's a trend that accelerated during last years, especially after the economic crisis of the 70s and 80s and the aggravation of the problem of external debt. In consequence of that, almost all developing countries have signed free trade agreements and have adopted policies of economic liberalization, supported by World Bank structural adjustment programs and by International Monetary Fund credits. But the attempt to encourage export sectors and the inflows of capitals involves the risk to put more pressure on natural resources, particularly by expanding the monoculture to supply goods for the world market.

However, mathematical macroeconomic models cannot exhaustively analyse the transformations deriving from the integration in the world economic system, such as other relevant factors. First, some variables, like bribing or power relations in the society, can be hardly quantified; second, only a more specific research is able to individuate the direct agents of deforestation. For other possible determinants, quantitative analysis could give important elements if data were available; for instance as regards land use rights or property distribution, which, among other things, could be influenced by economic openness.

The last variable that emerges, together with rural population density and trade openness, from the regression analysis, is the average fertiliser use. It may be affected by recent liberalization policies, too, but not in a univocal manner. On one hand, the reduction of subsidies to agricultural inputs should reduce their use. On the other, an increase of chemical inputs can be anticipated if the traditional agriculture for local consumption is replaced by the modern production for wide markets. But, in the latter case, fertiliser use is a part of a bigger transformation, whose effects may be opposite to what described in models; this may happen, for example, if it determines a marginalization of a part of rural population. Another element can influence the relation between fertiliser use and deforestation: the degradation of natural resources, particularly soil and water, that derives from chemical inputs. If this happens in the long run, the apparent intensification of production systems hides the perspective of a reduction in cultivable land, with negative consequences on forests that are hardly reflected in the results of quantitative models.

These last questions warn against a mechanical interpretation of the role of factors examined. In fact, it's necessary to keep in mind both the interrelations among variables and the processes in which they explicate their action. Among other things, the present analysis is essentially static, though it often refers to long periods; so, some effects that are a part of long-term dynamics can't be completely considered. These limits show the necessity to deepen the research towards a specification of socioeconomic dynamics and a better comprehension of the mechanisms that operate at a micro level. However, models here elaborated can give some indications on the way to face tropical deforestation. In particular, the results suggest the opportunity to reconsider the growing trade liberalization of tropical countries, which has represented, during the last two decades, a largely dominant paradigm in international

organizations and in most Third World governors' programmes. Finally, a restructuring of production systems on the basis of local needs should be promoted, together with the conditions for a transfer of workers to secondary and tertiary sectors and for a technological progress in agriculture that permits to save land in the present and in the future.

References

Annis S. [Ed.] (1992). Poverty, Natural Resources, and Public Policies in Central America. Transaction Publishers for the Overseas Development Council, New Brunswick.

Barney G.O. [Study director] (1980). The global 2000 report to the president of the U.S.. Pergamon Press, New York, Vol. I.

Belsley D.A., Kuh E., Welsch R.E. (1980). Regression Diagnostics. John Wiley & Sons, Inc., New York.

Binswanger H.P. (1991). Brazilian Policies that Encourage Deforestation in the Amazon. *World Development*, **19** (7): 821-829.

Boado E.L. (1988). Incentive policies and forest use in the Philippines. In R. Repetto and M. Gillis [Eds.]. Public policies and the misuse of forest resources. Cambridge University Press, Cambridge.

Bunyard P. (1999). Eradicating the Amazon Rainforests will Wreak Havoc on Climate. *The Ecologist*, **29** (2): 81-84.

Cropper M., Griffiths C. (1994). The Interaction of Population Growth and Environmental Quality. *The American Economic Review*, **84** (2): 250-254.

Food and Agriculture Organization (FAO) (1993). Forest resources assessment 1990: tropical countries. FAO Forestry Paper 112, Roma.

Gillis M. (1988a). Indonesia: public policies, resource management, and the tropical forest. In Repetto and Gillis. Public policies and the misuse of forest resources. Cit.

Gillis M. (1988b). Malaysia: public policies and the tropical forest. In Repetto and Gillis. Public policies and the misuse of forest resources. Cit.

Griffin K. (1989). Alternative strategies for economic development. OECD Development Center, Basingstoke, London, Mac Millan, Paris.

Hardin G. (1968). The tragedy of the commons. *Science*, **162** (3859): 1243-1248.

Hildyard N. (1987). Tropical Forests: A Plan for Action. *The Ecologist*, **17** (4/5): 129-133.

Kahn J., McDonald J. (1994). International debt and deforestation. In K. Brown and D.W. Pearce [Eds.]. The Causes of Tropical Deforestation. UCL Press, London.

Kaimowitz D., Angelsen A. (1998). Economic Models of Tropical Deforestation: A Review. CIFOR, Bogor.

Kummer D., Sham C.H. (1994). The causes of tropical deforestation: a quantitative analysis and case study from the Philippines. In Brown and Pearce. The Causes of Tropical Deforestation. Cit.

Lélé S.M. (1991). Sustainable Development: A Critical Review. *World Development*, **19** (6): 607-621.

Lutzenberger J.A. (1982). The Systematic Demolition of the Tropical Rain Forest in the Amazon. *The Ecologist*, **12** (6): 248-252.

Myers N. (1980). Conversion of tropical moist forests. National Academy of Sciences, Washington, D.C..

Naudet D. (1994). Une analyse du degré d'ouverture internationale. *Économie Internationale*, **58** (2): 53-81.

Palo M., Lehto E. (1996a). Modeling underlying causes of pantropical deforestation. In M. Palo and G. Mery [Eds.]. Sustainable forestry challenges for developing countries. Kluwer Academic Publisher, Dordrecht, Boston and London.

Palo M., Lehto E. (1996b). Tropical Asian deforestation and sustainability prospects. In Palo and Mery. Sustainable forestry challenges for developing countries. Cit.

Palo M., Mery G., Lehto E. (1996). Latin American deforestation and sustainability prospects. In Palo and Mery. Sustainable forestry challenges for developing countries. Cit.

Palo M., Mery G., Salmi J. (1987). Deforestation in the tropics: pilot scenarios based on quantitative analyses". In M. Palo and J. Salmi [Eds.]. Deforestation or development in the Third World? Volume I. Metsantutkimuslaitoksen Tiedonantoja 272, Helsinki.

Plumwood V., Routley R. (1982). World Rainforest Destruction - The Social Factors. *The Ecologist*, **12** (1):

4-22.
Repetto R. (1988). Overview. In Repetto and Gillis. Public policies and the misuse of forest resources. Cit.
Rock M.T. (1996). The stork, the plow, rural social structure and tropical deforestation in poor countries?. *Ecological Economics*, **18** (2): 113-131.
Sabatini R. (1998). La deforestazione tropicale: una rassegna critica dei problemi e della modellistica. *L'Italia Forestale e Montana*, **LIII** (2): 68-108.
Southgate D., Sierra R., Brown L. (1991). The Causes of Tropical Deforestation in Ecuador: a Statistical Analysis. *World Development*, **19** (9): 1145-1151.
Stonich S.C. (1992). Struggling with Honduran Poverty: The Environmental Consequences of Natural Resource-Based Development and Rural Transformations. *World Development*, **20** (3): 385-399.
United Nations (UN) (1966). Demographic Yearbook 1965. United Nations, New York.
White H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica*, **48** (4): 817-838.
World Bank (WB) (1992). World Development Report 1992. Oxford University Press, New York.
World Bank (WB) (1995). World data 1995: World Bank indicators on CD-ROM. The International Bank for Reconstruction and Development/The World Bank.

LAND DEGRADATION AND COMMUNITY AGRICULTURAL POLICY: EFFECTS OF ALTERNATIVE SCENARIOS IN AN HYDROGRAPHIC BASIN OF BASILICATA REGION (ITALY)

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Summary

Since the middle '80's the role of agriculture of developed countries is changing. It is clear that the agricultural activities are strongly involved in the management of territory as well as in food production. The Common Agricultural Policy (CAP) has registered a parallel evolution, culminated in the last big reform (1992). This reform has generated many expectations from the environmental point of view, particularly in the environmental fragile areas. The study attempts to evaluate the effects of the CAP reform in one of this area, simulating the effects of different scenarios. The methodology used came from the Agricultural Household Theory, with a mathematical programming empirical model. The results show an interesting possibility to obtain environmental benefits without budget increase, utilising specific and local policy instruments instead of the present one.

Introduction

Since many years is in action a depth afterthought of the role of the agriculture in the economic systems. The conception of a sector exclusively devoted to the traditional production functions has been replaced by the idea of agriculture directly and intensely involved in the management of the territory. So the agriculture is seen as able to develop a decisive role in the maintenance of the soil fertility, essential for the safeguard of the rural world and for the maintenance of a historical-cultural patrimony in which sink the roots the whole society.
The problem of promoting a development at the meantime economically and ecologically sustainable has been taking body in all the recent EU Documents and Agricultural policy instruments.
This study starts analyzing the results of the Agricultural Policy born after the '92 Reform which tries to take in account the previously consideration.
After few years of application it has been recorded a substantial failure of these policies, in many areas of the Italian Mezzogiorno, where more conspicuous should have been the deterioration and the impact of the new European measures.
In order to understand the reasons that have determined that failure of the last big CAP Reform, it is necessary to individualize the economic subjects that apply the tools of Agricultural Policy and translate them in operational choices. As it is known, in Europe the decisional consolidated and prevailing unity is the family-farm.
The agricultural family nucleus has the triplex role of family, that is responsible of the consumption, tries to optimize the expenses, as responsible unity of the labor available

by the own components and of responsible unity of the enterprise, that look for to optimize the production. Therefore, any variation in the economic coordinates of reference is reflected on the decisions of production.





At same time it influences the decision of consumption and the allocation of the family labor. In doing so it causes effects that depends on the interaction of all three main decisional variables which are conditioned by the characteristics of the family, by the farm typology and by the territorial context within which the farm is integrated.
A specific model derived by the *Agricultural Household Theory* (Quaranta, 1992) has been utilized to simulate different scenario on the family-farm decision about the land use.

Study area and Methodology

The study area coincides with the hydrographic basin of the Agri River, in Basilicata Region. The area extends on a surface of about 1,700 sq. Km's, representing about the 20% of the regional one. The resident population in the whole area is of around 100,000 unity (1/ 6 of the regional population) with a density of 48 inhabitants/ sq. Km's.
Within this area a random sample of family-farms has been set up and interviewed.
Analyzing the results of the gathered information, four representative family-farms have been selected in order to perform the simulation. They are representative of four different groups fitting the sample. So we obtained the following family-farms:
Representative Farm1
The farms which represents the first group is located in the Lower part of the basin, it is managed by young and male farmer, with an high degree of education. It is irrigated and produces horticultural and permanent crops.
Representative Farm 2
The farm which represents the second group is prevalently located in the middle part of the Basin. The conductor is male, with a low degree of education having a family in the middle age and a cropping system based on sown land (particularly wheat).



Representative Farm 3
An elderly family manages this farm and it is located in areas interested by serious soil degradation phenomenon (calanchi).
Representative Farm 4
Males, with a middle age of 42 years, with low degree of schooling manage this representative unit. It is irrigated land performing livestock production.
The empirical model used is formulated in terms of mathematical programming and recalls the leading philosophy of the AH models.

Hypothesis adopts for the simulations

Staying unchanged the general scheme of each model, three alternative scenarios have been hypothesized. The assumptions adopted can be schematically reassumed:
Scenario 1 (s1): leaving unchanged the gross income of all the other crops, the EU additional integration given to the durum wheat has been transferred to the pasture land adding to the gross income of that crop.
Scenario 2 (s2): with this simulation has been delineated the elimination of the EU integration to the arable land and, to the meantime, the transfer of the durum wheat integration remain to the pasture.
Scenario 3 (s3): in this scenery the total absence of the EU intervention is hypothesized, forcing, the model to select the farm activities in reason of their profitability coming from the market conditions. It has been, in substance, prefigured an extreme possibility but, however, not total impossible and distant to the imminent reality.

Results

In the underlining the cropping system adopted by the farmers, reference to the classification of the Environmentally Sensitive Areas (ESA's), have been explicitly done. That is to a distinction of the crops in four classes depending on their impact on the soil (starting from 1 -no problem- up to 4 -worst situation- (Kosmas C., et al, 1999).
Performing the model for each farm typology and comparing them to the present situation by indexes of variation we can observe the following results.

- The scarce, if not straight nothing, reactivity of the farm cultivating horticultural crop.
- Large impact it is determined on farm typology more sensitive to the policies investigates, in which a radical transformation of the use of the resources is recorded.

In a more general sense we can conclude as follows:
1) To maintain a diffused network of family-farms in areas strongly degraded under the demographic and environmental profile, it is necessary the promotion of sustainable use of the land that would mean to assure a vital and functional life of the whole territory.
2) The development of the livestock activities induced by the new cropping systems could originate a considerable demand of additional jobs.
3) In parallel to the development of the livestock sector (goats and sheep) would resolve the growth of a sector that is not subject to strong limitations to EU level. The conditions, in fact, could be created for the exploitation of the peculiarities of these

typical productions and that could represents an important factor for the local development, transforming resources degradation into opportunities of development.

References

BOVE, E., QUARANTA, G., (1995) Desertification in southern Italy – the case of Clay- hill areas in Basilicata Region, ICALPE, Corte.

BOVE, E., QUARANTA, G., (1996) EC Agricoltural Policy Impact on Land Use in Southern Italy: The Case of Clay Hill Areas in Basilicata Region, Paper presented at the Internetional Conference on Land Degradetion, Adana, Turkey, 10-14 June.

BOVE, E., QUARANTA, G., (1996) Socio- Economic and political aspects of Agri Basin desertification, Poster presented at the International Conference on Mediterranean Desertification, Research Results and Policy Implication, 29 October – 1 November 1996, Crete – Hellas

QUARANTA, G. (1994) Sistemazione critica dei modelli Agricoltural Household, rivista di Economia Agraria, n. 2.

QUARANTA, G. (1997) Rural development and local labour market: An agricoltura Household derived model for allocation of family farm labour in southern Italy, paper presented at Congress of the ESRS, Chania, August, Crete.

CHARACTERIZATION OF SOIL-VEGETATION SYSTEMS AT LANDSCAPE LEVEL IN THE CAMPANIA REGION (SOUTHERN ITALY)

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Abstarct. The soil-vegetation systems of three sites in the Campania region (southern Italy) have been studied. In terms of pedo-geographical characterization a detailed map of soil units was produced for each area. Moreover, at the landscape level a schematic transects, representative of the distribution models of the main soil-vegetation units, was reported for each site.

Key words: soil unit, soil profile, mediterranean area.

Introduction.

These studies provided detailed descriptions of the areas which were useful to understood the ongoing vegetation dynamics. In fact, given the recent changes of land use, the natural vegetation is showing great recovery by colonizing abandoned agricultural fields and pastures. The speed and spatial patterns of these processes is strongly influenced by the soil conditions.

Study sites and Methods.

Soil studies at landscape and community levels were carried out in three areas of the Campania region: Ferriere Nature Reserve (Amalfi Cost), Tresino promontory (Cilento), Vesole, mountain (Cilento) (Figure 1).
The Ferriere Reserve is a coastal area ranging from 300 to 1200 m a. s. l. and characterized by limestone mountain with pyroclastic depositions from Vesuvious eruptions. This created a complex mosaic of very deep and fertile soils with deciduous broadleaved woods and shallow eroded soils with outropping limestones covered by low maquis and steppe.
The Tresino promontory presents low coastal hills of flysh-marls sandstone ranging from 0 to 200 m a. s. l.. Ancient terracing maintened locally by very developed soils which were cultivated in the past and are now abandoned in most cases. Natural vegetation ranges from steppe to mesophilous wood and is heavely disturbed by grazing and fire.
The Vesole limestone hill complex is characterized by developed volcanic soils covering calcareous rocks. The elevation ranges from 50 to 800 m a. s. l.

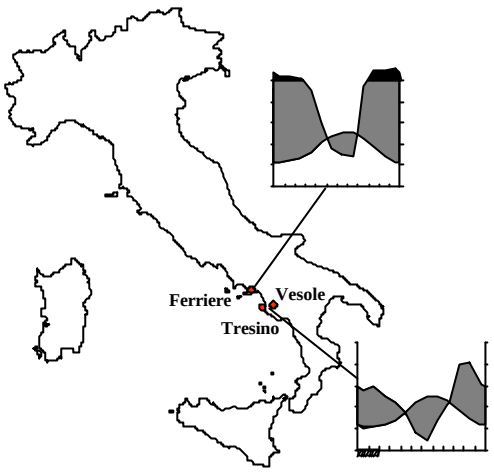


Figure 1: ModMED soil study sites.

The vegetation is mostly influenced by exposure and the woods have been traditionally coppiced. The main vegetation types found are mesophilous woods with *Fagus silvatica*, chestnut woods, *Quercus ilex* coppices, macchia in various stages of degradation and xerophilous grassland.

Soil profiles description were conducted according to the Soil Survey Manual (Soil Survey Division Staff, 1993). Representative soil of each map unit have been classified according to Soil Taxonomy (Soil Survey Division Staff,1994 and FAO Legend, 1990.

The identification of landscape units and the consequently sampling selection were carried out by means of panchromatic aerial photographs at 1:28.000 scale.

The representative soil for each map units were described according to physical and chemical characteristics. Soil analysis were done according to the official methods recommended by italian Soil Science Society (SISS 1994).

The soil maps of the study areas have been digitalized using the software Arc/Info.

Results.

In terms of pedo-geographical characterization a detailed map of soil units was produced for each area.
The environmenatl condictions and soil classification of the main soil-vegetation units mapped for Ferriere Nature Reserve are reported in Table 1. A schematic transect representative of the distribution model of the main soil-vegetation units recorded in this area was shown in Figure 2
The environmental condictions and soil classification of the main soil-vegetation units mapped for Vesole mountain complex are reported in Table 2. A schematic transect representative of the distribution model of the main soil-vegetation units recorded in this area was shown in Figure 3
The environmental condictions and soil classification of the main soil-vegetation units mapped for Tresino promontory are reported in Table 3. A schematic transect representative of the distribution model of the main soil-vegetation units recorded in this
area was shown in Figure. 4.

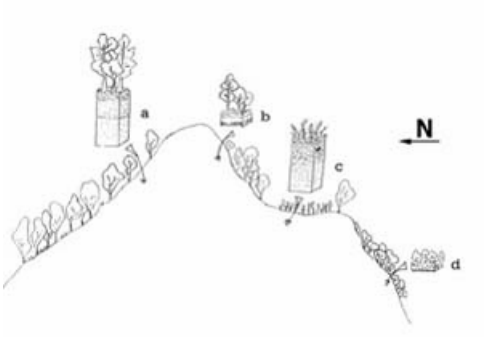


Figure 2: Geographical distribution of the main soil-vegetation units at Ferriere Nature Reserve. a) Map unit 3.Deep soil on pumices; b) Map unit 5. Moderately deep soil on hard limestone; c) Map unit 1. Very deep soil with thik surface layer on volcanic ashes; d) Map unit 7. Shallow soil on hard limestone.

