A.D. MDLXII

Università degli Studi di Sassari

Corso di Dottorato di Ricerca in

Scienze Agrarie

Dipartimento di Agraria

Curriculum: Monitoraggio e controllo degli ecosistemi agraria e forestali in ambiente mediterraneo

XXXIII CICLO

Modelling land Suitability for Cedrus libani afforestation and reforestation in Lebanon

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Acknowledgements

I wish to record my thanks for everyone who helped me to fulfill my thesis.

I am grateful to my Advisor, Professor Salvatore Madrau and Professor Mario Pirastrou who gave me the opportunity to work with them on my thesis, and accompanied me throughout the work. Providing me with all the support and help in addition to their precious time and expertise, for facilitating the way to achieve all the necessary trainings and information regarding GIS, which is a new, tool that I have acquired.

I express my thanks to the Dean of the Faculty of Agricultural Engineering and Veterinary Medicine at the Lebanese University Professor Nadine Nassif and Professor George Hassoun my supervisor of my thesis.

The CNRS has welcomed me into its arms and words cannot describe my gratitude for everyone's support and encouragement throughout this thesis. I am honored to have gotten the chance to be part of such a wonderful staff. A special thank you goes to the director Dr. Ghaleb Faour and Dr. Talal Darwich, for believing in me and inspiring me to strive for perfection.

Foremost, I present my earnest gratitude to Professor Ihab Jomaa expert on Station of climate change in LARI.

I would like to thank my reviewer prof. Riccardo Scalenghe from the University of Palermo for taking the time and effort necessary to review my thesis. I sincerely appreciate all valuable comments and suggestions, which helped us to improve the quality of my study.

I am thankful to my family who supported me during the months of stress and hard work I have faced and providing me with all my needs. My Ph. D degree would not have been accomplished without their presence and the enthusiasm and trust they gave me. I am grateful for my friends who offered me moral support encouraging me to give my best to fulfill my dream.

Table of Contents

List of figures

List of Tables

List of Abbreviations

AFDC: Association for Forest Development and Conservation

CBD: Convention on Biological Diversity

CN: CNRS: National Council for Scientific Research in *Lebanon*

EU: Union European

FAO: Food and Agriculture Organizations of the United Nations

FLRM: Forest Landscape Restoration Mechanism

FRA: Forest Resources Assessment

GEF: Global environment facility

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH

GTZ: German Agency for Technical Cooperation

HCEFLCD : Haut-Commissariat aux eaux et forêts et à la lutte contre la désertification

International Fund for Agricultural Development.

LOST: Lebanese Organisation for Studies and Training

LRI: Lebanese Reforestation initiative

NFA: National Forest Assessments

NFAP: National Forestry Action Programme

NFP: National Forestry Program

IDAL: Investment Development Authority of *Lebanon*

IFAD: International fund for agriculture development

IUCN: International Union for Conservation of Nature

MOA: Ministry of Agriculture

MOE: Ministry of Environment

PAP: Protected Areas Project

UNCCD: United Nations Convention to Combat Desertification

UNDP: United nation development programme

UNFCCC: United Nations Framework Convention on Climate Change.

UNEP-WCMC: United Nations Environment Programme World Conservation Monitoring Centre

USAID: States Agency for International Development.

VCs :Vocazione Colturale specifica assessment

WTP: Willingness to Pay per household and per year

SALMA: Smart Adaptation of Forest Landscapes in Mountain Areas

Abstract

The aim of this study is to identify the suitable areas for reforestation and afforestation of *Cedrus libani* at an altitude above 500 m in Lebanon. In this purpose, a GIS- model for assessing the susceptibility of territory, by using a parametric concept of land evaluation, has been proposed. Additionally, elevation and eight other limiting factors (aspect, rainfall, substrata relative soil deposits and geological characteristics, soil depth, soil drainage, soil pH, CEC capacity and nutrients deficiencies) affecting land suitability for cedars trees were identified and integrated into the model. The results indicate that 8.9% of the area of study is highly suitable for natural regeneration, 40.3% is moderately suitable, while 50.8% of this area is unsuitable for habitation. The analysis obtained can be considered as a preliminary indication for future reforestation and afforestation intervention to facilitate the process of planting of *Cedrus libani*.

Keywords: *Cedrus libani*, natural regeneration, soil, land suitability, reforestation and afforestation.

Introduction

Forest management has a long and storied history in worldwide research. Currently, forest losses are one of the trending environmental studies. The forest ecosystem can play a crucial role in maintaining soil characteristics, topography, global climate, and vegetation productivity (Kenaan et al., 2015). Today, forests are suffering from degradation, fires, insects breaking out, changes in climate, urbanization, grazing, and conversion of forests to agricultural lands (Smith et al., 2021). Recent changes in forestry practices, along with the generalized projected global warming under climate change, will pose many challenges for the future condition and health of Mediterranean forests, potentially compromising their capacity for service provision (Morán-Ordóez et al., 2020).

On the eastern shores of the Mediterranean region lies a small country, Lebanon. This region houses 36 endemic conifer tree species and subspecies from the genera of Cupressus, Cedrus, Juniperus, Pinus, Abies, and others with a narrow distributional range (Walter & Gillett, 1998). *Cedrus libani*, like all Mediterranean species, is facing a gradual decrease and degradation in its vegetative cover in Lebanon. The cedar of Lebanon (*Cedrus libani* A. Rich) is one of four species found in the genus Cedrus (Boydak 2003, Sattout & Nemer 2008). Currently, the Lebanese cedar forests are limited to the small mountain land grace due to overexploitation of anthropogenic activities (Hajar et al., 2010) and to climate change (Tirado et al., 2021).

Several efforts were established in this context. Khozami (1983) was the first to define the bioclimatic zone of *Cedrus libani*. Boydak (2002) was working to develop a general review on the ecology and natural regeneration of Lebanon cedar forests together with its artificial regeneration on bare karstic lands in Turkey and make suggestions to restore and expand its populations developed and based on an international journal. *Cedrus libani* was conserved through somatic division in the past and future in order to monitor the loss of cedrus species (Sattout et al., 1995; Kury et al., 2002; Fadi et al., 2008). Ducray (2015) determined the variability in growth, carbon isotope composition, leaf gas exchange, and hydraulic traits in the eastern Mediterranean cedar, Cedrus libani. Additionally, Sattout (2008) described the economic value of *Cedrus libani* for the Mediterranean aspect. In addition, for the protection of cedar forests in Lebanon, Bassil (2018) studied the impact of Cephalcia tannourinensis Chevin proliferation.