Map unit	Geomorfology, Substrate	Vegetation Land use	Soil type Classification (Soil Taxonomy 1994)
1	Karst plain filled	Pteridium aquilinum grassland	Vitric Hapludands sandy loam
2	Upper, moderately steep slopes	Chestnut coppice	Eutric Hapludands with tick topsoil
3	Regular, moderately to very steep slopes on limestone	Chestnut coppice	Vitric Hapludands sandy loam, deep
4	Regular, very steep slopes with common rock outcrops	Chestnut coppice, Mixed mesophilous woods	Vitric Hapludands, moderately deep
5	Crest and upper slopes,	Steppe, gariga, macchia,	Lithic Hapludands

	very steep with common rock outcrops	woodland	loamy with rock outcrops
6	Very steep, rocky and irregular slopes	Mixed mesophilous woods with Quercus ilex	Vitrandic Haplustands sandy loam, moderately deep on hard limestone
7	Very steep, rocky and irregular slopes	Steppe, gariga, macchia, mesophilous woods of interfluves	Lithic Hapludands, Loamy and Lithic Xerochrepts loamy skeletal with rock outcrops
8	Precipitous, irregular rocky slopes	Xerophilous grassland	Rock outcrops

Table 1: Soil-vegetation units mapped at Ferriere Nature Reserve.

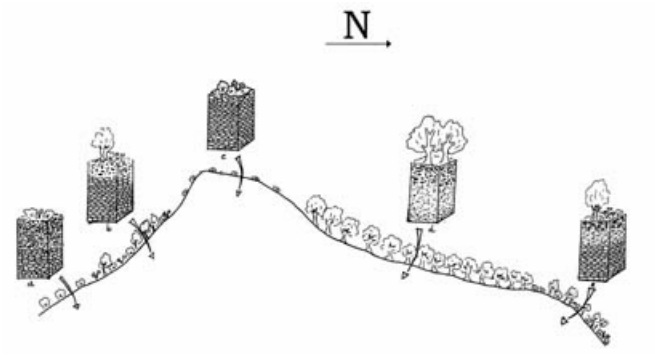


Figure 3: Geographical distribution of the main soil-vegetation units at Vesole mountain. a) Map unit 1. Lower slopes on colluvial deposits. Moderately deep soils with thik surface horizon; b) Map unit 1. Shallow to moderately dep soils on pyroclastic materials covering limestone on upper and mid-slopes; c) Map unit 6. Shallow soils on pyroclastic materials covering the limesone under open beech woods; d) Map unit 9. Very deep soils on pyroclastic materials under chestnut woods; e) Map unit 8. Moderately deep soils on pyroclastic-colluvial materials under degraded woodland.

Map unit	Geomorfology Substrate	Vegetation type	Soil type Classification (Soil Taxonomy 1994)
1	Regular, very steep slopes on limestone	Quercus ilex coppice with deciduous trees (lower slopes); Q. ilex coppice (upper slopes)	Vitrandic Haploxerolls – loamy skeletal Lithic Hapludands
2	Very steep slopes on limestone,eroded	Xerophilous grassland, macchia	Lithic Xerochrepts - loamy skeletal
3	Precipitous, rocky slopes on limestone	Xerophilous grassland, macchia	Rock outcrops - Lithic Xerochrepts - loamy skeletal
4	Very steep slopes on limestone and marls	Open woodland, Pinus spp. plantation	Lithic Xerorthents - loamy skeletal
5	Upper, very steep slopes on limestone	Fagus sylvatica woodland	Typic Hapludands fineloamy, moderately

			deep
6	Crest on limestone	Fagus sylvatica woodland and grassland	Lithic Hapludands loamy. Rock outcrops
7	Regular, steep slopes on limestone	Xerophilous grassland, mesophilous woods in interfluves, Pinus sp. plantation	Lithic and Typic Haploxeralfs clayey skeletal
8	Lower, very steep slopes on limestone and marls	Open woodland, Pinus sp.plantation	Lithic Haploxeralfs fine Vitrandic Haploxerolls loamy skeletal
9	Regular, mid-slopes on limestone with piroclastic materials	Castanea sativa woodland	Typic Hapludands loamy

(Continued on the following page)

Table 2: Soil-vegetation units mapped at Vesole mountain.

(Continuation)

10	Karst plain	Castanea sativa woodland with Q. pubescens	Typic Hapludands loamy, moderately deep
11	Moderately steep slopes on sandstones and colluvial deposits	Grassland, mixed mesophilous woods	Lithic Hapludands loamy skeletal. Typic Hapludands loamy, moderately deep
12	Moderately steep slopes ond small, level to gentle plains on marls	Crops	Aquic Xerochrepts fine silty

Table 2: Soil-vegetation units mapped at Vesole mountain.

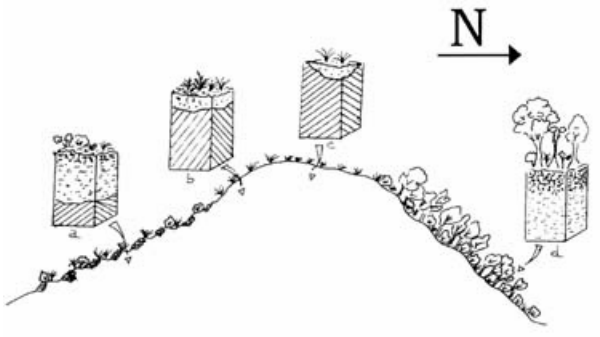


Figure 4: Geographical distribution of the main soil-vegetation units at Punta Tresino. a) Map unit 2. Moderately deep soils with clay-enriched subsoil under Ampelodesmos grassland and garigue. b) Map unit 1. Shallow, calcareous soils under Ampelodesmos grassland and garigue. c) Map unit 1. Very shallow, undifferentiated soils under Ampelodesmos grassland and garigue. d) Map unit 3. Moderately deep soils with clay-enriched subsoil and thik topsoil under mesophilous woodland.

Map Unit	Geomorfology Substrate	Vegetation type	Soil type Classification (SoilTaxonomy 1994)
1	Roundend crest on sandstones	Ampelodesmos mauritanicus steppe, macchia, gariga	Lithic Xerochrepts loamy skeletal Lithic and Typic Xerorthents loamy skeletal
2	Regular slopes on sandstone with ancient, small man-made terraces	Ampelodesmos mauritanicus steppe, macchia, gariga	Typic Haploxeralfs fine loamy
3	Regular slopes on marls	Mixed mesophilous woodland	Typic Haploxeralfs fine loamy, with thik topsoil
4	Very steep,regular slopes on sandstones and marls	Quercus ilex coppice	Typic and Lithic Xerochrepts loamy-skeletal
5	Lower, very deep slopes on sandstone and marls	Macchia, Pinus spp. plantation	Lithic Xerorthents loamy-skeletal

(Continued on the following page)

Table 3: Soil-vegetation units mapped at Tresino promontory.

(Continuation)

6	Irregular slopes on marls	Abandoned field with shrubs	Aquic Xerochrepts fine silty, moderately deep
7	Level to very slight plains on marls	Abandoned field with shrubs	Aquic Xerochrepts fine silty, deep

Table 3: Soil-vegetation units mapped at Tresino promontory.

References

Buol S.W., Hole F.D., McCracken R.J., 1989. Soil Genesis and classification.-Third edition, Iowa Univ. Press.

di Gennaro A., D'Antonio A., Ingenito M.R., Lulli L., Marseglia G., Terribile F., Toderico L., 1995. I suoli della provincia di Napoli. CUEN, Napoli, pp 37-50. .

Lulli L., 1990. Breviario sui suoli che derivano da materiali vulcanici in Italia. In: Lulli L. et al. (ed.) I suoli caposaldo dell'apparato vulcanico di Vico. Istituto Sperimentale per lo studio e la difesa del suolo, Firenze.

Mazzoleni, S., Legg, C., Strumia, S. & Migliozzi, A. (eds): ModMED - Modelling Vegetation Dynamics and Degradation in Mediterranean Ecosystems. Final report (manuscript), Napoli. .

Quantin, P., 1990. Andisols. In: Baize D., Girard M.C. (ed.) Referentiel pedologique francais, 3eme proposition. A.F.E.S., Plaisir, pp 71-78.

Soil Survey Division Staff, 1993. Soil Survey Manual. USDA Handbook n.18, Washington, D.C. .

Soil Survey Staff, 1992. Keys to Soil Taxonomy, 5th edn., SMSS Tech. Mon. n.19, Blacksburg, VA. .

VULNERABILITY OF THE CARBONATIC AQUIFERS WITH SINTACS METHOD: THE CASE-STUDY OF THE GRAN SASSO MASSIF (CENTRAL ITALY)

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Abstract. In land planning, above all as regards protected areas (natural parks), it is important to have aquifers vulnerability maps because the groundwater and hydrological resources drive the biological activities too. Nowadays one of the most recent and flexible approaching to elaborate Vulnerability maps is the application of the SINTACS method.

Key words: Vulnerability, aquifer, SINTACS.

The Sintacs method

The SINTACS method is a Point Count System Model for the assessment of groundwater pollution hazard. It was created in 1990 by M. Civita et al. within the VAZAR (Vulnerabilità degli Acquiferi nelle Zone ad Alto Rischio) project of CNR (Italy).
It is based on the evaluation of 7 parameters; each of them corresponds to the initials of SINTACS abbreviation, that is:
S = "Soggiacenza" (depth to water);
I = "Infiltrazione efficace" (net recharge);
N = "autodepurazione del Non saturo" (impact of vadose zone);
T = "Tipologia della copertura" (kind of soil cover);
A = "composizione litologica dell'Acquifero" (lithology of the aquifer);
C = "Conducibilità idraulica dell'acquifero" (hydraulic conductivity of the aquifer);
S or **X** = "acclività della Superficie topografica" (slope).
SINTACS score for each parameter ranges from 1 to 10. The choice of right scores is helped by using graphics and diagrams elaborated by the authors for each parameter; the higher is the score, the higher is the pollution hazard associated to that parameter. The final outcome is the calculation of *intrinsic vulnerability index* that results from summation of all parameters, each multiplied by its own weight.
Weights are conceived to represent the different importance that each parameter assumes, compared with the others, in different hydrogeological situations. The most important situations considered in the SINTACS method are: ordinary, widespread pollution sources, drainage from surface water bodies, karstic areas.
In general before the calculation it is necessary to divide up the area in EFQ (Elementi Finiti Quadrati = square finite dimensional elements) with 0.5 km long sides. Finally the intrinsic vulnerability index (I) is calculated in each EFQ. It ranges from 23 to 260 points and it is divided into 6 classes:

$I > 210 \Rightarrow$ Very high vulnerability
$186 < I < 210 \Rightarrow$ High vulnerability
$140 < I < 186 \Rightarrow$ Moderately high vulnerability
$105 < I < 140 \Rightarrow$ Medium vulnerability
$80 < I < 105 \Rightarrow$ Low vulnerability
$I < 80 \Rightarrow$ Very low vulnerability

Application of sintacs method in the case-study of the gran sasso massif

This method is really useful to elaborate aquifer vulnerability maps especially in case of large and complex aquifers as it is the Gran Sasso carbonatic massif. As the planning was carried out in a very large area, the map's scale is 1:100.000. So it is necessary to use elementary areas larger than the EFQ; those are irregular bounded areas but, on the other end, are very homogeneous from pedological and geomorfological point of view.
Furthermore the evaluation of SINTACS parameters in this case is based on large sets of underground data and, especially, on very large sets of surface data that are well scattered within the whole area. Therefore it is possible to develop calculations for each parameter in a more accurate way, particularly as regards the I parameter (application of Soil Conservation Service *Curve Number Method*) and the T parameter (additional evaluation of *depth factor* and *structure factor* among pedological features).
As regards the last two issues, i.e. the calculations of parameters I and T, there is a more detailed report in the paragraphs below.

Description of the hydrogeological structure of the gran sasso massif

The examined area concerns a large part of central Appennine in the districts of L'Aquila, Pescara and Teramo in the Abruzzo region.
The Gran Sasso massif is quite an orographic-tectonic unit having approximately the shape of a right-angled triangle. The northern cathetus is formed by the E-W line of the highest peaks (M.Corvo, Corno Grande, M.Camicia); the eastern one by the line N-S of M. San Vito, M.Cappucciata, M.Scarafano. The hypotenuse is formed by the Aterno Valley which morphologically separate the Gran Sasso from the Sirente massif.
The Gran Sasso area presents a great number of shapes which testify a wide range of geomorphological processes.
In the lowest zones of the massif, especially on the northern side, processes of accelerated gully erosion are predominant. these processes above all are in relation to the lythological features of the formations; in fact we pass from calcareous formations (at higher levels, under deep erosion) to more marly-arenaceous materials (at lower and lower levels, facing the Adriatic sea).
In the centre-southern area, as the nature of the different formations is prevalently calcareous and the orographic configuration is favourable, **karstification** is deep and widespread. Both limestones and quaternary detrital deposits are shaped in different ways by the karstifications

with consequent dolinas and more developed epigeals karstic formations. Moreover, in the area considered, the superficial hydrography is very poor while the absorption of water towards the subsoil is quite intense. As regards the above situation an important role is played by the **endoreic basins** (particularly Campo Imperatore) which act as concentrated infiltration areas since they pour into the subsoil almost all the rainwater.
From the geological point of view, the Gran Sasso massif is an important unit formed by platform and transitional carbonatic sequences. As a result we have the shape of an arc convex towards the Adriatic sea, clearly overslipped to the North over the terrigenous strata of the Laga massif but, at the same time, shifted also towards East with other important appenninic structures.
From the hydrogeological point of view the boundaries of the Gran Sasso massif are well outlined on the northern as well as on the eastern side: they are no doubt formed by the overslipping towards N of the carbonatic formations over the terrigenous strata of the Laga massif which make a sharp limit as regards the water table since they are marked by a very low permeability. This watertable occupies chiefly the carbonatic rocks with some outcrops through the quaternary deposits. Besides, some of the structural discontinuities situated within the massif constitute limits of permeability with consequent falls in the water level.
At last we can state that *the ground waters which saturate the massif prevalently flow towards the south-eastern zone*. Such directions are guided by the levels of the hydrogeological boundaries: waters flow prevalently towards areas where limits are at lower levels.
The **springs** surely fed by the Gran Sasso are located both on the northern side (generally over 1000 m a.s.l., for a total amount of about 2 m^3/s) and on the southern side (greater flows for a total amount of over 10 m^3/s) and are situated in the lowest points of contact between carbonatic rocks and other geological formations with low permeability which are around. Besides we must consider the *drainage of the motorway tunnel*, dating from the 1978, with a flow of about 1.5 m^3/s.

Hydrogeological changes caused by the building of the motorway tunnel

From the hydrogeological point of view the building of the motorway tunnel has played a double role: on one hand it has given the opportunity of collecting a large set of data concerning the hydrogeological situation at the time of excavation but, on the other hand it has given way to great permanent modifications in the original situation.
In fact the tunnel goes through the Gran Sasso massif from SW to NE, exactly in the zone where the water levels are higher (1600 m a.s.l.). Since the water picked up has all been drained and conveyed towards the two entrances, the portion of aquifer overstanding the tunnel has become unsaturated rock.
It is necessary also to consider that, in general, the massif presents, just along the axis of the tunnel, a zone with high karstification between about 1500 and 1650 m a.s.l., where water flow is intense; below this level the carbonates are generally less and less permeable, owing to the lithostatic pressure. In this case it is clear that karstification takes place in the water level oscillation zone, through quite pervious calcareous rocks.

We can try then to find out the real extent of the aquifer portion lost as a consequence of the Gran Sasso tunnel. As regards the above situation and starting from some piezometric data we can suppose that on both lateral sides of the tunnel the piezometric gradient may be approximately of 50%. This means that at about a lateral distance of 1.2 km we can find piezometric levels 500-600 m higher than the tunnel; these values are similar to those we had before the building of the tunnel.
Therefore, the maximum piezometric level, of about 1600 m, has not subsided too much, so that the main springs on the northern side, between 1000 m and 1500 m a.s.l., are still active, even though they show a decreasing flow. Nevertheless we can say that the building of the Gran Sasso tunnel has caused a considerable upset to the previous hydrogeological balance (some small sources dried up).

The *s* parameter: depth to water

We can define "depth to water" as the depth of water table from ground level. From the value of this parameter and from the hydrogeological features of the unsaturated layers we can value the Time Of Travel of any possible pollutant carried by waters and the duration of purifying action within the strata. The SINTACS score as regards the S parameter decreases with depth to water, assuming values from 10 to 1.
From measured data and model analysis, the Authors have considered a hyperbolic decrease in the SINTACS score with the increase of depth to water. For values over 60 the score tends asymptotically to 1.
Since it is clear that (chiefly in case of carbonatic fractured aquifers) is always not useful to reconstruct continuously the trend of any hydrogeological parameter, then it is more correct to use measurable data and so to try a discrete reconstruction. First it is necessary to assign a value that estimate the height of the water-table above sea level in each elementary area.
Some certain data from which we can start are:

- *The height of the main springs above the sea level.*
- Some well-known data about depth to water near the Aterno river.
- The altimetric course of the line that represents northern and eastern limits of the massif: in fact this line is really the superficial counterpart of an hydrogeological underlying limit for the aquifer .
- *The motorway tunnel lay-out*, as the tunnel is a very big drainage, so the water-table level has sunk till the tunnel level.

Given the above we might assign first the values of water level in those elementary areas that include the zones where data are well-known. For the interposed elementary areas we might suppose an almost constant steepness in the water-table surface. Afterwards we assign for each area a value that represents the medium height of the ground surface.
so we can immediately calculate depth to water by subtracting each other the last two values obtained above. Finally it's very easy to calculate SINTACS scores by using the relevant graphic.

The *i* parameter : net recharge; calculation of water budgets by using scs-cn method

Net recharge (mm/year) is the rain water quantity that yearly infiltrates through the deepest underground strata, as the runoff and the evapotranspiration are excluded. This parameter is very important for the assessment of vulnerability as it influences the infiltration of the pollutants and their dilution too.

Since in this case we are going to use a procedure which is different from the standard one, we can say that usually this parameter is obtained from effective rainfall and from hydrogeological surface conditions (surface lithology, hydraulic characteristics of soils, slope, fracture degree) which are included in the infiltration index χ.

The necessary data for the assessment of net recharge are the historical sequences of *pluviometrical and thermometrical monthly data* coming from all local measurement stations. By using these data we calculate the values of medium annual rainfall and medium annual evapotranspiration.

Then, as we obtain the values of net recharge, we can calculate SINTACS scores by using the relevant diagram, which assigns the highest scores to the infiltration values that range from 250 to 300 mm and assigns lower scores where net recharge is higher than 300 mm as in this case the dilution of pollutants is prevalent.