Several decision analyses have an increasing way of improving the management of forest ecosystems in order to prevent further degradation and increase the sustainability of land use (Ahmadi S. et al. 2016). The process of predicting land performance over time based on specific types of use is known as land evaluation (Diepen et al., 1991; Rossiter, 1996). Currently, remote sensing, geospatial information systems (GIS), and modeling software are some of the important applications integrated to analyze and monitor the evaluation of forestland over time. Land suitability is one of the widely used tools in forest evaluation (FAO, 1984). El Hag (2011) has develop the land suitability for Afforestation and conservation of forest nature practices using GIS and remote sensing. Kandari (2020) evaluated the land suitability analysis using multicriteria approach for forest regeneration. The proposed model created by Madrau (2006) and Cossu (2019) used for assessing the susceptibility of plantation for OAK forests and conservation that is derived from Vocazione Colturale Specifica (VCs) (Danuso et al., 2001). In Lebanon, the land suitability approach for *Cedrus libani* is still in progress and limited to some studies. Stephan et al. (2016) elaborated an effective study about land suitability for natives species using MaxEnt model. In addition, Kattar (2017) developed the land suitability map of Pinus Pinea, as well as, Jezzini (2021) elaborated the future distribution of Autochtonous species using the FAO suitability classification to mitigate the negative impact of climate change.

Hence, the objective of this work is to develop a GIS-based evaluation model of the Lebanese territory for reforestation with *Cedrus libani* that allows, at a medium-scale level of detail, 50 000. It should be noted that this model represents only a first step in assessing the territory. First, establish a hierarchy of territorial classes based on their productive responses to new forest plants, and then arrange interventions by concentrating them first in the most suitable places and monitoring the state of C. libani's natural regeneration in its native range. Second, it involves the use of land (soil and morphological) traits as well as climatic elements that might affect plant development favorably or adversely.

Chapter I

1. Mediterranean forest

1.1. State of Forest Mediterranean

Mediterranean forests are well known to be ecologically and aesthetically attractive due to their considerable range of characteristics and extraordinary wide range of environmental conditions. In addition, the Mediterranean woodlands include a wide variety of plants and animals with considerable genetic heterogeneity. This is one of the world's hotspots of biodiversity.

The mosaic of its woodland landscapes substantially contributes to the biological wealth and the various attractions that every year draw tourists from all around the world. These Mediterranean Forest landscapes help reduce poverty, contribute to the socio-economic growth of rural areas, promote food safety for the local people and preserve the many eco-services that the international community considers today to be of global importance (carbon sequestration, biodiversity, landscape quality, preservation of water resources and fight against land degradation).

Despite their seeming fragility, the Mediterranean forests have been influenced by human activity and have proven their great resistance to anthropological change for numerous centuries.

The Mediterranean Basin is the largest of the world's five Mediterranean climate regions, covering more than 2 million square kilometres (Myers et al., 2000). The Mediterranean basin is rich in plant variety (Mittermeier et al., 2004), with over 25,000 plant species (Thompson, 2005). The area also has a rich endemic nature in plants and bushes (290 indigenous woody species and subspecies, 201 of which are endemic (Fady-Welterlen, 2005). A lot of these are the most famous species, like cedars, the Argan tree (Argania spinosa, L.) and the Crete date palm (Phoenix theophrasti, Greuter, 1967). More than 220 land mammal species, 25 of which are endemic (11%), are also present in the Mediterranean Basin (Dernegi, 2010). The Mediterranean forest ecosystems are closely linked to human activity; this relationship results from the existing degree of endemism and biodiversity.

However, the increasing pressure will disperse the impact on these ecosystems. The loss of biodiversity will undoubtedly affect the future economic potential of these places. Today, just 9 million hectares cover protected areas, accounting for 4.3 percent of the entire area of the region (***Figure 1***). In the north, the biggest protected area is present (UNEP-WCMC and IUCN, 2017).

Today, however, forests are confronting an unprecedented risk that will have to be adapted to in the next decades. It is predicted that climate change will considerably and, if not seriously, damage the Mediterranean ecosystems while at the same time greatly increasing the population of the

Mediterranean area by 2050 (**Annex 1**). The principal drivers of biodiversity loss in the region are to transform the natural areas into agriculture and urban development, to introduce invasive alien species, to pollute or over-exploitation of water and soils, and to hunt wildlife at an unsustainable level.

Figure 1: Protected areas (green) and limits of the Mediterranean biodiversity hotspot (blue UNEP-WCMC and IUCN (2017).

This poses key issues. What can we do to guarantee that Mediterranean forests adjust themselves to new social, economic, environmental and climate situations in order to ensure that people continue to offer products and services? How might regional collaboration in this field at the intersection of Africa, Europe, and Asia help governments successfully react to emerging climate change challenges? How can the Mediterranean area, notably affected by global climate change, become a laboratory in some respects to develop, test, and spread best practices to encourage forest-based adjustment to climate change and other challenges in the 21st century?

Natural land ecosystems are experiencing a more or less strong comeback of forests in the nations of the northern Mediterranean Sea (see ***Figure 2***), owing to the abandonment of marginal farmland and reforestation initiatives. In the south, and especially in the Maghreb, the ecosystems are still subject to increased fabricated pressure to clear, grow, and over-exploit marginal areas and firewood. The woodland and scope of the southern Mediterranean is mostly semi-arid with frequently poor soils and limited water. These systems are especially delicate, sensitive, and one of the world's most threatened because of the prevailing environmental and climate circumstances. Many natural flora and animal species are either endangered or extinct (FAO, 2013).