In the study-case of the Gran Sasso massif the existence of CN data well widespread within the whole area, has brought us to use the SCS-CN method (Soil Conservation Service of the USA) for the calculations of the water budgets and therefore of the net recharge. This method is based on the following concepts:

If S (mm) is the maximum immediate soil storage during an only pluviometrical event, then:

$S = (25400/CN)-254$

There are 3 choices:

$RO = 0$	if $P < 0.2\ S$
$RO = (P - 0.2\ S)^2/(P + 0.8\ S)$	if $0.2\ S < P < 4.2\ S$
$RO = P - S$	if $P > 4.2\ S$

CN is a whole number that ranges from 30 to 100. This range allows us to consider many different factors as kind of soils, land use, vegetation cover, etc.

While the CN allowed us to make a first division of the case-study area, on the other end both monthly rainfall and monthly temperatures have permitted a further division of land units up to 118 homogeneous areas that we used to calculate the monthly water budgets (Thornthwaite method).

It is necessary now to know the local rainfall distribution. In the case-study area we can rely on a good number of pluviometrical stations (24) which are also well distributed on the territory: with the available data from each of these stations we can draw monthly *isohyets* with good approximation. Thanks to the isohyets we change pluviometrical local data into continuous widespread informations and then we can fix a medium estimated value of rainwater for each of the 118 homogeneous units.

To calculate water budgets we need also to check monthly *temperatures* within each homogeneous area. The data we have are only those from the above measurement stations. We try now to obtain monthly maps of temperatures all over the case-study area. As regards

temperatures we can say that *isotherm and isohypse curves approximately coincides*. In fact horizontal variations of the temperature are slight compared with the lapse rate.
So we have divided the case-study area in belts with same altitude by drawing isohypse every 400 m, starting from 600 m a.s.l. For each belt we assigned the intermediate level temperature. Afterwards we assigned a climatic zone to each elementary area and consequently a well-known thermic regime.
In order to carry out water budgets it is also necessary to know the soil storage (ST).
In this case, for every kind of soil of the area, we can dispose of AWC data (in mm) which approximately correspond to ST. In the case of no soil or bare rocks we assume ST = 0.
Before calculating the final monthly water budget we must consider two basic problems.
The first one concerns the runoff. We know that in the Gran Sasso area karstic phenomena are well developed and, together with them, we also note the *endoreic basins*, that is hydrographic closed areas. The runoff waters in the above areas remain in the lowest zones and percolate into the subsoil. In such areas also the runoff gives place to net recharge; therefore it is necessary to know which elementary areas are situated in such zones. So in the relevant water budgets we must add the runoff to the amount of net recharge.
The second problem concerns the remarkable extent of *snow fall* during the winter season. As a consequence we have almost no infiltration under snowy conditions but in fact we have a progressive storage of solid state water; such a water will flow again during the thaw months and will be added to the rainwater (P) that will fall in these months. So we shall consider the snow accumulation only in those elementary areas with medium temperature below zero. Therefore as regards the areas within the A zone (medium level 2200 m a.s.l.) we shall consider precipitations exclusively as snowfall during the months of December, January, February, and March. For the areas within the B zone (medium level 1600 m a.s.l.) we shall consider precipitations exclusively as snowfall during January and February. Besides as regards the areas within A zone we shall consider as thawing months April, May and June; for the areas within B zone the months of March and April. Finally we assume F, that is monthly water amount coming from thawing snow, as a constant calculated from winter solid state water amount divided by the number of thawing months. So, for each thawing month, the water quantity available for water budgets is obtained by summing F with P which regards only this month.
Once we have all monthly water budgets, we shall add the 12 monthly results for each elementary area in order to obtain the total yearly net recharge. At last we can use the graphic which allow us to fix the SINTACS score for I parameter starting from net recharge values.

The *n* parameter: impact of the vadose zone

The unsaturated vadose zone is that part of subsoil between soil bottom and the water table level. Such a zone, where the water flow is prevalently vertical, is limited in the lower part by the surface of an unclosed aquifer, so its thickness may sometimes change remarkably following the variations of water table level. Within this zone both physical and chemical factors facilitate processes of water purification.

We can value the impact of this zone on the pollutants starting from the geolythological characters, that is to say lithology, fracture degree, karstic features. We can fix the SINTACS score as regards N parameter within every elementary area by identifying the prevailing lithology and then using the relevant diagram.
For the identification of the lithologies we used Geological map of Abruzzo (Ghisetti F., Vezzani L., 1998) Geological map of Laga-Cellino Complex (see References, 1992), geological sections, fracture map and karst distribution maps (Consorzio di ricerca del Gran Sasso). At last we have decided to consider two ranges of fractures degrees:

- *High* fracture degree, with values of more then 20 fractures per m (f/m);
- *Medium-low* fracture degree, with values of less then 20 fractures per m.

Within the areas where karstic phenomena are well developed we can neglect further information regarding lithology and fracture degree since such a hydrogeological situation always means 9 points.

The *t* parameter: kind of soil cover

The typology of soil cover plays a very important role in mitigating pollutants: it is the first front line for the defence of water. Among all factors which affect the mitigation power, the most important are texture, depth and structure.
The SINTACS method takes the *texture* as the most important reference datum. Starting from the relevant diagram we can get to rather limited score ranges corresponding to every kind of texture: within such ranges we can move taking account of other pedological features among which *depth* and kind of *structure* are already well-known (there are available data from the studies of "Consorzio di Ricerca del Gran Sasso").
In order to fix the score concerning the T parameter we have decided to consider each pedological unit as regards its texture class; so that we can have a first value for scores by using the T SINTACS diagram.
If we want to consider also the soil depth (after some analysis here omitted) we can reduce scores by 1 in case of deep soils, leave score as it is in case of medium depth soils, increase scores by 1 if soils are thin (in case of no soils we shall always have 10).
As regards the structure factor, the kind of structures are 6: platy, prismatic, columnar, blocky, granular, crumby; among the above structures the last three ones favour a good increase in vulnerability, while the second and the third favour a less remarkable increase in vulnerability. We point out that within the case-study area soils belong to structural classes between 4 and 6; therefore we have decided to multiply the relevant scores by 1.25. That means a score of 10 within no soil areas, while we must multiply by 1.25 the scores obtained within all the other areas after considering texture and depth factors.

The *a* parameter: lithology of the aquifer

All up to date hydrological research identifies the aquifer as the saturation zone within a given hydrogeological complex. The aquifer typology deals with the processes which take place

below water level that is dispersion, dilution, absorption and chemical reactivity of rocks: they are deeply influenced by the lythological kinds as well as by the permeability of the aquifer. Therefore we must consider all these characteristics to value the parameter. Starting from the data we have we shall try to find the best satisfactory values within the ranges shown by the SINTACS diagram where we can find the main lythological kinds of aquifers.
From the geological maps and sections we can clearly see that the Gran Sasso aquifer is almost all formed by the *carbonatic complex*. In fact if we examine the underground lithology we find also the marly and the dolomitic complexes, but we observe that they are not important for the ground waters storage. As an exception we observe the presence of quaternary deposits at the water level near the Aterno river and within Capestrano area.
We decided then to consider carbonatic complex and quaternary deposit lithologies in order to fix SINTACS scores. Within the carbonatic complex we must first distinguish three main geolythological situations: karstic rocks (quite pervious), fractured rocks (medium permeability), deep rocks (low permeability). Among these three cases the last one we find nearby the motorway tunnel, where calcareous rocks show substantially closed fractures, perhaps owing to great lithostatic pressures.
At last we could fix final scores by using SINTACS diagram.

The *c* parameter: hydraulic conductivity of the aquifer

The *hydraulic conductivity* K (m/s) measures flowing power of underground waters and therefore the flowing power of a water-carried pollutant within saturated rocks. This parameter measures the unit water flow and so the velocity of water towards the springs.
Since hydraulic conductivity data as regards aquifers are rarely available, the SINTACS method offers a direct approach with scores fixed starting from K values, and also an indirect method based on a diagram where the main lythological kinds of aquifer are represented together with the relevant values of hydraulic conductivity.
As regards the case-study area of the Gran Sasso we can dispose of data from direct drillings only within the motorway tunnel zone. With the exception of such area we don't dispose of other measurements and so we must fix values directly by using SINTACS diagram.

The *x* parameter: slope

Slope in the ground surface influences the vulnerability chiefly as it first influences the runoff percentage and the water flow velocity (as well as the velocity of a water-carried pollutant) above the ground. So we will fix a high score within low steepness areas where the pollutants can't shift very much under gravity action and so the infiltration is more intense. Therefore we make 5 *slope classes* with steepness between 0 and 30%, and the maximum SINTACS score is fixed in level areas.

The karstic phenomena and the sintacs sets of score weights

Karstic phenomena are surface and deep phenomena due to chemical and physical water action against soluble calcareous rocks. These processes are active within the whole rock mass and they cause a dimensional increase of void distribution.
By observing land forms tied to karstic processes we are able to find out the areas in which these processes are more active.
For a right use of SINTACS method, the only knowledge of the 7 parameters is not enough. In fact each parameter must assume a different importance, compared with the others, in different hydrogeological situations. So the method establishes to multiply each of the 7 scores by a coefficient (weight) that ranges from 1 to 5: this weight is 1 in case of a hydrological situation in which the relevant parameter has a very little importance compared with the others; the weight is 5 if the relevant parameter has a very big importance. The intermediate values (2,3,4) are useful to describe a large set of intermediate situations.
Among the different sets of weights given in the SINTACS method, in the case-study area we chiefly find two of them (weights are in bold fonts):
Ordinary Hydrogeological situation (S-**5**, I-**4**, N-**5**, T-**2**, A-**3**, C-**3**, S-**1**);
Karstic widespread phenomena (S-**2**, I-**5**, N-**1**, T-**3**, A-**5**, C-**5**, S-**5**).
Therefore it is extremely important to find out the real extent of karstic areas in order to decide which set of weights are more proper for each elementary area.
As regards the above issue we can say that the Gran Sasso massif area is characterized by very well widespread karstic land forms: these are chiefly well developed on the southern side where we can find many table-lands and where the parent material is prevalently calcareous. On the other hand in the NW and NE sides karstic phenomena are quite uncommon owing to high slopes and parent materials which are prevalently marly-calcareous and marly-arenaceous. Some of the most important karstic zones are well developed in the zone between *Castel del Monte*, *Campo Imperatore* and *M. Capo di Serre*, where besides large endoreic basins are evident.
Given the above we might assign "karstic" attribute and the relevant set of SINTACS weights only to the areas where phenomena are more evident; as a consequence in other areas we assign "ordinary" attribute.

The intrinsic vulnerability map of the gran sasso carbonatic massif

Now we finally have all the data which are necessary to calculate $I_{SINTACS}$ that is *intrinsic vulnerability index* within each elementary area and so to make the *Intrinsic Vulnerability Map of the aquifers*. The above index is:

$$I_{SINTACS} = \sum_{1}^{7}{}_{i} \left(Score_i * Weight_i \right)$$

By dividing the values of $I_{SINTACS}$ into classes with the suggested ranges, we obtain 5 classes of vulnerability each one represented on the map with a different colour, that is to say:

- High vulnerability (red colour) $\Rightarrow$ $186 < I < 200$;
- Moderately high vulnerability (orange colour) $\Rightarrow$ $140 < I < 186$;

- Medium vulnerability (yellow colour) $\Rightarrow$ $105 < I < 140$;
- Low vulnerability (light green colour) $\Rightarrow$ $80 < I < 105$;
- Very low vulnerability (green colour) $\Rightarrow$ $I < 80$.

References

A.N.A.S. & COGEFAR (1979): *Gran Sasso, il traforo autostradale*.

Borselli L.: *Il "Soil Conservation Service Curve Number Method"*. C.N.R. (Consiglio Nazionale delle Ricerche), Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche: *Linea 1: Previsione e Prevenzione degli Eventi Idrologici Estremi e Loro Controllo. Caratteristiche Fisiche ed Idrologiche del Suolo, Loro Derivabilità dalla Cartografia Pedologica ed Applicabilità in Modelli Distribuiti di Bilancio Idrologico di Bacino*. Presidenza del Consiglio dei Ministri - Dipartimento della Protezione Civile.

Celico F; Quaderni di Geologia applicata, volume 1, Gennaio-Giugno 1996 : *Vulnerabilità all'inquinamento degli acquiferi e delle risorse idriche sotterranee in realtà idrogeologiche complesse: i metodi DAC e VIR.*

Centamore E., Adamoli L., Berti D., Bigi G., Bigi S., Casnedi R., Cantalamessa G., Fumanti S., Morelli C., Micarelli A., Ridolfi M., Salvucci R.; Collaborazione di Chiocchini M., Mancinelli A., Potetti M., Chiocchini U. (1992): *Carta geologica dei bacini della Laga e del Cellino e dei bacini carbonatici circostanti (Marche meridionali, Lazio nordorientale, Abruzzo settentrionale), scala 1:100.000.* S.EL.CA., Firenze.

Civita M. (1994): *Le Carte della Vulnerabilità degli acquiferi all inquinamento*: *Teoria & pratica*. Pitagora Editrice, Bologna.

Civita M., De Maio M. (1997): *SINTACS: Un sistema parametrico per la valutazione e la cartogra-fia della vulnerabilità degli acquiferi all'inquinamento. Metodologia & automatizzazione*. Pitagora Editrice, Bologna.

Consorzio di Ricerca del Gran Sasso presso i Laboratori Nazionali INFN di Assergi (AQ) (1995): *Realizzazione di un sistema di monitoraggio idrologico del massiccio del Gran Sasso - Progetto Idrologia*. Studi preliminari eseguiti da "CISE tecnologie innovative"(G. P. Stigliano e R. Trucco) e "nuova Telespazio s.p.a."(P. Cecamore e M. Palandri).

Farroni A., Petitta M., Tallini M. & Togna A. (1999): *Indagine sull'impatto idrogeologico delle opere in sotterraneo sull'acquifero del Gran Sasso: revisione dei dati esistenti e nuove considerazioni*. Workshop nazionale sulle acque, Teramo, 24 ottobre 1997. Studi Geologici Camerti (in stampa).

Ghisetti F., Vezzani L.(1998): *Carta geologica dell'Abruzzo, scala 1:100.000*. S.EL.CA., Firenze.

Istituto Nazionale di Fisica Nucleare, Laboratorio Nazionale del Gran Sasso; Dipartimento di Ingegneria delle Strutture, delle Acque e del Terreno dell'Università degli Studi dell'Aquila (1997): *Indagine sull'eventuale impatto idrogeologico prevedibile con la realizzazione della galleria servizi e dell'ampliamento dei laboratori sotterranei del Gran Sasso*.

IMPACTS OF SPATIAL VARIATION IN SOIL PROPERTIES ON HYDROLOGY OF SEMIARID HILLSLOPES

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Abstract. In south-east Spain, rainfall runoff from hillslopes is collected in underground tanks (aljibes). Stone content and depth of soils along semiarid hillslopes vary significantly. A variation in runoff can be attributed to not only the amount and intensity of rainfall, but also to spatial variation in soil properties, infiltration and the size of the catchment and slope. It has been noted that aljibes volume does not increase linearly with catchment area. This is especially true for catchments with a high percent of rock outcrop. Hydrological models have been developed specifically for semiarid landscapes. However, the high sensitivity to the large variation in soil stoniness and thickness make their application at the hillslope / catchment scale still problematic. The aljibes allow a unique opportunity to monitor rainfall and runoff relationships along slopes displaying such variation in soil properties, and therefore further contribute to calibration of hydrological models. The catchment areas range in size from 0.5 - 16 hectares, so the opportunity available is to monitor hydrological properties of semiarid hillslopes on such a scale. Also there is an opportunity to develop a methodology to rapidly assess the variation in critical soil properties on semiarid hillslopes.

Key words: Water harvesting, runoff, soil thickness, soil stoniness, semiarid hillslopes, south-east Spain.

Introduction

Throughout southern Spain, a wide range of water harvesting systems can be found. These are designed to collect and store runoff from hillslopes and are designed to meet various domestic and livestock requirements. Similar water harvesting techniques exist in many arid and semiarid farming areas throughout the world (Yair, 1983; Carter & Miller, 1991; van Wesemael et al, 1998). One of the key characteristics of these systems affecting efficiency is the catchment's ability to produce runoff even during light rainfall, and for this runoff to be collected. Infiltration, soil thickness and soil stoniness are all features affecting this runoff production (Abu-Awwad & Shatanawi, 1997; Poesen et al, 1990). It has been illustrated that both the surface and sub-surface conditions of these semiarid hillslopes dictate the threshold for runoff to be generated (Lavee et al, 1997; Mulligan & Thornes, in press). The depth and stoniness of the soils along these semiarid hillslopes may display large spatial variation. This is partly due to natural processes of sediment transport and deposition. Another major affecting factor is the change in land use. The increasing use of heavy tractors has lead to an expansion of cultivated land and abandoning of remote, steep upper slopes. The large spatial variation in soil depth and

stoniness has a strong impact on hydrological properties along the hillslopes. Furthermore, the sparse and irregular rainfall leads to poor hydrological connectivity along the hillslopes. For these reasons, hydrological models mainly based on topographic attributes such as the TOPMODEL approach (Beven & Kirkby, 1979; Moore et al, 1993) that assume deep soils with homogenous hydrological properties, which give promising results in temperate regions are less applicable in predicting rainfall runoff relationships along semiarid hillslopes. An alternative method is the cellular approach (Mulligan & Thornes, in press) where hillslopes are modeled as a series of connecting cells. Whilst this approach performs well, difficulties arise in providing information on the spatial variation of soil properties such as stone cover and soil depth. As Pilgrim et al (1988) show, the diversity in hydrological processes and characteristics in semiarid regions require different approaches to rainfall / runoff modelling from those techniques appropriate to humid regions. Sparse rainfall, ephemeral channels and absence of ground water make calibration problematic. So far, there is a problem in calibrating models due to a lack of rainfall / runoff and the main factor contributing to runoff production from rainfall is the surface conditions of the hillslopes (Lavee et al, 1997; Nicolau et al, 1996; Puigdefabregas et al, 1998; Poesen et al, 1990). The catchments of water harvesting systems provide excellent monitoring possibilities to collect data on the factors affecting runoff production on semiarid hillslopes. The water harvesting systems themselves are of increasing interest due to the potential they provide in water supply for remote regions.

Rain-water harvesting is, in its simplest terms, the collection of run-off rainwater from a catchment area. This method is used for farming (watering livestock, crop irrigation) in arid and semiarid areas. Such systems existed 4,000 years ago in the Negev desert (Lavee et al, 1997). The method does not depend on high technology, but requires study of site suitability and system design. This is a low cost system promoting self sufficiency and sustainability in many local dry-land regions in Africa, Israel, Egypt, Tunisia, Libya, southern Algeria, North Yemen, India, and Southern Spain (Yair, 1982; Carter & Miller, 1991; Suleman et al, 1995; Lavee et al, 1997; Abu-Awwad & Shatanawi, 1997; van Dijk, 1997; van Wesemael et al, 1998).