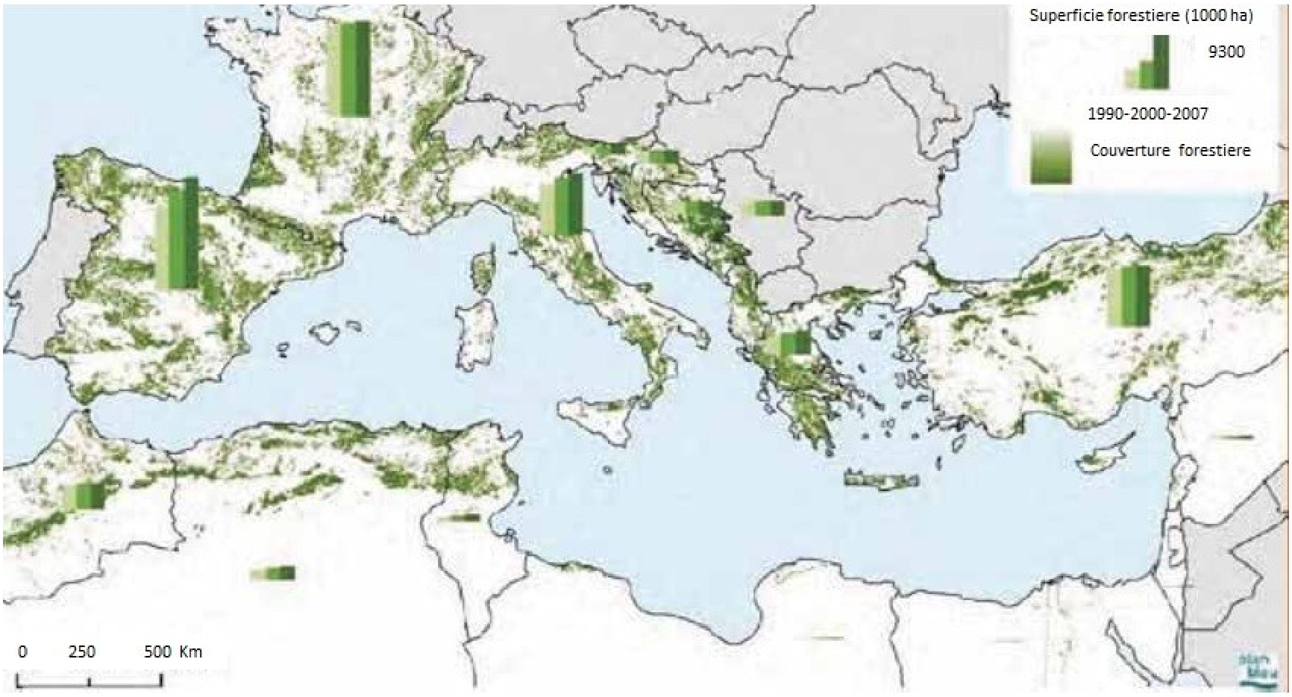

Figure 2: State of 2013 Forest cover around Mediterranean. State of the environment and development in the Mediterranean 2009, plan bleu based on FRA data.

The Mediterranean area contains 26 nations, having a total surface area of 8779 million km2. Although this is 6.7% of the global land area, the regional forest cover is 85 million ha, or 9.5% of the whole country and 2% of the global forest (***Table 1***), but Mediterranean woods have a considerably higher relevance than this statistic alone when compared to global woodland targets (FAO, 2015a).

In addition, the total amount of natural woodland in the Mediterranean increased to 115 million hectares, or almost 13% of the total area of the nations. Fifteen nations account for over 89% of the forest region and other woody land areas of around 28% of the region's land area. The area is usually semi-dry to desert in the south of the Mediterranean Basin, and deteriorated ecosystems have a major effect on the rural economy. It has a low forest cover, with woods covering 10% or less of the land area. In general, the forest vegetation consists of open forests with dispersed trees and xerophytic plants (FAO, 2013).

The Mediterranean Region is key in addressing global forest objectives, given the variety of biodiversity in Mediterranean forests and the region is one of the main areas of global climate change (Giorgi, 2006) and the fact that 7.3 percent of the world's human population lives in Mediterranean countries (World Bank, 2015a). (FAO, 2018).

Table 1: Forest area, percentage of forested area (with respect to land area or to total forest area), forest area growth and area of other wooded lands in Mediterranean countries FAO (2015a) and Hansen et al. (2013).

Country	Data extracted from FAO (2015a)					Data extracted from Global Forest Watch	
	Forest Area 2015 (x10^3 ha)	Land area with forest 2015 (%)	Share of regional forest area 2015 (%)	Change in forest area 2010-2015 (%)	Other wooded land area (x10^3 ha)	Area with tree cover ≥ 10% (x10^3 ha)	Area with tree cover ≥ 30% (x10^3 ha)
Albania	772	28.16	0.88	-0.82	256	939	777
Algeria	1956	0.82	2.22	1.98	2569	1690	1472
Bosnia and Herzegovina	2185	42.68	2.48	0.00	549	2900	2814
Bulgaria	3823	35.19	4.34	2.30	22	4461	4377
Croatia	1922	34.37	2.18	0.10	569	2691	2613
Cyprus	173	10.69	0.20	-0.17	213	154	132
Egypt	73	0.07	0.08	4.29	20	952	898
France	16,989	30.88	19.27	3.44	590	18,355	17,831
Greece	4054	31.45	4.60	3.87	2492	4767	4430
Israel	165	7.62	0.19	7.14	60	50	42
Italy	9297	31.61	10.55	2.98	1813	10,449	10,152
Jordan	98	1.10	0.11	-0.51	51	4	3
Lebanon	137	13.42	0.16	0.22	106	94	65
Libya	217	0.12	0.25	0.00	330	24	16
Malta	n.a.	1.10	n.a.	n.a.	0	0	0
Monaco	0	0.00	0.00	n.a.	0	0	0
Montenegro	827	61.49	0.94	0.00	137	692	667
Morocco	5632	12.62	6.39	-0.71	580	1,113	892
Palestine	9	1.50	0.01	0.00	0	2	1
Portugal	3182	35.25	3.61	-1.76	1725	3006	2756
Serbia	2720	31.10	3.09	0.26	508	3026	2943
Slovenia	1248	61.97	1.42	0.08	23	1342	1324
Spain	18,418	36.90	20.90	0.94	9209	14,326	13,061
Syrian Arab Republic	491	2.67	0.56	0.00	35	147	132
Republic of Macedonia	998	39.24	1.13	0.00	143	911	864
Tunisia	1041	8.70	1.18	5.15	293	286	257
Turkey	11,715	15.22	13.29	4.57	10,130	12,909	11,968
All countries	88,141	10.04	100.00	2.04	32,423	85,192	80,507

Ecologic services provided by forests and other forest land for a long time have been viewed as the usual results of smart forest management (soil-water preservation, biodiversity of flora and fauna and climate protection). In addition, different forestry administrations Referring to the 2015 FAO studies in Mediterranean countries, specific reforestation activities represented in ***Figure 3***, soils protection, land recovery, erosion and desertification fighting, watershed management and protection for rare or endangered species have already been undertaken by Mediterranean countries.

However, only quite lately did the services increase awareness about the economic worth of these services and about the need to manage them sustainably as such, within the framework of UNCCD and biodiversity conservation agreements (CBD)

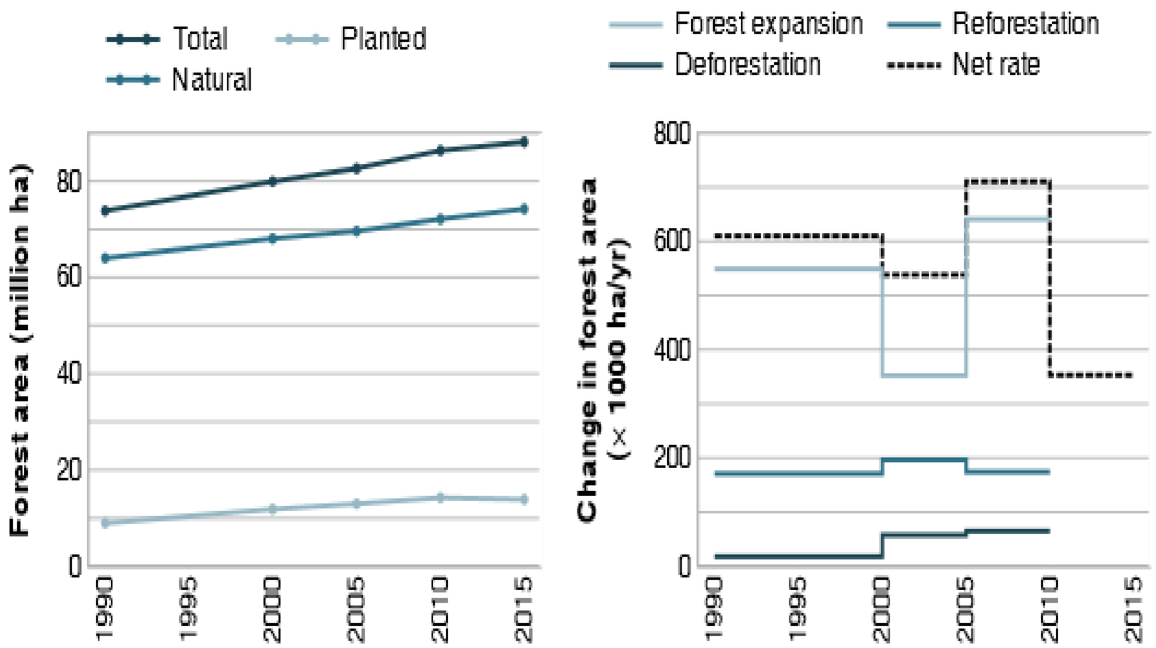

Figure 3: Total Forest area growth for Mediterranean countries and average annual rate of change in forest area Source: Adapted from FAO (2015a).

1.2. Threats of Mediterranean forest

The Mediterranean forests have been vulnerable since prehistoric times to environmental changes. The nature and position of the region have made it an adequate habitat for biodiversity. However, since the early days of human history, due to a complex socio-ecological balance, the woods have responded to the stresses of human growth. Nevertheless, this strain was never greater than it is today (FAO and Plan Bleu, 2018). Global change, which comes from human activity regarded as a broad range of environmental effects, influences the whole Mediterranean (Doblas-Miranda et al., 2017). Forests deliver essential environmental services—soil, water supply, storage of carbon, wood, medicine, food, urban microclimate stabilization, recreation, on which society depends. In severe environments such as the Mediterranean climate, where water constraints are the principal limiting factor, uneven water distribution may readily trigger soil erosion and water run-off when forest cover is removed. This is highly critical. The primary causes of Mediterranean forest degradation include rapid and abrupt land-use changes, largely because of urban development pressures; habitat fragmentation; over-exploitation of resources; and inadequate management (FAO, 2013).

The present paradigm of growth has resulted in tremendous human strain on forest genetic resources, with diverse consequences on the Mediterranean north and south. The first days of farming in the Near East are 10,000 years since the husbandry of animals that affected forests as clearings. Today the high population growth, low income per capita, high rural density and small diversification activities have contributed to producing precious primary resources to the local populations' lives, including forests, garrigue and maquis and products they supply (firewood, grass, aromatic and medicinal plants). (Palahi et al., 2008).

Similarly, land abandonment and a marked drop in the number of free-range animals were followed by the urbanization and decline in agricultural population (Lasanta-Martínez et al. 2005). Urbanization often encourages young workers to relocate to suburbs to make sure the majority of the elderly live in rural regions. This population is less inclined to accept new agricultural technology or contemporary methods. In distant rural locations, lower income rates have made many small farms unprofitable, driving abandonment of farming techniques (MacDonald et al., 2000) which make the woods of abandonment particularly exposed to the risk of fire. The overuse of forests for fuel timber, clearing of farmland and overgrazing in Southern and Eastern sub-regions are further serious challenges to forest sustainability (Palahi et al., 2008). Excessive collection of wood has devastated huge forest tracts in locations like the Middle Atlas Cedar Forests (HCEFLCD, 2005).

In addition, the vegetative cover of the Mediterranean derives from the lengthy evolutionary process that shapes the climate elements defining the region (Valladares et al., 2014). Although low temperature thresholds, fungi, survive many arthropods and diseases are dry (Jactel et al., 2012). Socioeconomic factors have, nevertheless, traditionally affected the ecosystems of the Mediterranean, and contribute too many anthropogenic conditions, unsustainable forestry and forest depletions.

The combination of the climate change, anthropogenic disorder (super exploitation and deforestation of the forest resources, human-induced fires) and other global change (in particular the use of land and pollution) will have multiple effects on Mediterranean forest vegetation (Peñuelas et al., 2010) presented in ***Table 2***. While fires are predicted to aid in the structure of Mediterranean forest ecosystems, increased fire frequency and severity pose a variety of threats to plants and animals. (Doherty et al., 2015). Vegetation response to fire is highly complicated (Gitas et al., 2012); plant sensitivity to fire can modify the composition of vegetation on a continuous basis (Pérez-Cabello et al., 2009).

Table 2: Effects of climate change on the Mediterranean forest vegetation (State Mediterranean Forest, 2018)

Observed effects	Cause	Consequences
Changes in forest plants, growth and health	Increased CO_2 concentrations	-Increased productivity of some species -Increased biomass production of some species: greater number of leaves, higher total leaf area per plant, large diameter stems and branches -Reduction of growth and health of local vegetation
Changes in vegetation patterns and distribution	Drought, rainfall and extreme weather events	-Influences plant productivity and efficiency of water use -Influences seed production -Habitat and coverage losses -Loss of biodiversity -Forest distributions shifting northward and upward
Changes in plants phenology	Decreased precipitation and increased average winter temperature	-Decrease in winter chilling requirement for flowering and seed germination -Advancement of flowering date -Increase in the length of growing season -Incomplete winter hardening -Reduction of in winter cold/snow damages
Changes in wildfires	Increased dry and warm conditions	-Increased frequency of fire events -Increased forest fire intensity and length -Replacement of forest with fire-prone shrub communities -High risk for native species to fail seed regeneration -High risk of increased invasion by non-native species
Pest outbreaks	Increased winter temperatures and extreme temperature episodes	-Increased frequency and intensity of pest outbreaks -Pest location and range shift pole ward or to higher altitudes

In view of the Mediterranean states in particular, there is an urgent need, at the national and regional level, to integrate the reduction of fire risk and adaptation requirements into all of the sectorial policies, laws and rural/urban development plans relating to forest ecosystems (***Figure 4***).