Harvesting rainwater can be accomplished using a broad range of technologies from very simple, natural catchment areas (southern Spain) to more extensive and complex ones using a broader range of techniques such as shaped compacted-earth, wax treated shape compacted-earth, gravel-covered plastic and reinforced-mortar-covered plastic (Cluff, 1989). Systems are very flexible and most systems contain five basic components: a catchment area, the capability to channel water from catchment to storage, a storage tank, conveyance system (gravity fed or pumped), and some level of water treatment

The main aim of this research project is to provide rainfall / runoff data from water harvesting systems using a hierarchical approach. Relatively uniform small catchments (0.5 ha.) to large and complex catchments (16 ha.) containing several geomorphologic units will be studied. This data will then be used to assess the reliability of runoff supply potential as a function of catchment characteristics. The data will also be used to illustrate the discontinuous character of runoff on semiarid hillslopes and relate findings at the plot scale to the hillslope / headwater scale. Another aim of the project is to develop a simple and effective method to model runoff from stony hillslopes.

Runoff from semiarid hillslopes

The slopes of southern Spain often have only a shallow soil and rock fragment cover increases with local slope gradient (Poesen & Lavee, 1994; Simonton et al, 1994). Where as the base of slopes are found to be sediment fills (Nicolau et al, 1996). As Nicolau et al (1996) found, to understand flood forming conditions and the spatial distribution of overland flow requires accurate information on the localization of run-off sources and sinks, and the controlling factors. It has been widely found that the upper parts of semiarid hillslopes are the main areas of run-off production (Nicolau et al, 1996; Puigdefabregas et al, 1998), whereas the footslopes and alluvial fans of such slopes are clearly a sink for such run-off (Nicolau et al, 1996; Bergkamp et al, 1996). As Pilgrim et al (1988) show, Hortonian overland flow is the main mechanism for run-off, where the rainfall exceeds the maximum potential for infiltration. The spatial variation of soil characteristics along such semiarid slopes leads to a variation along the slope of infiltration capacities, leading, in turn, to partial area run-off. This effect can be further enhanced by vegetative cover along the slope.

Soil crust formation, or sealing, which reduces water infiltration is common in semiarid soils. This is due to low organic matter contents, high silt contents and low aggregate stability (Abu-Awwad & Shatanawi, 1997). Therefore both for steep and stony hillslopes, and for gentle slopes covered with a crust, the discontinuous characteristic of runoff means that smaller catchments are more efficient than large catchments that encompass a range of slopes and soil properties.

Another factor affecting rainfall runoff relationships in such semiarid catchments, is soil stone content and rock fragment cover. As the findings of Poesen et al (1990) show, the position of rock fragments in the top soil directly affects runoff production and the amount of infiltration. For well embedded rock fragments in the soil surface, infiltration rates decrease and runoff generation increase. With RF cover, however, for rock fragments resting on the surface of the soil, the infiltration levels increase and runoff volume decrease. With RF cover, the level of effect the rock fragment has on infiltration and runoff generation was shown to be proportional to cover percentage. The rock fragment cover and position must be accounted for when assessing or modelling the hydrological response of soils that contain rock fragments in their cover or are susceptible to surface sealing, especially if assuming run off generation as rock flow or as Horton overland flow (Poesen et al, 1990). As van Wesemael et al (subm.) show from studies on intensively cultivated semiarid hillslopes, rock fragments can have a complex effect on hydrological fluxes into, within and out of soil profiles. The effects studied can alter the moisture retention characteristics of the soil to a significant level and in turn effect overland flow generation.

Semiarid hillslopes show poor hydrological connectivity. The spatial variation of soil properties along the hillslopes along with sparse / variable rainfall means that terrain based hydrological models are not appropriate due to an absence of the homogenous hydrological soil characteristics they require. In semiarid conditions, potential evapotranspiration exceeds rainfall for large parts of the year. This leads to very little movement of soil water, or drainage down the slope. It is also often the case that rainfall events are few, and generally concentrated to one season. As Puigdefabregas et al (1998) state, saturated subsurface layers are rarely formed and the transfer of water generally occurs via overland flow or unsaturated sub-

surface flow. Pilgrim et al (1988) state that semiarid areas operate under a delicate hydrological balance. Therefore a prolonged period of drought or rain may change the hydrological nature of the area, and hence any values of model parameters. Yair (1983) presents data to support the idea that rock outcrops and thin stony soils produce the most runoff through hillslope hydrological studies coupled with the analysis of soil properties within and around the catchment areas. Yair (1983) shows that the run off yield increases with decreasing catchment area. Also run off yield decreases with slope angle and stone cover, as supported by Poesen et al (1990).

Research outline

In an inventory of 51 water harvesting systems in south-east Spain, it was shown that there was not a linear relationship between catchment area and cistern volume (van Wesemael et al, 1998) (fig. 1). This indicates a decrease in efficiency of the catchments with size, attributed to the limited extent of surfaces with a high runoff coefficient, such as rocky outcrops. The findings of Lavee and Yair (1990) and Puigdefabregas et al (1998) support the pattern of runoff production being mainly on steep rocky slopes and infiltration taking place widely in the colluvial mantle. These findings were from results on experiments conducted on small plots. The main aim of the present research, however, will be to indicate the importance of spatial variation of soil properties at the catchment scale. In semiarid areas there has been research into hydrology of large catchments and small plots of land, for run off model studies. Thusfar, hydrological research in semiarid areas has been confined to the very large scale (Boer, thesis; Kirkby et al, 1998) and the plot scale (Nicolau et al, 1996).
The range in size of the water harvesting systems in the Almeria province of south-east Spain from 0.5 - 16 hectares provide a unique opportunity to monitor rainfall and runoff relationships at the hillslope to head water scale. This data will allow us to determine the effect of scale and increasing spatial complexity of surface characteristics on the efficiency of runoff production within the catchment. Also, this data will provide information on the risks and reliability of water harvesting techniques. Most systems have been developed over centuries with the use of indigenous knowledge. These systems though can play a vital role in providing sources of water in remote areas for rural development in developing countries. Since the design of such systems is critical, and must be adjusted to both climatic factors and soil surface properties, there is a great risk in rapid implementation of these systems. The research being undertaken aims to develop criteria for design and risk assessment of water harvesting from natural catchments. The annual rainfall can only be used as an extremely crude method of indicating the production of sufficient runoff to fill the cisterns at regular intervals. Also, the dry spells between runoff events are of vital importance to the hydrological characteristics of the surface soil properties. The runoff curve number method (Rallison & Miller, 1982) was employed to assess the viability of characteristic water harvesting systems (van Wesemael et al, 1998). These authors tested the sensitivity of runoff generation to the runoff curve number of the catchment. Annual runoff was calculated based on daily rainfall records of nearby meteorological stations. Figure 2 shows the runoff depth needed to fill the aljibes connected to these catchments by the horizontal lines. The figure shows that although smaller catchments

produce the highest rates of runoff, their size means that a large runoff depth will be required before the aljibe is filled. Larger catchments however, although less efficient at producing runoff, require a lesser runoff depth to fill the aljibe due to the greater area of available catchment for runoff production. The aljibes in the Sierra de Gador were found to be the most reliable, as they were replenished at least once a year, even in 1984 when rainfall fell to 158mm (figure 2). It must be stressed, though, that these considerations were not based on actual runoff data. The proposed research aims to investigate the rainfall / runoff relations of some water harvesting systems in more detail.

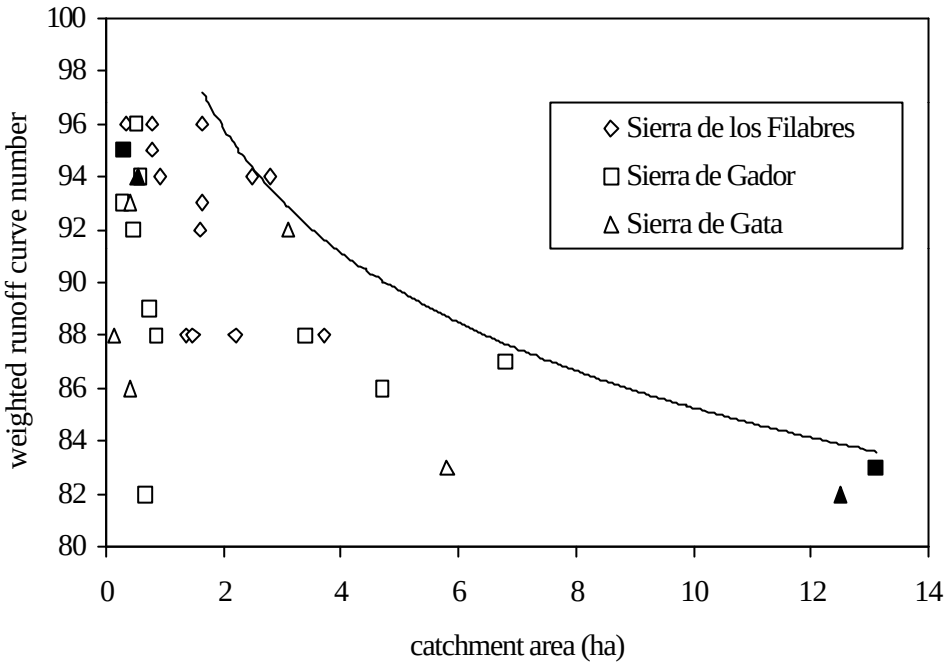


Figure 1 : Relationship between aljibe volume and catchment area. The graph shows regression lines for all aljibes (n=51) and for those on rocky hillslopes (n=34) (van Wesemael et al, 1998).

The problems associated with hydrological modelling are mainly in identifying an accurate, but simple, model to adapt. The runoff curve method discussed above is a simple model that is purely statistically derived, with very little scope for input of specific variables. However, landscape based methods such as the TOPMODEL approach (Beven & Kirkby, 1979) do not allow for spatial distribution of soil properties. Physically based models such as MEDRUSH (Kirkby et al, 1998), SHE (Abbot et al, 1986) and PATTERN (Mulligan, thesis), are problematic due to the large data requirement and the structure being grid cell based. A possible adaption for this research is the cellular approach coupled with a systematic pattern in soil properties, such as soil thickness and stone cover. There is also a difficulty in calibrating models in semiarid environments due to the many variable hydrological characteristics. Also, the discontinuous runoff, catena / landscape based concept developed by Mulligan & Thornes (in press) is not applicable.

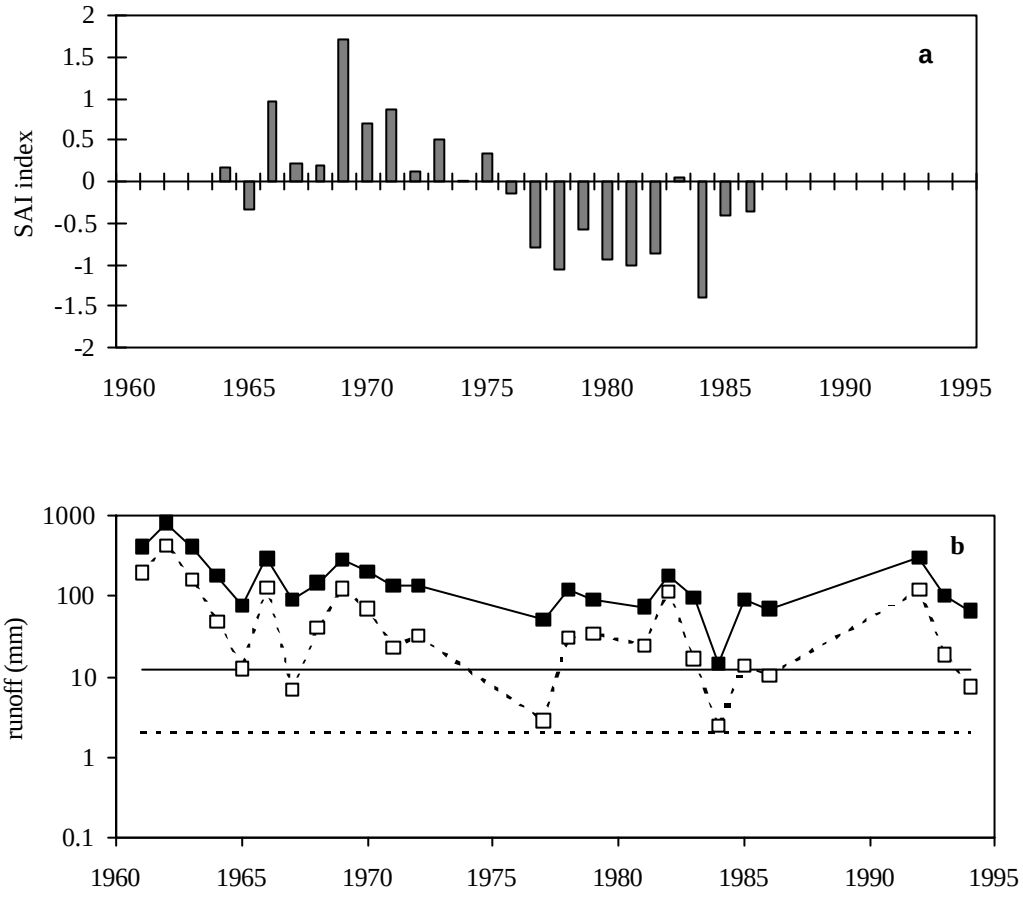


Figure 2: Annual trends in rainfall and runoff from four selected catchments. (a) Standard anomaly index (SAI) of annual rainfall; (b)runoff from catchments in the Sierra de Gador with high, CN(II)=95 (closed squares), and low, CN(II)=83 (open squares) run off curve numbers. The e amount of runoff that will fill the corresponding aljibes is indicated by the horizontal solid and dashed lines, respectively (van Wesemael et al, 1998).

Methodology

Four catchments will be selected that are connected to cisterns of water harvesting systems in the Sierra de Gador mountain range (south-east Spain). In this area there are aljibes with a range of catchment sizes still in use (fig. 3).

The storage systems in south-east Spain, known as aljibes (fig. 4), are rectangular basins lined with walls of masonry. The tanks are sunk to 2-3 meters in hill slopes with dome shaped roofs to prevent evaporation and keep water temperature low to maintain water quality. The tanks fill via runoff water produced from hill slope or fill from flood waters channelled into ephemeral

streams. The water is mainly for use with livestock, but some domestic use has also been found. Mean annual rainfall in this region is 420 mm and annual temperatures are 8 - 9°C (van Wesemael et al, 1998).

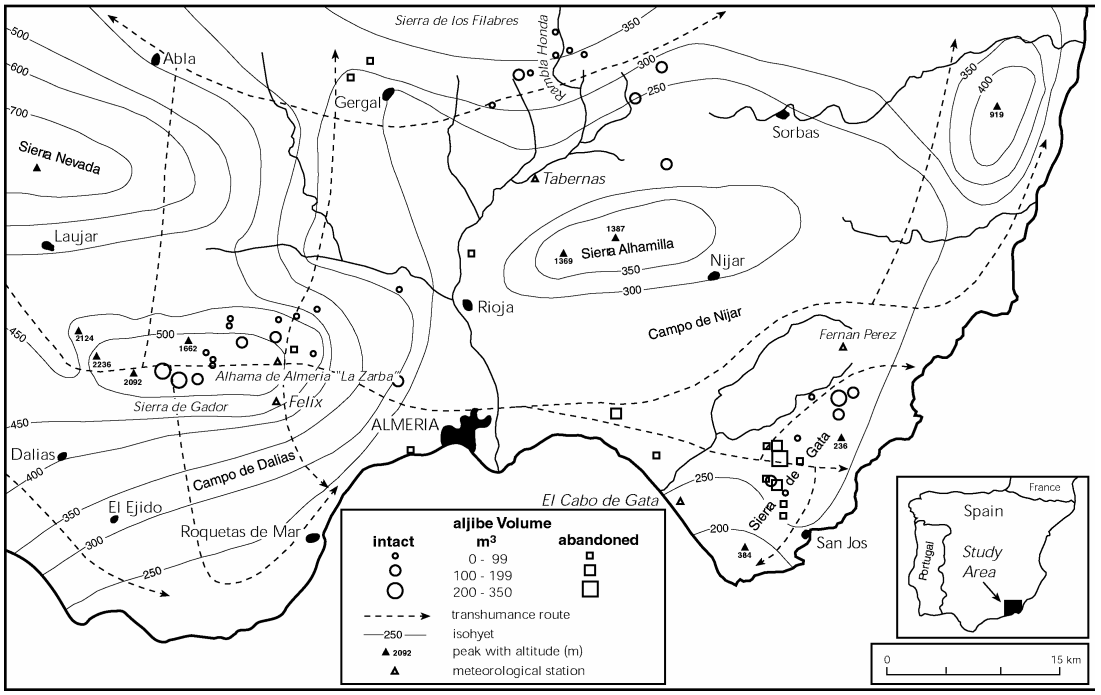


Figure 3: Distribution of the aljibes surveyed in Almeria province, also showing the transhumance routes (after Barrionuevo et Lopez, 1989) and the rainfall distribution (Molina, 1977), (van Wesemael et al, 1998).

Being a mountain range with very strong gradients ensures runoff producing rock outcrops within the catchments and thin soils. A hierarchical approach will be adopted, where by the size and complexity of the studied catchments will increase from 0.5 - 16 hectares. The selected cisterns will be fitted with water level sensors, and rainguages will be installed within the catchment areas. All data on rainfall and water level within the cisterns will be logged at the four sites over a two year period. Also, detailed surveys of the catchments will be carried out recording soil properties and topography via an electronic theodolite. Once completed, a digital elevation model (DEM) of the catchments will be produced to investigate the relationships between topography and soil properties, and to enable the routing of runoff obtained from the hydrological model. The DEM will also be used to pinpoint areas along the slopes for representative soil samples to be taken. This method for soil sampling will be adopted due to the "traditional" method of determining soil depth and stoniness being very labour intensive and therefore unsuitable for such a large area. The use of soil maps is not appropriate either due to the small scale of the area and the large soil variation in relation to the scale of soil maps. The relation between runoff, rainfall and catchment properties will be evaluated on an event basis. Also, the reliability of the systems and the yields will be evaluated

for risk assessment criteria for the possibility of implementing water harvesting systems with natural catchments in other areas. This will involve incorporating indigenous knowledge of the water harvesting methods, a look at the level of investment required and the possible return in water yield.



Figure 4: Position of a large aljibe (314m^3) with a catchment on a steep hillslope in the Sierra de Gata. Runoff conduits can be seen at the base of the hill leading runoff to the aljibe and the sediment cleared from the aljibe.