The increasing and rising danger of wildfires in the region calls for new fire management strategies and techniques. Removal strategies not correctly followed by the management of vegetation, forestry and integrated forestry may severely worsen forest degradation as fuel accumulates, leading to an increased risk of forest fires. This scenario calls for new fire fighting regulations and efficient prevention methods like forestry planning and coordinated fire fighting. The objective is to develop territorial strategies which permit fires to stay 'acceptable' as part of Mediterranean ecosystems. (State of Mediterranean forest, 2018).

Figure 4: Fire-risk reduction interactions (Corona et al., 2015. modified).

1.3. *Cedrus libani* forest in Mediterranean

It was widely known that Cedar (*Cedrus libani*) was the treasure that all governments of the Near East wanted and for which the former empires were prepared to battle (Basbous and De Tarade, 1968; Beals, 1965; Meiggs, 1998; Alptekin et al., 1997). They were utilized for grazing, fuel, and construction in particular parts of the nation. Lebanon's cedar is not only known for its wood but also for its symbolic and religious importance (Meiggs, 1998; Alptekin et al., 1997; Kuniholm, 2003). During warfare in Syria and Cilicia in the ninth century BC, wood was logged and resin produced from cedar wood was used as tax (Kuniholm, 2003). Since the early 14th century, these woodlands have been used as amenities for pilgrims and as resting places. Old paintings and gravings, as well as stories and epics, and religious transcripts, have revealed historical and cultural significance. Forests will play an important role in assisting parties to achieve their UNFCCC climate objectives (Grassi et al., 2017).

1.3.1 Population of *Cedrus libani*

FAO, 2011 indicated that the forests of the Cedrus constitute over 3.8 billion hectares of forests globally, with Turkey representing almost 30 percent of the total land cover. The total net loss of world forests during 1990-2005 was estimated at 66.5 million hectares, with a majority in the tropics (Lindquist et al., 2012).

In the Pineaceans family, there are four species of the genus Cedrus (*Cedrus deodora Loud, Cedrus libani, Cedrus Brevifolia Hen and Cedrus Atlantica*) dispersed on Mediterranean (Vidakovic, 1982; Yaltırık, 1993).

Lebanese cedrus A. Rich has a history of long-standing decline in resources across history. It is exhibited at 1400 to 2200 m at sea level in the mountaineers of Turkey, Syria and Lebanon as seen in ***Figure 5*** (Quezel and Medail, 2003). Since C. libani from the Turkey is very genetically differentiated and *Cedrus libani* from the Lebanon is high (Scaltsoyiannes, 1999; Bou Dagher-Kharrat, 2001), *Cedrus lebani* claimed that only 2000 ha of Lebanese are covered between 1500 and 1700 m, while more than 20,000 ha are extensively diffused in Syria (Seigue,1985). Turkey has the most land in Cedars Lebanon though, with 99,000 hectares of which 31,000 hectares are depleted. Lebanese are usually 800 to 2100 m above sea level (Evcimen, 1963; Boydak, 1986). Which steep slopes somehow protected their woods against overuse and extinction (Boydak, 2003).

Cedrus libani is currently on the red list of low-risk and almost endangered species of the World Conservation Union (ECODIT, 2009). For its historical, cultural, artistic, scientific, and economic reasons, it is therefore vital to protect this species (Boydak, 2003; SETS, 2007). Cedars are known to have been present in Turkey during the previous Glacial Quaternarian cycle (Zeist et al., 1975).

Cedrus libani's populations are dispersed and divided elsewhere. In the north, on the eastern side of Jabal and Nusayriya, in Syria, there is one population recorded. It comprises 150 hectares of degraded mixed woodlands of oak, pine, and fir, with a height of 1200–1850 m (Khouzami, 1994). It forms part of the protected area of Cedar-Fir, which ensures its conservation, but the seed set is poor and insect damage to the cones is evident (Musselman, 1999). In Western Europe, the cedar of Lebanon is a famous tree, both as a symbol of environmental deterioration and as a prized food tree (Khury et al., 2000).

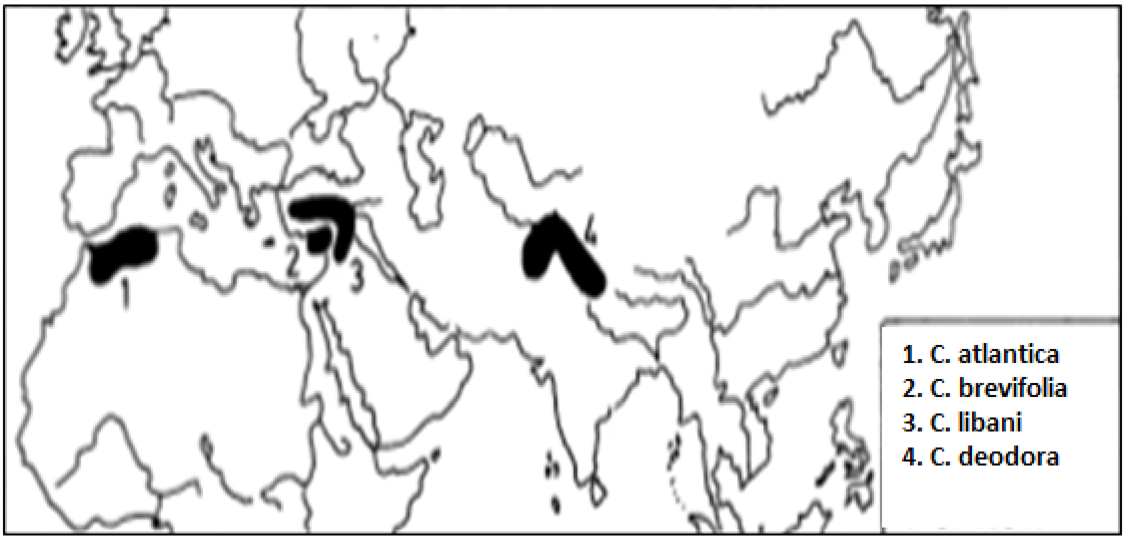

Figure 5*:* Natural distribution of Cedrus species in the world (Vidakovic, 1982)