Conclusions

The research being undertaken in this project aims to improve our understanding of rainfall / runoff relationships along semiarid hillslopes. It will lead to an understanding of the hydrological properties of a range of catchments increasing in size and complexity and incorporating different geomorphic units. These findings may furthermore increase runoff collection, and decrease the risks involved in water harvesting with sparse rainfall. There may also be a scope for incorporating new techniques that will improve catchment efficiency. The data collected will highlight how the systematic patterns in soil properties make it difficult to model runoff on the hillslope scale. This may help validate the efficiency of hydrological models in predicting the reliability of water harvesting systems.

References

Abbott, M.B., Bathurst, J.C., Cunge, J.A., O'Connell, P.E. & Rasmussen, J. (1986). An introduction to the European Hydrological System- Systeme Hydrologique Europeen, SHE, 2: Structure of a phisically-based, distributed modelling system. *Journal of Hydrology*, **87:** 61-77.

Abu-Awwad, A.M., & Shatanawi, M.R. (1997). Water harvesting and infiltration in arid areas affected by surface crust: examples from Jordan. *Journal of Arid Environments*, **37:** 443-452.

Bergkamp, G., Cameraat, L.H., Martinez Fernandez, J. (1996). Water movement and vegetation patterns on shrubland and an abandoned field in two desertification-threatened areas in Spain. *Earth Surface Processes and Landforms*, vol. 21, **12:** 1073-1090.

Beven, K. & Kirkby, M.J. (1979). A physically based, variable contributing area model of basin hydrology. *Hydrological Science Bulletin*, **24:** 469-486.

Boer, M. (thesis) (1999). Assessment of dryland degradation: linking theory and practice through site water balance modelling.

Cara Barrionuevo, L., & Rodriguez Lopez, J.M., (1989). El Ambito Economico del pastoralismo Andalusi. Grandes aljibes ganaderos en la provincia de Almeria. In: *Historia y Medio Ambiente en el Territorio Almeriense*, pp.49-82. Almeria: Universidad de Almeria. 369 pp.

Carter, D.C., & Miller, S. (1991). Three years experience with an on-farm macro-catchment water harvesting system in Botswana. *Agricultural Water Management*, **19:** 191-203.

Cluff, C.B. (1989). Water harvesting systems in arid lands. *Desalination*, **72:** 149-159.

van Dijk, J. A. (1997). Simple methods for soil moisture assessment in water harvesting projects. *Journal of Arid Environments*, **35:** 387-394

Kirkby, M.J., Bathurst, J.C., Woodward, I., & Thornes, J.B. (1998). Modelling the physical and biological systems. In: Mairota, P., Thornes, J.B., & Geeson, N. 1998 (Editors). *Atlas of Mediterranean environments in Europe. The desertification context*. Wiley, Chichester, UK. p. 60-69.

Lavee, H. and Yair, A. (1990). Spatial variability of overland flow in a small arid basin. *IAHS Publications*, **189:** 193-215

Lavee, H., Poesen, J. & Yair, A. (1997). Evidence of high efficiency water harvesting by ancient farmers in the Negev desert, Israel. *Journal of Arid Environments*, **35:**341-348.

Molina, J.J.C. (1977). *El clima de la Provincia de Almeria*. Almeria: Monte de Piedad y Caja de Ahorros de Almeria. 195 pp.

Moore, I.D. Norton, T.W. & Williams, J.E. (1993). Modelling environmental hetrogeneity in forested landscapes. *Journal of Hydrology*, **150:** 717-747.

Mulligan, M. (thesis) (1996). Modelling the hydrology of vegetation competition in a degraded semiarid environment. *Unpublished PhD thesis*, Department of Geography, King's College London, University of London.

Mulligan, M., & Thornes, J.B. (in press). Catena versus cellular approaches to hydrological modelling through the plant community in seasonally dry and dry environments. *Journal of Hydrology*.

Nicolau, J.M., Sole-Benet, A., Puigdefabregas, J. & Gutierrez, L. (1996). Effects of soil and vegetation on runoff along a catena in semiarid Spain. *Geomorphology* **, 14:** 297-309

Pilgrim, D.H., Chapman, T.G., Doran, D.G. (1988). Problems of rainfall-runoff modelling in arid and semiarid regions. *Hydrological Sciences Journal*, **33:** 379-400

Poesen, J., Ingelmo-Sanchez, F., & Mucher, H. (1990). The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer. *Earth Surface Processes and Landforms*, **15:** 653-671.

Poesen, J., & Lavee, H. (1994). Rock fragments in top soils: Significance and processes. *Catena*, **23:** 1-28.

Puigdefabregas, J., Barrio, G., Boer, M.M., Gutierrez, L. & Sole, A. (1998). Differential responses of hillslope and channel elements to rainfall events in a semi-arid area. *Geomorphology*, **23:** 337-351.

Rallison, R.E., & Miller,N. (1982). Past, present and future SCS run off procedure. In: *Rainfall-runoff relationship*. Proceedings of the international symposium on rainfall-runoff modelling. Mississippi State University. pp 353-364.

Simanton, J.R., Renard, K.G., Christiaensen, C.M., Lane, L.J., (1994). Spatial distribution of surface rock fragments along catenas in semi-arid Arizona and Nevada, USA. *Catena*, **23:** 29-42.

Suleman , S., Wood, M.K., Shah, B.H., & Murray, L. (1995). Rainwater harvesting for increasing livestock forage on arid rangelands of Pakistan. *Journal of Range Management*, **48:** 523- 527.

van Wesemael, B., Poesen, J., Sole Benet, A., Barrionuevo, L.C. & Puigdefabregas, J. (1998). Collection and storage of runoff from hillslopes in a semi-arid environment: geomorphic and hydrologic aspects of the aljibe system in Almeria Province, Spain. *Journal of Arid Environments*, **40:** 1-14.

van Wesemael, B., Mulligan, M., & Poesen, J. (submitted). Spatial patterns of soil water balance on intensively cultivated hillslopes in a semiarid environment: the impacts of rock fragments and soil thickness.

Yair, A. (1983). Hillslope hydrology water harvesting and areal distribution of some ancient agricultural systems in the northern Negev desert. *Journal of Arid Environments*, **6:** 283-301.

EVALUATION OF THE RISK OF SOIL DEGRADATION USING BOOLEAN AND FUZZY LOGIC THEORY TECHNIQUES

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Abstract. Conventional methods of soil evaluation use boolean logic in order to determine soil suitability classes, ignoring the continuous nature of soil and landscape variation and uncertainties in measurement of soil properties. The boolean maps were compared with those produced by fuzzy logic theory techniques. Fuzzy logic is a generalization of boolean algebra to situations where the class boundaries are not or cannot be sharply defined. In this study three soil properties: pH, organic matter and electrical conductivity were used in order to evaluate the risk of soil degradation.

Key words: Geographical information systems, Soil degradation, Fuzzy sets, Membership grade.

Study area

The area whose soils were evaluated for the risk of degradation covers a part of 4.000 ha near the city of Amfilochia in Western Greece. According to Soil Taxonomy the majority of soils (90%) are classified as Entisols while the rest 10% as Inceptisols (fig 1). For this area analytical data were taken from 130 borings with mean distance between them 300-500 m.

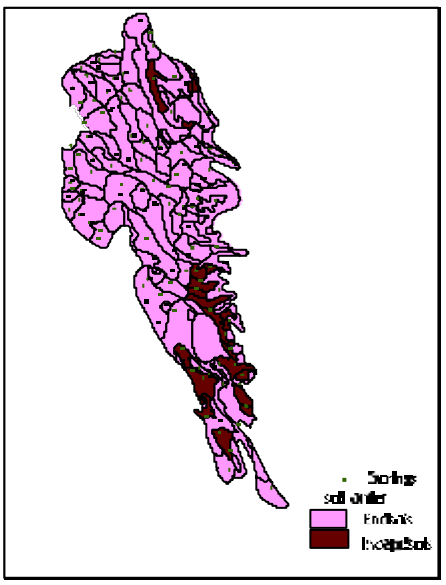


fig. 1

Geostatistical analysis

The values of the soil properties at not measured points were estimated using Kriging geostatistical interpolation which is provided by G.I.S. ARC/INFO software. The values of each soil property were interpolated to a regular grid of 149 x 343 cells with cell size 40 x 40 m. The exponential model was fitting to the experimental semi-variogram (fig. 2).

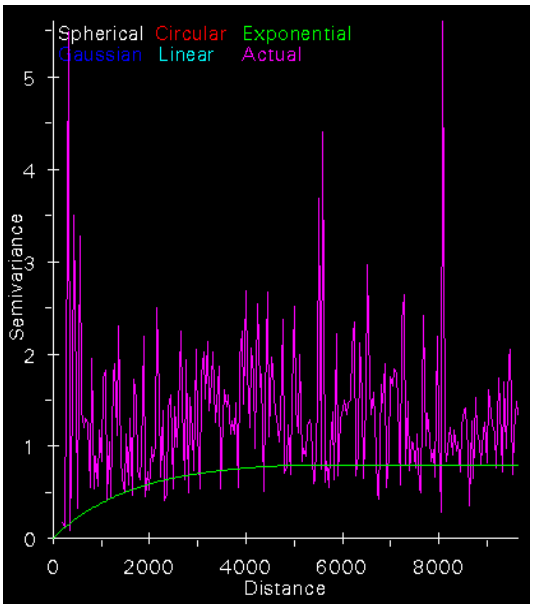


fig. 2

The soil properties

To determine the risk of degradation three soil properties were used: pH, organic matter and electrical conductivity. In some parts of the area, specific soil conditions such as lows values of pH or organic matter or high values of electrical conductivity in conjunction with prolonged intensive agriculture lead to soil degradation and make these soils unsuitable for agricultural use.

Evaluation of the risk of soil degradation

To identify the soils at risk the following conditions must be satisfied.

Soil properties	range of values
pH	≤5
organic matter	≤2%
electrical conductivity	≥2,5mmhos/cm

Boolean theory

First, a grid for each soil properties was produced using kriging interpolation. The pixels of the grids have the value 0 if the above specified conditions are not satisfied and value 1 when the conditions are satisfied. These grids were combined to one using boolean algebra (fig.3) in which black colour (pixel value = 1) present the soils at risk of degradation.

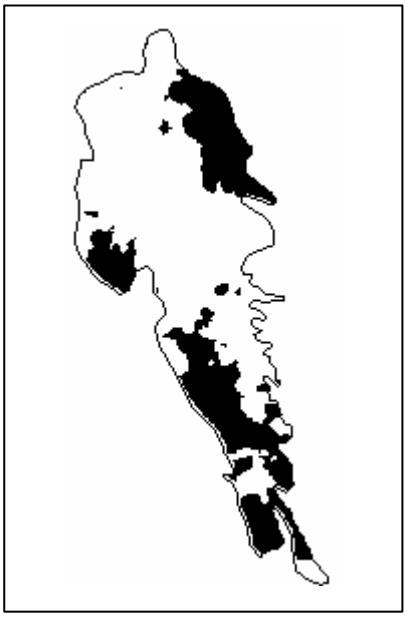


fig. 3

Fuzzy theory

Conventional methods of soil classification and land evaluation cannot deal with queries which are inaccurate, incomplete or inappropriate. Methods of fuzzy approach have used in soil survey as a means for dealing with inexact concepts.
Fuzziness is a type of imprecision characterizing classes that for various reasons cannot have or do not have sharply defined boundaries. These inexactly defined classes are called fuzzy sets. Fuzzy set theory is a generalization and not a replacement for the Boolean algebra.
Conventional or crisp sets allow only binary membership functions (true or false) but the fuzzy theory admit the possibility of partial membership so they are generalizations of crisp sets to situations where the class boundaries are not or cannot sharply defined.
Therefore, the boolean membership functions with values 0 or 1 are replaced with fuzzy membership function with a range of values between class interval [0, 1]. The membership function should ensure that the grade of membership is 1 at the center of the set (between the boundaries which have defined from the query e.g. $pH \leq 5$) and takes the value 0.99 to 1 outside the boolean boundaries. The point where the grade of membership is 0.5 called the cross-over point.

There are several suitable functions that can be used for defining flexible memberships grades, which can be easily adapted to specific requirements. The function that is used for the organic matter in this study is the following and it is graphically given in fig. 4.

$$\mu_A(x) = \frac{1}{1+\left(\frac{x-c}{d}\right)^2}$$

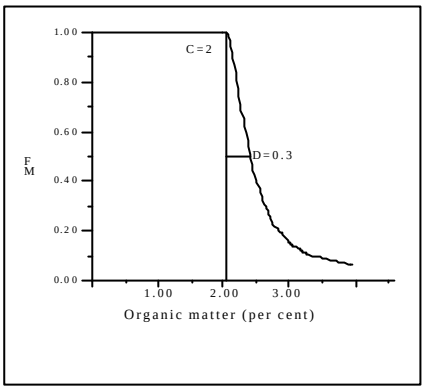


fig. 4

where c defines the value of the property at the central concept, and d is a parameter defining the width of the function at the point with membership grade is 0.5.
The membership functions and the values of the soil properties that were used for the calculation the fuzzy membership grades are given in the following table:

	range of value	distance	membership grade	membership function
pH	< 5	d = 0.5	1	$\mu_{pH}(x)=\frac{1}{1+\left[\frac{x-5}{0.5}\right]^2}$
organic matter	< 2	d = 0.3	1	$\mu_{org.}(x)=\frac{1}{1+\left[\frac{x-2}{0.3}\right]^2}$
elect.conductivity	≥2,5	d = 0.7	1	$\mu_{el.con}(x)=\frac{1}{1+\left[\frac{x-2.5}{0.7}\right]^2}$

The fuzzy sets that were produced using the functions are presented in figure 5 for the pH and in figure 6 for the organic matter.

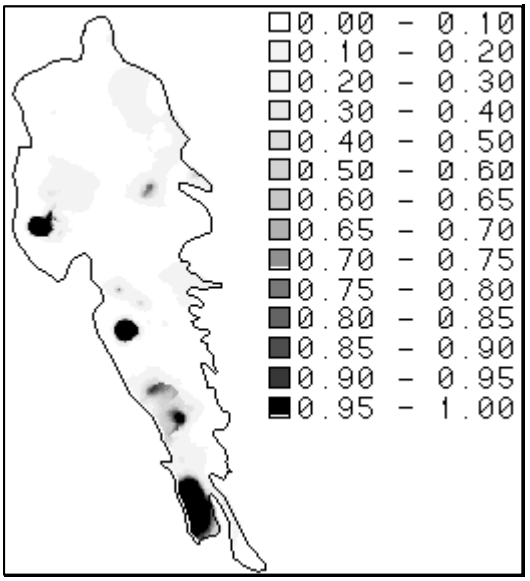


fig. 5

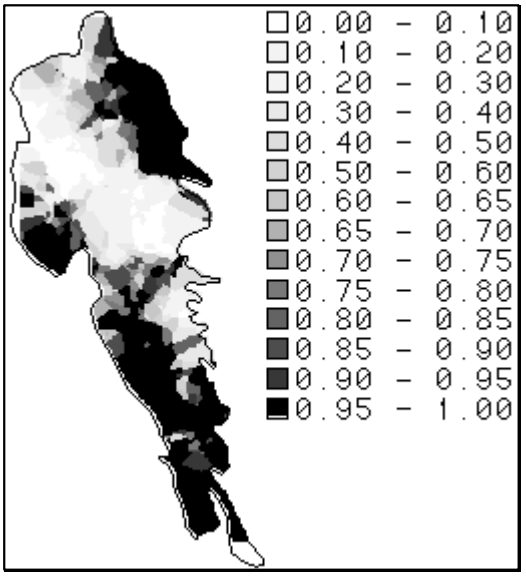


fig. 6

The above fuzzy sets show that soils where the value of pH is less or equal to 5 and organic matter less or equal to 2% take membership grade 1 and the soils with pH>5 and organic matter>2% take membership grades vary 0 to 0.99. Values near to central concept take membership grades close to 1.
The three fuzzy sets were combined in one called “fuzzy map” (fig. 7) whose each pixel was assigned the maximum from the three membership grades.

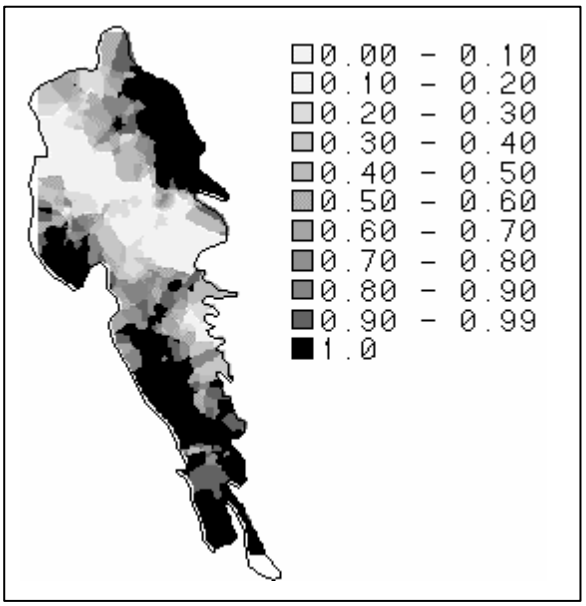


fig. 7

The colour of the fuzzy map ranges from stippled white to black. The areas with black colour (the membership grade equal to 1), have high risk of degradation. Darker tones indicate areas which are closer to the defined boolean requirements. Comparing the two maps produced by Boolean (fig. 3) and Fuzzy logic (fig. 7) theories we can see that the areas which have risk of degradation coincide in the two maps and they are showed with black colour. Additionally the fuzzy map shows areas with various levels of risk of degradation which cannot be defined with Boolean classification techniques.

Conclusions

Boolean algebra with strict true/false logic is often inappropriate for soil survey and soil evaluation because of the continuous nature of soil properties. According to the membership function fuzzy set theory can assign membership grades to the soils depending on their clossiness to the defined boolean requirements.
Both boolean and fuzzy operations give the same results with respect to extremes but in fuzzy sets there are soils with a risk of degradation (small to medium) that were rejected from boolean theory.
The applications of the fuzzy theory to the continuous variables, such as soil properties, is clearly a better approximation of reality than the crisp boolean approach.

References

Burrough, P.A., 1989. Fuzzy mathematical methods for soil survey and land evaluation. Journal of Soil Science, 40, 477-492.

Burrough, P.A., MacMillan, R.A., Van Deursen, W., 1992. Fuzzy classification methods for determining land suitability from soil profile observations and topography. Journal of Soil Science, 43, 193-210.

ESRI, 1997. ARC/INFO ver. 7.1.1, ESRI, Redlands, California.

Kollias, V.J., Voliotis, A.,1991. Fuzzy reasoning in the development of geographical information systems: FRSIS: a prototype soil information system with fuzzy retrieval capabilities. Int. J. Geographical Information Systems, 5, 209-223.

Kollias, V.J., Kalivas D.P., 1998. The enhancement of a commercial geographical information system (ARC/INFO) with fuzzy processing capabilities for the evaluation of land resources. Computers and Electronics in Agriculture, 20, 79-95.

Tsoulouchas, F., Trikatsoula, A.,Vavoulidou, E., Theocharopoulos, S., 1996. Soil survey of Amfilohia of Perf. Aitoloakarnania. National Agricultural Research Foundation, Athens, Greece, 170 pp (in Greek).

Zadeh, L.A., 1965. Fuzzy sets. Inf. Control 8, 338-353.

Zadeh, L.A., 1978. Fuzzy sets as a basis for theory of possibility. Fuzzy Sets Syst. 1, 3-28.

Zemankova-Leech, M., Kandel, A., 1984. Fuzzy relational databases – a key to expert systems. Rhineland, TUV, 180 pp.

DESERTIFICATION - THE HUMAN DIMENSION

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Abstract. The human dimension is a multi-layered process of human-environment interaction, including contributing to environmental degradation, designing and implementing mitigation measures. This paper is a preliminary exploration of the components of the human dimension that need to be investigated in order to comprehensively understand the human-environment relationship.

Key words: desertification, environmental management, policy design, policy implementation.

Chapter

Research into desertification has firmly focused on why, where, and to what degree it is occurring. The causes and processes of desertification have been clearly subdivided into 'physical' and 'human' processes (Perez-Trejo, 1992; Barrow, 1994; Thomas et al., 1995). In light of the signing and ratification of the Convention to Combat Desertification in 1998 by the European Union, policy formulation in relation to desertification is the next step. This paper, a preliminary exploration of the human dimension of desertification, emphasises analytical clarification over critical evaluation. The objective is to highlight the key issues that need to be considered when researching the human dimension, when designing and implementing policy. Drawing on social science theory a preliminary analytical framework/research methodology will be proposed to ensure an extensive analysis of the human dimension of desertification is conducted. It should be noted that the proposed framework/methodology does not claim to be comprehensive. Within the remit of this paper it will not been possible to account for all spatially and temporally specific factors which significantly influence the human dimension.

Desertification can be the consequence of a complex amalgamation of hidden and apparent causes (Warren & Maizels, 1977). Few would contest the statement that more is know today about the physical and human causes and processes of desertification than ever before (Brandt and Thornes, 1996; Mariota et al., 1998). However, even though there appears to be similar processes and causes at work in diverse regions, the reality may be very different, and interpretation needs caution (Spooner & Mann, 1982:5; Dregne, 1983:96), particularly in regard to the human dimension. Two clear reasons for prudence are evident. Firstly, there are often 'feedback mechanisms', which cause a web of causation/feedback/causation, such that a physical cause may lead to a human feedback and that to further physical causes or vice versa (Barrow, 1994). Secondly, research has failed to extensively investigate the influence of the political, social, cultural and economic variables, accounting for their spatial and temporal specificity.

The human dimension referred to in this paper is defined as, identifying and understanding the multi-layered process of human-environment interaction and proposing appropriate sustainable land use policies and environmental management strategies.

The failure of research to-date to have comprehensively examined the human dimension of the desertification process presents a number of concerns with regard to policy formulation. The EU embraces a group of structurally and culturally diverse countries, characterised by distinct political, socio-cultural and economic systems. A wealth of social scientific research clearly illustrates the relationship between these variables and the success of a government policy (Mann, 1980; Lipsky, 1980; Ripley, 1982, Winter, 1990). Failure to take account of these differences within policy design and implementation increases the likelihood that the aims and objectives of the programme will not be met. Lessons can be learnt, in regard to researching the human dimension appropriately, from environmental management and policy implementation theory.

Environmental Management (EM) is "*a multi-layered process associated with the interaction of state and non-state environmental managers with the environment and each other. Environmental managers are those whose livelihood is primarily dependent on the application of skill in the active and self-conscious, direct or indirect, manipulation of the environment with the aim of enhancing predictability in a context of social and environmental uncertainty"* (Wilson and Bryant, 1997). The definition set out above demands a wider definition of which actors are environmental managers. Table 1 sets out, in a simplified form, the main types of environmental managers. EM emphasises the need for interdisciplinary understanding of human-environment interaction and the nature of knowledge construction. EM presents a clear guide as to the groups that need to be researched and the forces that influence their behaviour.

Policy implementation theory, in contrast, offers insight into the execution process of a policy and presents a clear analysis of the relative power of individual actors involved in the implementation process. Policy implementation theorists have identified key variables that determine the outcome of a policy (Table 2). In order to ensure that the desired outcome is achieved the key determinants need to be clearly understood. Winter (1990) states that the relationship between the key factors is dependent on the specific policy being addressed and its socio-economic and political location.

Traditionally, research has been dominated by "policy advisers and scientific experts" and characterised by a highly quantitative and positivist scientific approach. The dominant rationale is to provide advice to the state and to offer a product usable by the state. These explanations are dominated by risk assessment, *"using data, assumptions, and models to estimate the probability of harm to human health or to the environment that may result from exposures to specific hazards"* (Miller, 1994:533; see also Brown et al., 1995, Adams, 1995). These accounts do little than mearly 'pay lip service' to the human dimension. The utility of such findings is limited as they fail to include a description of the totality of social and environmental conditions that influence EM practice, policy design and policy implementation. All facets of the problem are not being addressed (Wilson and Bryant, 1997).

The merging of these two frameworks raises a number of pertinent questions that must be addressed if the human dimension is to be accurately understood and accounted for when designing and implementing policy. It is these questions that form the basis of the framework/methodology being proposed.

Environmental managers	Examples	Level of environmental interaction
State	Department of the Environment Department of Forestry Ministry of Agriculture	Actively and self-consciously manage the environment at the local, national and global levels
Environmental NGOs	Greenpeace Friends of the Earth Haribon (Philippines) National Farmers Union (UK)	Active and self-conscious role influencing decisions about EM at the local, national and global levels
TNCs	Rio Tinto Zinc Monsanto Siemens Unilever	Actively and self-consciously manage the environment at the local, national and global levels
International financial institutions	World Bank International Monetary Fund Asian Development Bank	Active and self-conscious role in influencing decisions about EM at the local, national and global levels
Farmers, fishers, nomadic pastoralits, shifting cultivators	Farmers in the UK Spanish fishers Buroro nomads (Africa)	Actively and self-consciously manage the environment at the local and regional levels
Hunter-gatherers	Penan (Malaysia) Yanomami (Brazil)	Actively and self-consciously manage the environment at the local level

Source: adapted from Wilson and Bryant, 1997:8.

Table 1: Key types of environmental managers.

1. The character of the policy formation process prior to the law or decision to be implemented.
2. The political system
3. The legal system
4. The organisational and interorganisational implementation behaviour
5. Street-level bureaucratic behaviour
6. The response by target groups and other changes in society

Source: adapted from Winter, 1990.

Table 2: The key variables that determine implementation outcome.

Analysis of human-environment interaction must consider four principle components. Firstly, the human causes and processes that contribute to environmental degradation, exemplified by, exploitation for agriculture, inappropriate technology and policy restraints (Chambers et al., 1989; IIED, 1993; Cummings, 1997). Secondly, identify the main actors implicated in these causes and processes, for example, the Ministry of Agriculture, National Farmers Union, individual farmers and TNCs (Chambers, 1992;

Wilson and Bryant, 1997). Furthermore, the social, cultural, economic and political forces that affect current land management practice on local, regional, national and EU levels, such as, traditional land management practices, economic development policy and the Common Agricultural Policy (Blaikie, 1985; Lowe et al., 1986; Palumbo and Calista, 1990; Walker and Mendlovitz, 1990; Whitby and Lowe, 1994). Finally, the main actors implicated in land management decisions, for example, the Forestry Department, the Ministry of Agriculture and Directorate General VI of the EU (Welford, 1996; Wilson and Bryant, 1997).

Research with the purpose of informing future proposals for sustainable land use policies and environmental management strategies must, in addition, determine the legal and political mechanisms at the disposal of the policy makers. Moreover, at the local, regional, national and EU levels the actors that will be involved in the implementation process of the policy or strategy being proposed must be ascertained. Consultation with each group of actors will have the added advantage of empowering all those involved with the policy or strategy. Actors are reported to benefit considerably from being consulted particularly in relation to understanding their contribution to environmental degradation and of the mitigation measures being proposed (Lipsky, 1978; Blaikie and Brookfield, 1987; Hjern and Hull, 1982). This has the potential to prevent future obstacles to successful implementation such as actors choosing not to participate in the programme. Evidence suggests that failure to sufficiently structure the policy and implementation process results in a 'policy-implementation gap' where local EM actors often deflect centrally planned programs towards their own ends, conflicting with the policy designers intent (Berman and McLaughlin, 1976; Ingram, 1977; Elmore, 1978; Lipsky, 1978, 1980; Barrett and Fudge, 1981). In addition, cross-referencing with other related local, regional, national and EU policies will ensure that unforeseen conflicts do not arise which could compromise the ability of the policy or strategy to achieve its aims and objectives. Failure to examine these issues thoroughly could result in implementation failure in certain regions or countries.

The philosophy of land degradation management has shifted from soil conservation to land husbandry (Hudson, 1992). Therefore, complex spatially and temporally specific uncertainties (environmental, political, socio-cultural and economic factors), all of which are pertinent to the decision-making process, must not be generalised (Blaikie, 1985; Blaikie and Brookfield, 1987; Wilson and Bryant, 1997; Palumbo and Calista, 1990). Methodologically, research into the human dimension, and particularly where results are intended to feed into policy design, needs to draw upon hitherto neglected qualitative techniques such as participant observation, in-depth interviews, rural rapid appraisal (RRA), participant rural appraisal (PRA) (Chambers, 1992), backward and forward mapping (Elmore, 1979), to establish the human-environment relationship of state and non-state environmental managers regarding desertification.

Policy design and implementation have been dominated by three analytical models: top-down; bottom-up; and the hybrid model. The top-down model advocates that as long as the conditions outlined in Table 3 are met, through legal and political mechanisms at the policy makers disposal, the actions of implementation actors can be controlled. Conversely, the bottom-up model advocates that it is the 'street-level bureaucrats', whom in most programmes perform the delivery and control functions, who are responsible for the failure or success of a programme (Lipsky, 1980). The hybrid model addresses the criticisms of its predecessors. Table 4 sets out the key variables that it defends as determining implementation outcome.

1)	Clear and consistent objectives[1].
2)	Adequate causal theory[2].
3)	Implementation process legally structured to enhance compliance by implementing officials and target groups[3].
4)	Committed and skilled implementing officials[4].
5)	Support of interest groups and sovereigns[5].
6)	Changes in socio-economic conditions which do not substantially undermine political support of causal theory[6].

Table 3: Necessary conditions for the effective implementation of legal objectives.

1.	The character of the policy formation process prior to the law or decision to be implemented.
2.	The organisational and interorganisational implementation behaviour.
3.	Street-level bureaucratic behaviour.
4.	The response by target groups and other changes in society.

Table 4: The sets of key variables that determine implementation outcome.

Historically, the European Union (EU) has adopted a top-down approach within policy design and implementation. This paper asserts that the models described above are not comprehensive enough, avoiding potentially relevant factors. For desertification mitigation to be successfully achieved through EU policy EM needs to shift away from state-centred, bureaucratic, academic authoritarianism towards increased emphasis on grassroots actors, examining how all EM actors relate to the environment and to each other (Wilson and Bryant, 1997).

References

Adams J. (1995). *Risk*. UCL Press, London.

Bardach E. (1979), *The implementation game*. Cambridge (MA.): MIT Press.

Barrett S. and C. Fudge (eds) (1981), *Policy and action: essays on the implementation of public policy*. London: Methuen.

Barrow C.J. (1994). *Land degradation*. Cambridge University Press, Cambridge.

Berman P. and M. McLaughlin (1976), *Implementation of educational innovation.* The Education Forum, 40, pp 345-370.

Blaikie P. (1985). *The political economy of soil erosion in developing countries*. Longman, London.

Blaikie P. and Brookfield H. (1987). *Land degradation and society*. Metheun, London.

Brandt J. and Thornes J.B. (eds.) (1996). *Mediterranean Desertification and Land Use*. John Wiley & Sons, Chichester.

[1] For a more detailed explanation see Van Meter and Van Horn, 1975.
[2] For a more detailed explanation see Pressman and Wildavsky, 1973.
[3] For a more detailed explanation see Pressman and Wildavsky, 1973.
[4] For a more detailed explanation see Lipsky, 1978 and Lazin, 1980.
[5] For a more detailed explanation see Downs, 1967; Murphy, 1973; Bardach, 1979; and Sabatier & Mazmanian, 1979.
[6] For a more detailed explanation see Hofferbert, 1974; Aaron, 1978).

Brown V., Smith D.I., Wiseman R. and Handmer J. (1995). *Risks and opportunities: managing environmental conflict and change*. Earthscan, London.

Chambers, R. (1992a), *Rural Appraisal: Rapid, Relaxed and Participatory*. Institute of Development sStudies at the University of Sussex, Brighton.

Chambers R., Pacey A. and Thrupp L.A. (eds.) (1989), *Farmer first: farmer innovation and agricultural research*. Intermediate Technology, London.

Cummings F.H. (1997), 'Role of Participation in the Evaluation and Implementation of Development Projects', *The International Journal of Knowledge Transfer and Utilization*, 10, 1/2, 24-33.

Dregne H.E. (1983). *Desertification of Arid Lands*. Harwood Academic Publishers, Chur.Hudson (1992).

Elmore R.F. (1979). *Backward Mapping: Implementation Research and Policy Decisions*. Political Science Quarterly, 94(4), pp.601-616.

Elmore R.F. (1978). *Organisational models of social program implementation*. Public Policy, 26(2), pp.185-228.

Hjern B. and Hull C. (1982), *Implementation research as empirical constitutionalism*. European Journal of Political Research, 10, pp.105-116.

IIED (1993). RRA Notes 14 & 16, *Sustainable Agriculture Program*, International Institute for Environment and Development, 3 Endsleigh Street, London WC1H 0DD.

Ingram H. (1977), *Policy Implementation through bargaining: The case of federal grants-in-aid*. Public Policy, 25, pp 499-526.

Lazin F. (1980), *The effects of administrative linkages on implementation: Welfare policy in Israel*. Policy Sciences, 12.

Lipsky M. (1980), *Street-level bureaucracy: dilemmas of the individual in public services*. New York: Russell Sage Foundation.

Lipsky M. (1978), 'Standing the study of implementation on its head'. In Burhman, W.D. and D. Winberg (eds), *American politics and public policy*. Cambridge (Mass.): MIT Press.

Lowe P., Cox G., MacEwen M., O'Riordan T. and Winter M. (1986). *Countryside conflicts: the politics of farming, forestry and conservation*. Gower, Aldershot.

Mariota P., Thornes J.B. and Geeson N. (eds.) (1998). *Atlas of Mediterranean Environments in Europe: The Desertification Context*. John Wiley & Sons, Chichester.

Miller G.T. (1994). *Living in the environment: principles, connections, and solutions, 8th edn.* Wadsworth, California.

Palumbo D.J. and Calista D.J. (1990), 'Opening the black box: implementation and the policy process'.
In: Palumbo, D.J. and Calista D.J. (eds.) (1990), *Implementation and the policy process: opening up the black box*. Greenwood Press, Westport (Conn).

Perez-Trejo F. (1992). *Desertification and land degradation in the European Mediterranean*. The European Commission EPOCH programme, October 1992, Directorate-General XII, EUR 14850 EN.

Pressman J.L. and Wildavsky A. (1973), *Implementation: how great expectations in Washington are dashed in Oakland, or why its amazing that Federal programs work at all, this being the saga of the Economic Development Administration as told by two sympathetic observers who seek to build morals on a foundation of ruined hopes*. Berkeley: University of California Press.

Sabatier R.A. and Mazmanian D. (1979),*The conditions of effective implementation: a guide to accomplishing policy objectives*. Policy Analysis 5: 481-504.

Spooner B. and Mann H.S. (eds.) (1982). *Desertification and Development: dryland ecology in social perspective*. Academic Press, London.

Thomas D.S.G., Middleton N.J. and Naylor R.E.L. (1995). *Desertification: Exploding the myth*. Wiley, Chichester.

Van Meter D.S. and Van Horn C.E. (1975), *The policy implementation process: a conceptual framework*. Administration & Society, 6, pp 445-488.

Walker R.B.J. and Mendlovitz S.H. (eds.) (1990). *Contending sovereignties - redefining political community*. Lynne Rienner, Boulder (CO).

Warren A. and Maizels J. (1977). Ecological change and desertification. In United Nations (ed), *Desertification: its causes and consequences*. pp.169-260. Pergamon Press, Oxford.

Welford R. (ed.) (1996). *Corporate environmental management - systems and strategies*. Earthscan, London.

Whitby M. and Lowe P. (1994). 'The political and economic roots of environmental policy in agriculture'. In Whitby M. (ed.) (1994), *Incentives for countryside management: the case of environmentally sensitive areas*. CAB International, Wallingford, pp.1-24.

Wilson G. and Bryant R. (1997). *Environmental Management: New Directions for the Twenty-First Century*. UCL Press, London.

Winter S. (1990). 'Integrating implementation research'. In: Palumbo, D.J. and Calista D.J. (eds.) (1990), *Implementation and the policy process: opening up the black box*. Greenwood Press, Westport (Conn), pp. 19-38.

DESERTIFICATION IN CHINA

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Abstract. This paper introduces the subject of desertification in China including its causes, consequences, classification and distribution. The paper also discusses strategies and techniques used to combat desertification.

Key words: Desertification, land degradation, China

Introduction

"Desertification" means land degradation, a process of reduction or loss of the biological or economical productivity and complexity of rainfed cropland, irrigated cropland, range, pasture, woodlands and forest in arid, semi-arid and dry sub-humid areas resulting from various factors including climate variations and human activities. Land degradation can be one of the following forms:

- soil erosion caused by wind and/or water;
- deterioration of the physical, chemical and biological or economic properties of soil;
- long-term loss of natural vegetation (UNEP, 1997).

Desertification is one of the major environmental issues around the world. It is estimated that about one sixth of the world's population and one quarter of the global terrestrial land is threatened by desertification (UNCED, 1994). Desertification has a great impact on the environment on which people's life and existence rely in many developing countries and it is a significant factor leading poverty and preventing economic and social development in a sustainable way.

China is a developing country with the largest population in the world over 1.2 billion and it is also one of the countries affected most seriously by desertification. The affected area is about 3.317 million km^2, accounting for 34.6% , approximately one third of the nation's land area with around 400 million people being under the threat of desertification. Desertification is widely distributed in arid, semi-arid and dry sub-humid areas of the Northwest China, North China and the western part of Northeast China (CCICCD, 1996). The ecological system is fragile and the environment is damaged seriously in the above areas. China is being challenged by the dual tasks of economic development and environmental protection. With the daily-increasing pressure of population and demand of natural resources for rapid economic development, the situation of land degradation/desertification is accelerating and becoming worse. This adverse affect of desertification brings serious threats and damage to the regional/local environment and socio-economic development and to local people's livelihood. How to undertake sustainable development strategy and take effective measurements to combat desertification and ensure the economic development is a big issue for China.