1.3.2 Environmental state of *Cedrus libani* in Mediterranean

The forestry methods affecting *Cedrus libani* have numerous environmental aspects (soil, climate, altitude, slope and aspect) as well as biological (genetic structure of population or individual plants). Lebanon cedar is found in the Taurus Mountains, facing the Supra-Mediterranean, Mountain-Mediterranean and Oro-Mediterranean areas, which prevail on wet, humid, sub sub-damp and semi-arid climatic conditions (Quezel, 1979, 2000). Its overall distribution in semi-arid bio climate is rather limited in this general aspect of Taurus Mountains. The rearward Lebanon cedar and the internal Anatolian climate prevail, respectively, under sub-humid and semi-arid environments. In central Anatolia, its inhabitants are very limited and mainly deteriorated (**Annex 2**). The yearly average temperatures in the area vary between 6 and 12 °C. Temperature in July is between 18°C and 25°C, maximum absolute above 30°C. The average temperature of January ranges from zero to −5°C, with a minimum of -35°C. Mean annual rainfall ranges from 600 mm to 1200 mm. Its rainless summers. The snow cover duration varies between 1 and 5 months. During the growth season, relative humidity varies from around 40 to 60% (Atalay, 1987, 1990).

In fact, forests of cedar of Lebanon are mostly found in calcareous formations in Turkey on diverse geological formations and parent materials (Sevim, 1955a, Atalay, 1987, Gunay, 1990). Small, medium, or medium-deep soils are typically found (Kantarcı, 1990). However, many splits between calcareous stones include fine soil and produce a deep soil (Sevim, 1955b). The soils are well drained; nevertheless, the water holds fine dirt within cracks is quite high (Atalay, 1987). The soil's pH is rather high (6.5–8.1) depending on parent material (Kantarcı, 1985).

The Taurus Mountains between the Mediterranean coast and Central Anatolia are Turkey's largest and most important karst area. The entire thickness of the carbonate series is around 200 kilometres broad and over 1000 m in certain parts. The terrain seems quite harsh in terms of towering mountains, jagged peaks, deep rivers, and tight gorges. The area features one of the most complicated networks of karst circulation in the Mediterranean nations (Eroskay, 1982). Deep soil is not associated with soil erosion on robust terrains of these calcareous regions (Atalay, 1988, 1997, 1999; Kantarci et al., 1990). The forming of the surface soil is quite sluggish as the snow and rainfall go straight into the rock cracking system. On this soil, the fissures and stratified surfaces of the limestone are produced (Atalay, 1988, 1997, 1999). Furthermore, normal soil growth is intimately linked with the area's topography, i.e. geomorphological features. With rising path, the thickness of the soil layer drops and increases with decreasing path (Atalay, 2006). The grade of slope is the principal factor in erosion control (Koulouri and Giourga, 2007). With the rising degree of slope, the number of materials carried by erosion rises. As a result, the slope is steadily growing (Atalay, 2006), and soil depth and fertility are declining.

Because of its effect on soil and forest development, as well as the habitat, defining the slope route is one of the most important environmental elements because of its ease of implementation and low cost of identification in forestry and watershed operations for managers. Aspect may also have a strong temperature impact. The angle of the sun is less than 90 degrees in the northern and southern hemispheres and straight overhead (Yazici et al., 2017).

2. Native tree species in Lebanon

2.1. Description of forest cover

Lebanon, located in the eastern Mediterranean, is relatively small (10,452 km^2). The landscape is made up of four parallel structures: the coastline, Mount Lebanon, the valley of Bekaa and Anti-Lebanon Mountains (***Figure 6***). The altitudes range in mountains for Mount Lebanon from about 3000 m.a.s.l. to about 2680 m.a.s.l. in the Anti-Lebanon region. The Bekaa valley separates these two mountain regions (elevation c. 800 m.a.s.l.). It still harbors more than 2600 vascular plant species, about 12 per cent of which are unique to the east of the Mediterranean (Zohary, 1973). More than 300 of these are indigenous to the East Mediterranean (Zohary, 1973). More than 300 have been endemic to Lebanon alone, with several existing only in isolated regions in Lebanon (Tohmé and Tohmé, 2007a). (Davis et al., 1994). These steno-endemics exist over tree lines (jurd in Arabic), although the bulk of rare and endemic species is in forest and forestry environments (Yazbek et al.

2010; Sattout and Caligari 2011).

Currently, Lebanon has about 13% forest cover (1394 km^2) of 23 subtropical (48%), dry sub-tropical (38%) and steppe-subtropical classifications (13.9 percent). Of these 97.4% are classified as 'production' and 2.6 % as reserves (Sarkissian, 2015). The major length is Mount Lebanon and the south of the Anti-Lebanon mountain forests and woodland (Abi Saleh, 1978). The forest area in Lebanon is characterized by wide forests, with a total size of 78,887 acres. The second biggest category consists of 44,879 hectares of coniferous forest in the forest region. The forest of 15,610 hectares is defined as the forest, with at least 25% of each coniferous and wide-flowered trees as shown in ***Figure*** *7* (NFA, 2005). Most woods in Lebanon and other woody regions lie along the western and eastern flanks of Mount Lebanon and start from Akkar to Marjayoun in the far north to the extreme south. The Anti-Lebanon Mountain range also has far smaller patches of forests and other woods (e.g. Mount Hermon in the southeast). (Arbi J. Sarkissian, 2015). Additionally, 10% of Lebanon's land cover is categorized as 'other wooded land' (or 1.084 km^2), with canopy covering less than 10% (3% within nature reserves). (NFA, 2005).

The coniferous forest split into many types of forest according to the composition of the trees. These kinds are: Cedar, Cypress, mixed Coniferous, other Pine, Junipers, Fir, Cypresses (FRA, 2005). The most significant of the areas are the other pine forest (Pinus brutia and Pinus halepensis) with a distance of 17,952 hectares of total forest coniferous, 10,502 hectares of Juniper, 7943 hectares of forest Pinus pinea, 259 hectares of forest Cedar, and 1257 hectares of Cypresses, with a 5206 hectare coniferous forest. The other forest is the largest area with the other coniferous trees. (NFA, 2005).