Causes and consequences of desertification in China

Causes of desertification

Desertification is the combined results of interactions between various natural and human factors, and it is mainly caused by human activities and climatic variations. The processes of desertification associated with the physical geographical features and climatic variations are slow, but human activities have accelerated desertification processes (CCICCD, 1997a).

Human activities

The increasing population and its greater pressure on land resources are the ultimate driving force behind the desertification. Human activities can be one of the following forms:

- overgrazing of arid rangeland ;
- extensive management of rainfed farming ;
- blind reclamation and overcultivation;
- irrational utilization of water resources;
- excessive collection of firewood and herbal medicine plants;
- illegal cutting of timbers and deforestation;
- unplanned mining activities

Overgrazing is the major cause of rangeland degradation. In the Inner Mongolia Autonomous region, the area of seriously degraded rangeland is more than 133,000 ha under the pressure of serious overgrazing, and consequently, 175 households of herdsmen in 4 township and communities have been forced to migrate into other regions. It is estimated that the actual carrying capacity of animals per ha is far beyond the theoretical carrying capacity in many parts of rangeland in arid, semi-arid and dry sub-humid areas (Zhu G. Y, 1996).

On the Loess Plateau with undulating topographic features, the cultivation of steep slopes is the main factor leading to land degradation. On the basis of field observations, the annual loss of top soil on the fields with less than 5^{o} of slope is approximately 15 t/ha, and the annual loss of top soil of the fields with slope of 25^{o}, is 120 - 150 t/ha. There is no soil loss on the terraced field (CCICCD, 1997a). According to information of the national integrated survey on deserts, Gobi and desertification , the average population density in arid, semi-arid and sub-humid arid areas in some provinces and autonomous regions in North China is 24 persons/km^2, which exceeds the threshold of the carrying capacity of human population of such environments.

Illegal collection of firewood and unwise collection of herb medicines and deforestation are human activities which directly cause land desertification. In Qaibam Basin, there were more than 2 million ha. of natural vegetation which played an important role in fixing sand, but more than one third of this vegetation has been destroyed by firewood collection since the middle of the 1980's. It is estimated that the annual requirement of firewood in the desertification -prone land areas in Xinjiang Uygur Autonomous region is 3.5 - 7 million tons, and thus a large area of desert vegetation has been destroyed.

Poorly planned irrigation methods are the direct cause of secondary salinization of arable land where there are 50% of arable lands on the irrigated Hetao Plain (Grand Bay of the Yellow River) that have been degraded into secondary salinization affected lands. It is estimated that 66% of the degraded arable land area in arid, semi-arid and dry sub-

humid areas in Hebei province have been degraded into secondary salinization affected lands under the impacts of these practices. (CCICCD, 1996).

Natural factors

Geographic environment factors

The arid, semi-arid and dry sub-humid area in China are located in the inland of the continent. The long distance to oceans and the mountain ranges, particularly the uplifting of Qinghai-Tibet plateau have blocked the movement of water vapour from oceans. and consequently, these mentioned areas have been turned into the driest parts of China with fragile eco-systems, the least precipitation and the highest evapotranspiration compared with other continental land at the same latitude.

The worst affected area is located in the centre of a high pressure anti-cyclone on Siberia and Mongolia, frequent strong winds from west to east and north to south form suitable conditions for wind erosion; and locally the undulating landform, thick and loose sandy soil and high –intensive thunder storms have promoted and accelerated the processes of water erosion. As a result, the transitional zone between north Loess Plateau and Ordos Plateau and the central west parts of the Loess Plateau have been turned into the most serious desertification -prone lands under the impacts of water erosion. The extreme doughtiness at large scale and the local distribution of low-lying depressions with poor drainage systems, the sparse precipitation and high evapotranspiration have promoted soil salinization .

Climate factors

Precipitation in some parts of the arid, semi-arid and dry sub-humid areas in China is being reduced in the recent four decades. Temperature in other parts of the mentioned affected regions increased, and consequently, the evapotranspiration potential is being accelerated and formation of soil salinization is being deteriorated by the above mentioned tends. In recent years, sand-dust storms are a frequent occurrence in Northwest China and North China..

Consequences of desertification

Desertification has brought about adverse effects on people's livelihood and restricted sustainable economic and social development of the desertified areas. It leads to the shrinkage of usable land, decline in land productivity, deterioration of farming conditions and serious threats to farmland, pastureland, towns, villages, communication lines and water conservancy facilities. Over 13 million ha. Of farmland are vulnerable to damage of desertification, with low and unstable crop yield, farmland degeneration rate of over 40% and grassland degeneration rate of 56.5% (CCICCD, 1996).

Desertification has brought about deterioration of the environment. The damage to vegetation has increased the occurrence of sand storms and the silt flow into rivers. Desertified land with water erosion problems totals about 200,000 km^2 in the northern part of the Loess Plateau (arid and semi-arid areas). Silt flow into the Yellow River has made the riverbed in the lower reaches rise 5-10cm. Annually. Part of the riverbed in the lower reaches is over 10 meters higher than the ground, thus becoming a river over the ground and imposing a serious threat to life and property security of local people in the lower reaches of the Yellow River (Zhu, G.Y, 1996).

Desertification is the root of poverty and the obstacle to sustainable economic and social development. The desertified areas in China are also the most concentrated areas of

impoverished population. According to provisional estimates, the direct economic loss caused by desertification in China reaches up to US $6.5 billion, and the indirect economic loss is double or triple this.

Classification and distribution of desertification

Classification of Desertification

The desertification is divided into five types according to the major external movement forces to cause desertification process.

- desertification caused by wind erosion
- desertification caused by water erosion
- desertification caused by freezing and melting process on cold plateau
- desertification caused by soil salinization
- desertification caused by other interacting factors

Classification of climate type of desertification

Arid, semi-arid and dry sub-humid areas mean those regions where the ratio of annual precipitation to evapotranspiration is between 0.05 and 0.65. (UNCED, 1994). The ratio is called the moisture index. The indicators of the classification of climate types for desertification are listed in table 1.

Based on these indicators, the total area of arid, semi-arid and dry sub-humid areas, the geographic scope where the occurrence of desertification is possible is approximately 3.317 million km^2, occupying 34.6% of the total territorial area of China. In which, the arid area is 1.427 million km^2, the semi-arid area is 1.139 million km^2 and dry sub-humid area is 0.751 million km^2 (table 2). The arid, semi-arid and dry sub-humid areas in China are widely distributed in most parts or some parts of 471 counties in 4 autonomous regions (Xinjiang, Inner Mongolia, Tibet and Ningxia), 12 provinces (Qinghai, Gansu,Hebei, Ningxia, Shaanxi, Shanxi, Shandong, Liaoning, Sichuan, Yunnan, Jilin, Hainan, Henan) and 2 cities (Beijing and Tianjin) (Map 1). Inside these geographic locations, the actual existing area of desertification affected land area (ie, the total area of desertification affected land are of China) is 2.622 million km^2 (CCICCD, 1997a), occupying 79.0% of the mentioned geographic locations or 27.3% of total territory of China (Map 2).

Climate type	Moisture index (MI)
Extreme arid area	MI <=0.05
Arid Area	0.05<MI<0.20
Semi-arid Area	0.20<MI<0.50
Dry sub-humid area	0.50<MI<0.65
Humid area	MI>0.65

(Source: CCICCD, 1997a)

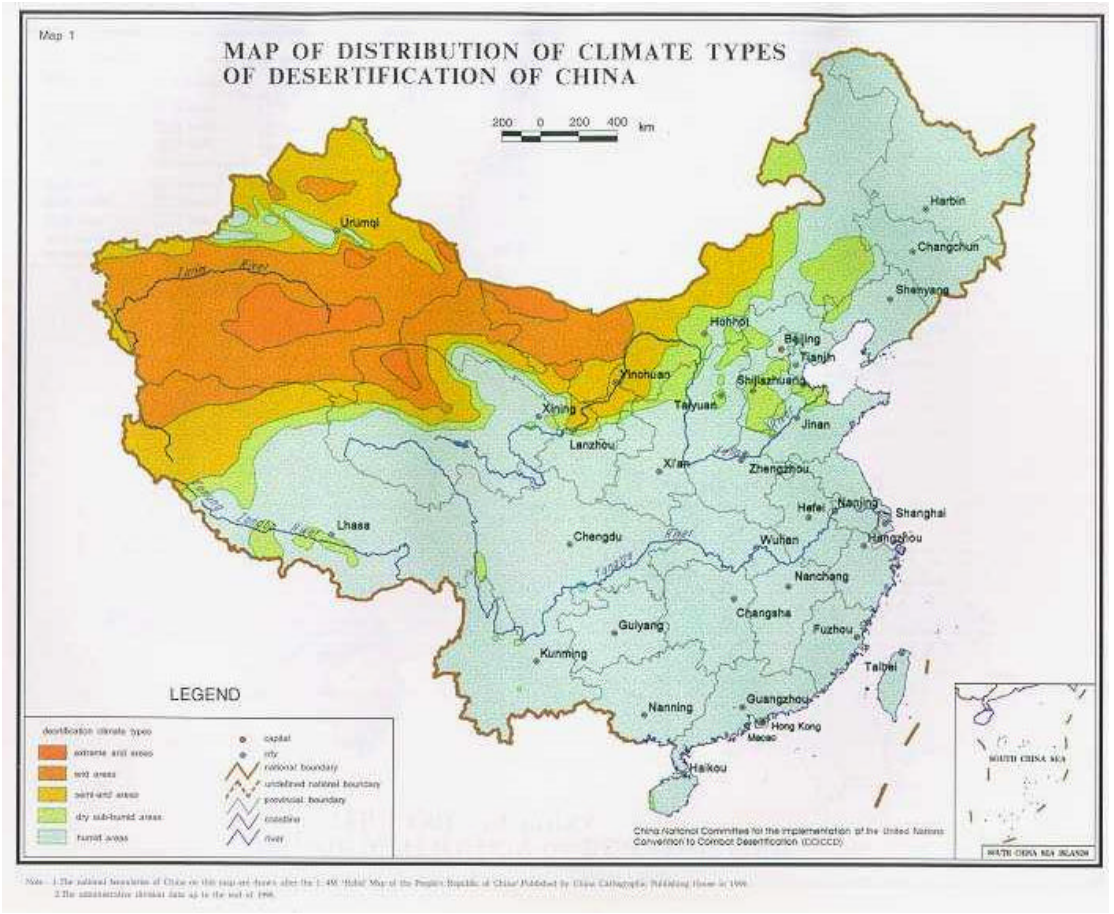
Table 1: Indicators of classification of climate type of desertification

Unit: 10^3 km^2

Types	Arid area	Semi-arid area	Dry sub-humid area	Total
Area	1,427	1,139	751	3,317
percent in total affected area	43.1	34.4	22.5	100
percent of total land area	14.9	11.9	7.8	34.6

(Source: CCICCD, 1997a)

Table 2: The areas of arid, semi-arid and dry sub-humid area of China



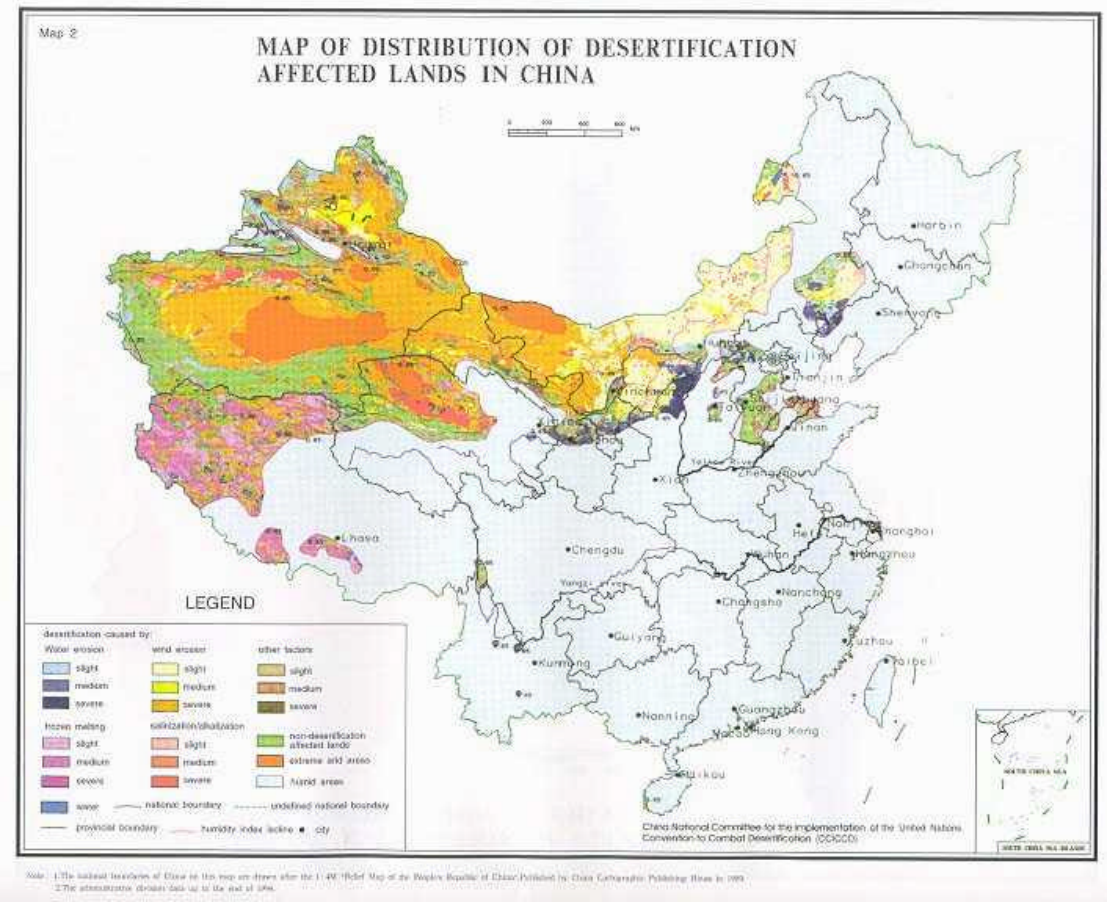
(Source: CCICCD, 1997)

Map 1: Distribution of Climate Types of Desertification in China

The distribution of desertification affected land areas in China crosses vertically in a range of several thousands meters from sea level to cold desert at plateau upland. Broad territory and diversities of climate types and landform types create leading factors to desertification. Water erosion, wind erosion, freezing and melting processes and their denudation, soil salinization exist everywhere and consequently the patterns of desertification in China complex and diversified.

In light of classification of leading factors , the area of desertification caused by wind erosion is 1,607 million km^2 ; the area of desertification caused by water erosion is 0.205 million km^2; the area of desertification caused by freezing and melting processes is 0.363 million km^2; the area of desertification caused by soil salinization is 0.233

million km^2; and the area of desertification caused by other prevailing factors is 0.214 million km^2 (table 3) (CCICCD, 1999a).



(Source: CCICCD, 1997)

Map 2: Distribution of Desertification In China

Unit: 10^3 km^2

Types	Area	Percent in total affected area (%)
Wind erosion	1,607	61.3
Water erosion	205	7.8
Freezing and melting		
Processes	363	13.8
Soil salinization	233	8.9
Others	214	8.2

(Source: CCICCD, 1997a)

Table 3: The areas of different classification of desertification of China

Fundamental strategies and techniques to combat desertification

Raising public awareness and education to combat desertification

The spreading tendency of desertification is difficult to control. The situation is that desertification rehabilitation coincides with spreads of desertification. Desertification has been controlled at particular sites, but been expanded in the entire area. The main reasons are the lack of public awareness to combat desertification. The short-term

activities driven by greed have not been linked with the long-term health of the environment. Therefore, it is necessary to carry out long-term and lasting publicity and education. Meanwhile special attention and concerns should be made to the prevention and rehabilitation of those lands withoud risk of desertification and degradation or those lands that have been slightly degraded or desertified.

Consolidaton of legal knowledge, enforcement and improvement of laws and regulations.

The continuation of the spread of desertification caused by human factors is related to the paucity of the legal framework. It is essential and necessary to adopt the legal means to limit and standardise people's behaviours. Therefore, it is needed to propagate and execute existing laws and regulations, i.e. "grassland Law", "land Law", "Environmental Protection Law" etc. to increase legal sense at all levels.

Achievement and experiences in combating desertification in China.

China began combating desertification as early as the 1950s. The government organized people to harness the areas affected seriously by dust stores, water and soil erosion and soil salinizaton as a priority task. Since the 1980s, it worked out and implemented a series of guidelines , policies, laws and measures associated with combating desertification in the 1980s and a series of key ecological projects were started undertaking comprehensive control over desertification with remarkable results achieved. In "Three North" (northwest, north, and northeast of China) areas 16.63 million ha. of plantations were established increasing the forest cover from 5.05% in the late 1970's to the present 9% and bringing 10% of desertifed land under control. 11 million ha. of farmland was brought under effective protection which increased the food production (Zhu, G.Y, 1996). The comprehensive exploitation and use of resource in sandy areas, such as wind energy and solar energy, has been developed in several places. Through prevention and control over desertification, the environment in some places has been improved dramatically which facilitates local economic and social development and improves gradually the living standard of people living in desertified areas. Since the signing of the United Nations convention to combat desertification, the Chinese government has made further efforts to combat desertification, bringing desertification combating into a new stage of scale treatment, effective control and steady development (CCICCD, 1997b).

Effective progress in the aspects of dune fixation, sand stabilization, rangeland improvement and soil water conservation have been made in the affected areas. Some acceptable and practical techniques successful demonstrations and rich experiences to combat desertification and manage dry lands have been developed at grassroots, community, local levels

Combating desertification can be summarised in three aspects : prevention; control and utilisation. It means that effective measures should be taken to prevent the occurrence and development of desertification; harness desertified land and utilise the natural resource in the desertified regions (CCICCD, 1997c).

There are several effective measures taken in China to combat desertification thought experiment in several decades .

- fixing sand by planting
- fixing sand by engineering work
- fixing sand by chemical methods

- water-saving techniques

(1) Fixing sand, by planting grass and trees is an effective and economic technique. Not only do plants fix sand in a long-term but also provide fuel and forage and help the rehabilitation and improve the ecological environment in the affected area. After several decade's continuous research great achievements have been made in prevention and control of desertification. Airbone-seed planting is a typical effective technique employed in combating desertification in china.

(2) Fixing sand by engineering techniques is another method. The engineering work involves setting up block or covering sand to block sand or let wind through on the sand surface using different kinds of available materials such as straw, clay, branches of trees and pebbles. This is another cheap and effective way and it has been used successfully along railways, highways and important mining cites threatening by running sand.

There are three different methods of engineering techniques. One method is to cover totally the sand surface and isolate the sand surface from wind by using straw, pebbles and clay. Another method is to set up barriers on the sand surface to decrease the wind speed and its affect. It can be implemented by self-covering strawed mess barriers, pebbles barriers and clay barriers. The straw-grid barrier is used widely in the sand region in the north of China. The third method is to block sand and let sand through and to block the upward wind to blow the sand in the areas or induce wind to the downward of protection areas preventing sand accumulation using fence, grid, fence-wall. The method is generally used in Gobi and desert area and as an outside barrier. One of successful examples is that this method has been employed along railways and highways in sand areas for over 40 years and ensures the train and cars go freely.

(3) Chemical techniques

The aim of this method is to form a layer of protection with some intensity on the sand surface to isolate the wind from the sand. This method is very efficient and it is generally used in the areas prone to be damaged greatly with high economic loss such as airports, railways, highways etc. It is combined with the plant measures and acts as a aide and transition measures to combat desertification.

(4) Water-saving techniques

Water shortage is one of the critical problems in desertified areas. Development of effective water-saving irrigation techniques is one of the important measures in combating desertificaiton. These techniques include preventing seepage in channel , water transport through low-pressure pipes, spray irrigation and micro-drop irrigation

(5) Integrated watershed management

On the Loess Plateau every small watershed is treated as a unit to take effective measurement to control soil erosion. Terraces are built on the slope for planting crop and fruit trees. The pits with the shape of fish-scale are dig in the steep for fruit trees. Barriers are added in the small gullies to slow down flood runoff and prevent the undercutting of the gullies; Silt arresters are constructed in most of the gullies to trap not only flood water not also eroded soil; Check dams are built in large gullies to retain major floods. When the flood water is drained the land filled with fertilised sediment can be used as cultivation land. In more densely populated areas, the gullies are built up in steps with warping dams to create a series of crop lands at the bottom of the gullies.

Conclusion

China has been suffering seriously from desertification resulting from climate variations but mainly from human activities. Desertification takes place widely in the arid, semi-arid and dry humid areas in Northwest China, northern parts of the North China and the western parts of the Northeast China ("Three North") and it has a great impact on local people livelihood and socio-economic development. Although some fundamental strategies and practical and economical practice have been implemented to combat desertification and achievements have been reached, it is still a tough task in China under the pressure of increasing population and demand of natural resources for rapid economic development. Attempts should be made to adopt powerful approaches to control and rehabilitate desertification.

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References

CCICCD, 1996, Country report on combating desertification, The Proceedings of the Asia-Africa Forum on Combating Desertification, Beijing.

CCICCD, 1997a, Country Report on Combating Desertification.

CCICCD, 1997b, Report on Urgency to Combat Desertification (in Chinese).

CCICCD, 1997c, Report on Analysis on Necessity to Combat Desertification (in Chinese)

UNCED, 1992. Earth Summit'92. The UN conference on Environment and Development. Rio de Janeiro.

UNCED, 1994. "United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa". New York.

Zhu, G. Y., 1996. Desertification combating in China. The Proceedings of the Asia-Africa Forum on Combating Desertification, Beijing.

A CONTRIBUTION TO THE ASSESSMENT OF LAND USE IMPACTS ON LAND IN MEDITERRANEAN AGROPASTORAL SYSTEMS. THE CASE OF THE BARONIE REGION (SARDINIA - ITALY)

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Abstract. In the Mediterranean environment the main causes of land degradation are urbanisation, semi-intesive exploitation of agricultural lands, overgrazing and the marked reduction in wooded areas (Mairota et al., 1997; UNEP, 1994).
In Sardinia, during the '80s the agricultural exploitation of unsuitable marginal areas to create new pastures was one of the most dangerous human activities for its high land degradation/desertification risk.
This paper presents an approach based on GIS methodology to assess man-induced land degradation/desertification risk due to the impact of agropastoral activities.

Key words: Gis, Land Evaluation, land degradation, agropastoral activities

Introduction.

Among the different agricultural activities, livestock breeding is considered one of the main causes of land degradation in the Mediterranean basin (van der Leeuw, 1998). The impact of animal production systems mainly depends on social and economic conditions: the major driving force is the shift from traditional to more and more intensive production systems.
During the last decades, in Sardinia, there has been a large increase in livestock numbers, resulted in a greater demands for forage production. Local agricultural policies have supported the creation of artificial pastures by means of amendment actions, the so called "pasture improvement actions", practices adopted to increase pasture productivity and to keep lands clear from shrubs: brush and stone removal, deep tillages by means of heavy machinery, and so on. Unfortunately, due to the lack of technical guidelines these interventions were often carried out on unsuitable lands using high impact techniques causing widespread land degradation phenomena due to overgrazing and overcultivation, particularly in slope areas.
In this context, the evaluation of both potentiality and vulnerability of the Land in relation to such kinds of actions, can be an effective tool to assess the potential impacts and to prevent degradation phenomena.
This work presents an approach based on GIS methodology to assess man-induced land degradation risk due to the creation of artificial pastures. The FAO Framework for Land Evaluation has been kept as methodological reference.
This study was part of the research activities that the NRD (Nucleo Ricerca Desertificazione) of the Sassari University carried out within the EC-MEDALUS III Project.

Material and methods

The study was carried out on an area (Fig. 1) of central eastern Sardinia (Municipalities of Irgoli, Onifai, Orosei) covering 21,000 ha. The area is representative of the marginal rural areas of the island, where agropastoralism is still the main economic activity.
A GIS was created for the whole area, via ARC-INFO software, by digitizing the pedological map and the multitemporal land cover maps of 1955 and 1996 (previously realised by the NRD at a 1:25000 scale) and by building the Digital Terrain Model (DTM). Aspect and slope layers were automatically derived from the DTM.
The methodology developed and applied can be described according to the following phases:

1_ analysis of the historical land cover dynamics, to highlight the increase of the anthropic pressure on land and the actual weight of the artificial pastures. The analysis has been carried out by overlaying the multitemporal land cover maps (1955 and 1996);
2_ evaluation of the "land suitability to the creation of artificial pastures" by means of a GIS-based model previously tested and validated (Zucca et al., 1998). The model calculates the cumulative Suitability Index (SI) by summing the suitability coefficients of seven variables:

$$SI = C_s+C_r+ C_{st} +C_v+C_a+C_{sd}+C_{pc}$$

Where C_s, C_r, C_{st}, C_v, C_a, C_{sd} and C_{pc} are the suitability coefficients for respectively slope, rockiness, stoniness, vegetation cover, aspect, soil depth and physical-chemical characteristics
3_ derivation of a map of the "environmentally sensitive areas to desertification due to irrational pasture creation actions" by matching the artificial pastures map and the land suitability map for this utilisation type.

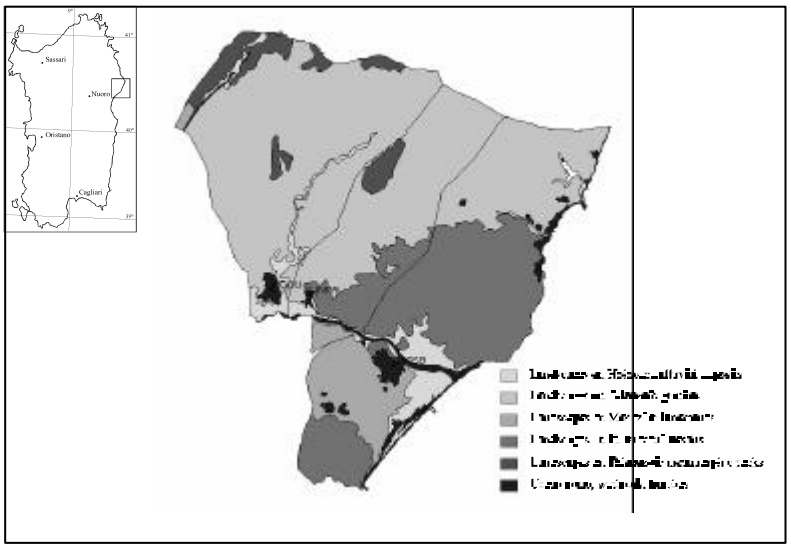


Figure 1: Location of the study area and main landscapes

Results

Land cover/use dynamics

The dynamics highlighted (Fig. 2, Tab. 1) are to be mainly ascribed to the shift from extensive to semi-extensive grazing systems occurred during the last 25 years.

During the analysed period, forest areas (woodland, maquis and forest plantation) have undergone a marked reduction (-34%) to be totally ascribed to maquis (-65%). Most of these areas were subjected to "pasture improvement actions".

The extension of artificial pastures has more than doubled (from 1,497 in 1955 to 3,392 ha in 1996). By taking into account the distribution of the artificial pastures, 14% are located on areas whose slope is higher than 25% and 14% on areas where slope is between 15% and 25%. These data reveal the high land degradation risk related to this type of land use, on which attention has been focused.

Land cover classes	*Surface (ha)*		*Difference (1955-96)*	
	1955	*1996*	*(ha)*	*(%)*
Agricultural areas	2,454	2,932	+ 478	+19.5
Natural pastures	3,334	2,803	- 531	-15.9
Artificial pastures	1,711	3,388	+ 1,677	+98
Shrublands	4,216	5,462	+ 1,246	+29.5
Woodlands	1,625	1,517	- 108	- 6.7
Mediterranean maquis	6,240	2,409	- 3,831	-61.4
Forest plantations	687	1,582	+ 895	+130.3

Table 1:Land cover changes in the study area (1955-1996, simplified).

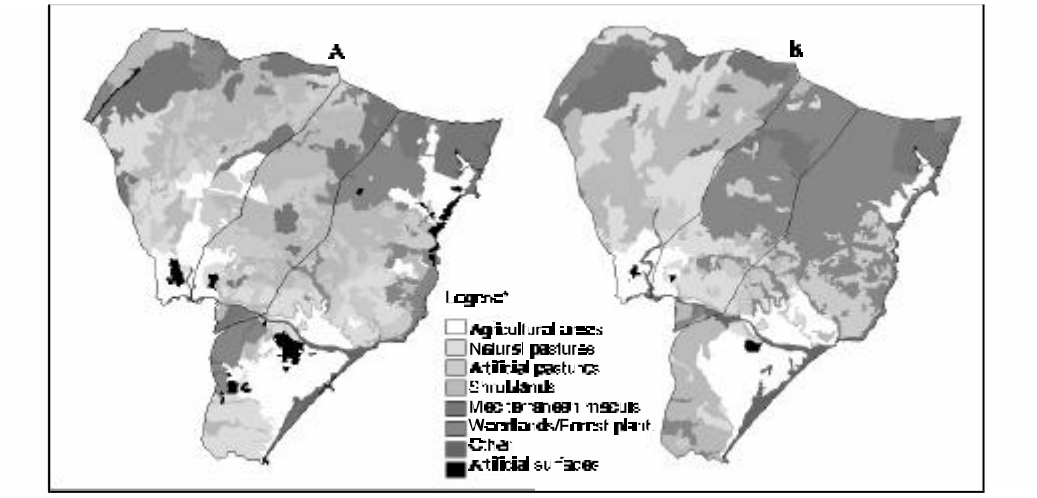


Fig. 2:Land cover maps; a. 1996; b. 1955 (the legend is purposely simplified)*

Land suitability to pasture improvement

Five suitability classes (FAO, 1976) have been derived: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (currently not suitable), N2 (permanently not suitable). About 44% of the study area (Fig. 3, Tab. 2) has been classified as not suitable (N2 and N1), and a further 30% as marginally suitable (S3).

Class	Surface (Ha)
S1	875
S2	1645,34
S3	6218,03
N1	3449,93
N2	9667,96
Other	770,34

Tab 2: statistics on classes of land suitability

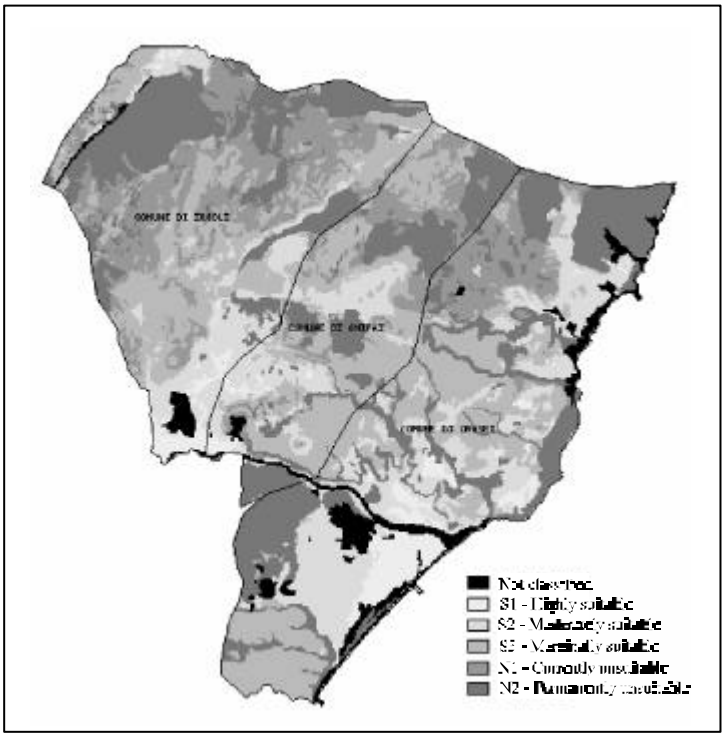


Fig. 3: Map of land suitability to the creation of new pastures.

Environmentally sensitive areas to land degradation/desertification due to agropastoralism

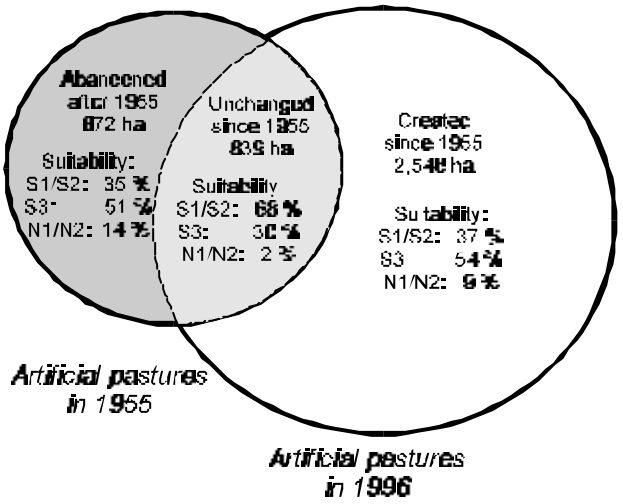
By matching the presence of artificial pastures obtained from the land cover map and the suitability class derived from the model (Tab. 3), the study area has been classified according to its sensitivity to land degradation in relation to this land use. Only a small part of the area

(3%, permanently unsuitable) can be classified as critical sensitive area: these areas are characterised by high risk and, often, are largely affected by land degradation; a further 5% (currently unsuitable) is affected by land degradation at a lower extent (fragile sensitive area). About 48% of these areas is threatened by desertification (marginally suitable areas) and classified as potential sensitive area if the current agronomic practices are repeated over time. Irgoli is the municipality with the highest desertification risk: 12% of the total area was classified as unsuitable (critical or fragile) and 56% as marginally suitable (potential sensitive areas). Actually, in this municipality agropastoralism has represented and still represents the most important economic activity.

Class	Total	%
S1 (not threatened areas)	119,33	4
S2 (not threatened areas)	1372,52	40
S3 (potential sensitive areas)	1611,07	48
N1 (fragile areas)	183,87	5
N2 (critical areas)	101,34	3

Table 3. Improved pastures by class of land suitability.

Taking into account the land cover map of 1955, the complex dynamics of artificial pastures in the study area can be highlighted: as shown by the fig. 4, only 839 ha out of the original 1,711 ha have remained unchanged; the remaining 872 ha have been substituted by agricultural areas or by shrublands or maquis once they have been abandoned. It can be seen that a significant portion of the artificial pastures currently on marginally suitable or not suitable land are newly created ones. That confirms the high risk induced by the recent "improvement actions".



Municipality	Slope		
	<15%	15-25%	>25%
Irgoli	547	360	415
Onifai	838	85	47
Orosei	436	17	4
Total	**1,621**	**462**	**466**

Fig. 4:Origin and evolution of artificial pastures and land suitability classes; slope classes for the newly created artificial pastures.

Conclusions

This study has contributed to highlight the often negative effects that agricultural policies have had on the study area during the last decades. These policies, aiming at improving agricultural and animal productions, economically encouraged pastures improvement practices, without taking into account the real suitability of the land and of its components.
In this context, it is particularly important to identify the areas at high desertification risk where land conservation programmes can be proposed. This is particularly important also in view of the future implementation of the National Action Plans provided for by the United Nations Convention to Combat Desertification.
The methodology presented can constitute an effective tool for land planning in those areas threatened by land degradation due to agropastoral activities.

References

d'Angelo M., Madrau S., Pulina G., Enne G. (1997). Land cover changes as land degradation indicators in areas characterised by high anthropic pressure due to agropastoral activities. Presented at the FAO Network of Cooperative Research on Sheep and Goats. Bella (Italy) 25 - 27 September (In press).

FAO (1976). Framework for Land Evaluation. Soil Bulletin n° 32. FAO. Rome.

Mairota P., Thornes J., and Geeson N. (1998). Atlas of Mediterranean environments in Europe: the desertification context. John Wiley, Chichester.

Previtali F., Madrau S., (1997). La valutazione dell'attitudine dei suoli come strumento di prevenzione della desertificazione. Genio Rurale LX, 6: 40-47.

Pulina G., d'Angelo M., Caredda S., Dettori S. and Enne G. (1997). Attività agropastorali e degrado ambientale nel bacino del Mediterraneo. Genio Rurale, LX, 6:48-53

Pulina G., d'Angelo M, Madrau S., Zucca C., Enne G. (1998). Indicators of land use intensity in agropastoral ecosystems. Proceedings of the International Seminar on Indicators for Assessing Desertification in the Mediterranean, Porto Torres (Italy) 18-20 September. (In press).

UNEP (1994). United Nations Convention to combat desertifications in those countries experiencing serious drought and/or desertification, particularly in Africa. UNEP, Geneve.

van der Leeuw, S.E. (Editor), 1998. The Archeomedes Project. Understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean basin. European Commission - Directorate General XII, Brussels, EUR 18181 EN.

Zucca C., Loda B., d'Angelo M., Madrau S., Percich L. and Previtali F. (1998). Sisemi agrosilvopastorali mediterranei: un approccio metodologico per la valutazione delle terre all'utilizzo agropastorale. Genio Rurale, LX, 3:47-56.

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The Course was organized in cooperation with the Nucleo Ricerca Desertificazione of the University of Sassari and the Osservatorio Nazionale per la Lotta alla Desertificazione of the Ministero dell'Ambiente.

The main objectives of the course were i) to review land degradation / desertification issues in Europe, ii) to present techniques and methods useful to combat desertification and finally iii) to present the institutional aspects, with particular reference to the implementation of Annex IV of the United Nations Convention to Combat Desertification.