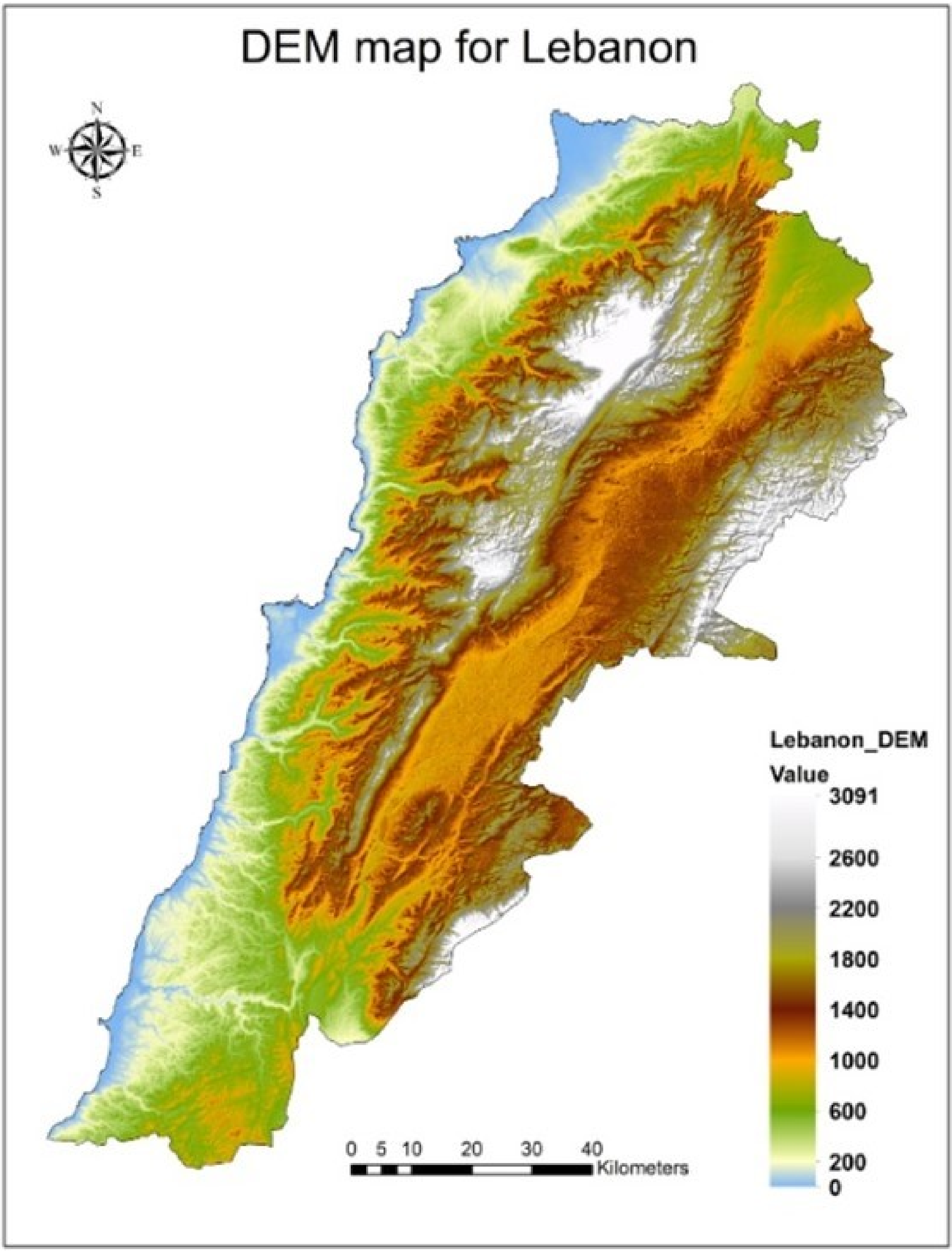

Figure 6: DEM for Lebanon Mountain Ranges. (El Arab M., 2021).

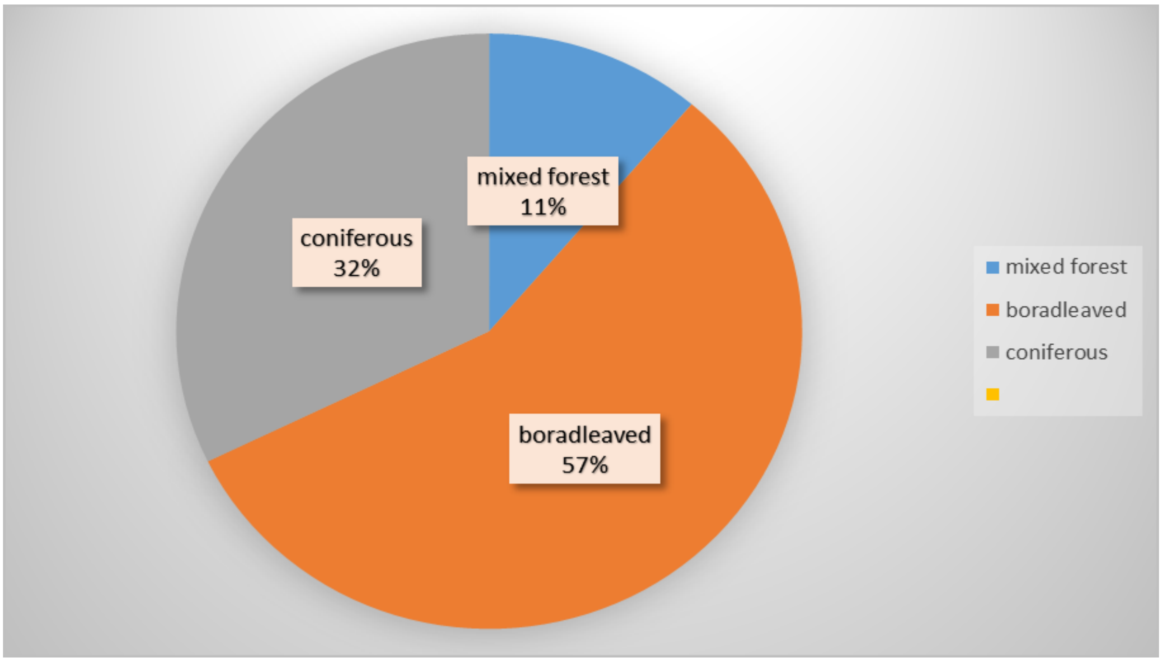

Figure 7: Forest area by forest type (NFA. 2005)

2.2. Land use/Land cover

The categorization method for land use / land cover used by the NFA is detected in ***Figure 8***. Level 1 is consistent with FRA Global Classes – Level 2 and Level 3 was agreed by the FAO and Lebanon's Ministry of Agriculture during a workshop at the initial phase of the project (***Table 3***). Recent studies utilizing satellite pictures show that while the general trend has somewhat increased forestry cover, it is rather fragmented and patchy (Jomaa, 2008).

Cedar woods in Lebanon cover remnant forest areas that have remained anthropogenic for thousands of years. They are located mostly at altitudes range between 1400 and 2000 m a.s.l. in the mountainous bioclimatic Mediterranean area, with the most south limits of the *Al Shouf Cedar reserve* (El-Hanna et al. 1999; Sattout and Nemer, 2008).

The Cedar of Lebanon is present in mixed stands with other tree species, but most of its forests consist of pure sedge and shelter sporadic tree species like Cilicia firm (*Abies cilica Antoine et Kotschy, Carrière 1855*), *Malus sylvestris Miller, Acer hermoneum Bornm & Schwer), Oak and Cyliprinos*. Cedar of Lebanon is found in the mid-stages of the Lebanese tree species (*M. Bieb, Quercus Calleprinos Webb, Q. Oliv*) (Sattout and Nemer, 2008)

Table 3: Land Use/Land Cover classification system (FRA, 2005).

Level 1	Level 2	Level 3
Forest	Coniferous	Cedars Pinus pinea Other Pines Juniper Fir Cypressus Mixed Coniferous[2]
	Broadleaved	Deciduous Evergreen Mixed Broadleaved[3]
	mixed[1]	
Other wooded Land (OWL)	Coniferous Shrublands Broadleaved Shrublands Mixed Shrublands Grassland with trees	
Other Land (OL)	Other Land (OL) Woodlots Grassland Cultivated Land Artificial Area	
Land Water	Wetlands Barren Land	

1. *Mixed Forest*: is a forest which contains at least 25% each of coniferous and broadleaved tree species
2. *Mixed coniferous forest*: is a forest, which contains at least 25% each of two or more coniferous tree species
3. *Mixed broadleaved forest*: is a forest, which contains at least 25% each of deciduous and evergreen tree species

2.3. Forest cover and bioclimatic zones

Abi-Saleh and Safi (1988), depicted in ***Table 5***, classified the vegetation of Lebanon. The proposals provide an altitude, climate and nature distribution of plants depending on the rock source (***Figure 9***). There is a thermo-Mediterranean area in the coastal area up to 500 m high: this coastline line has damaged plant groups. Examples of vegetation are *Quercus lentiscus Series, Pinus pinea, Ceratonia siliqua and Pinus brutia.*

The *Mediterranean floor* (500 to 1000 m) is mostly filled with scrub, which has been damaged by conflict, the manufacture of charcoal and firewood gathering. *Quercus infectoria and Pinus brutia* are examples of a number of species

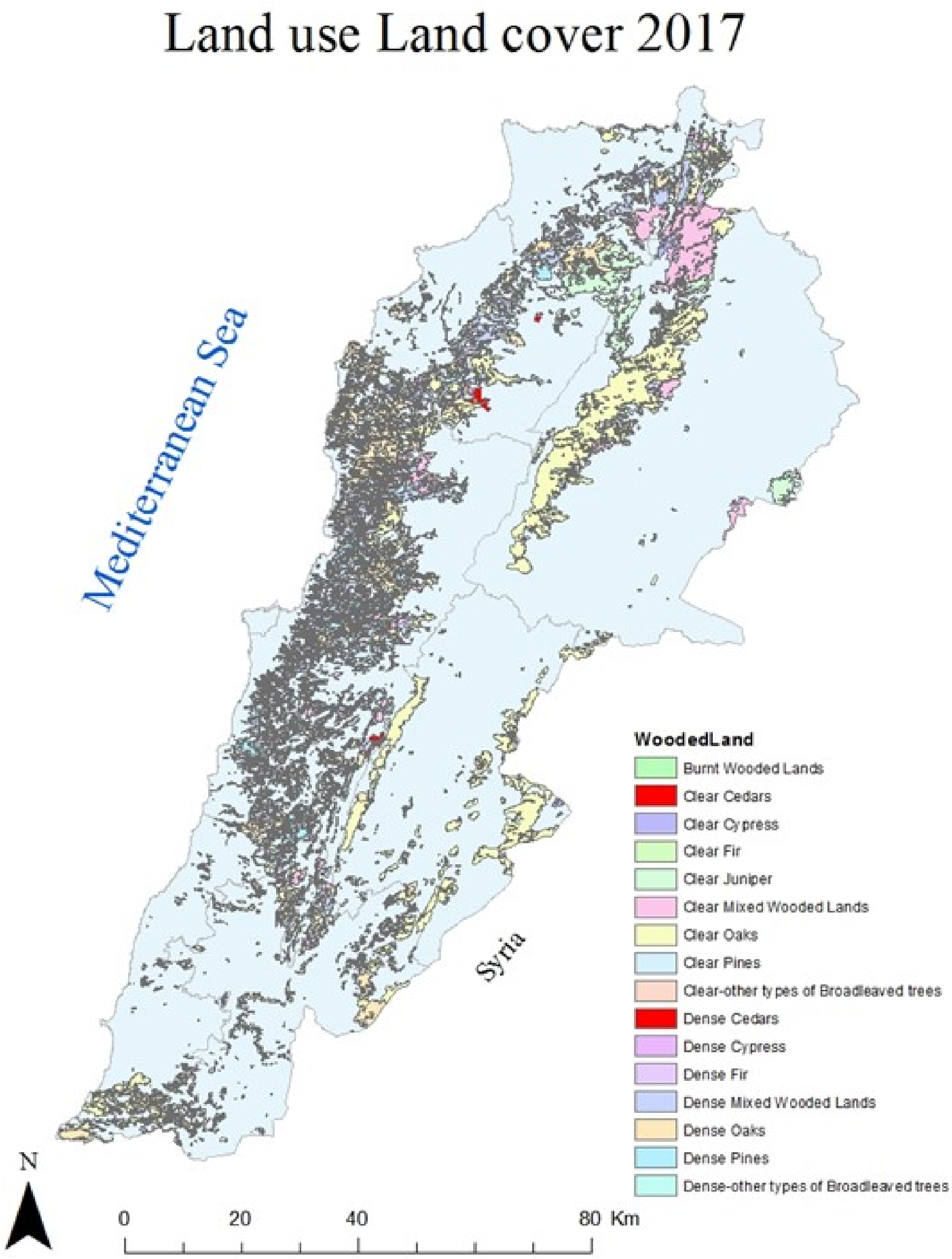

Figure 8: Map of Land use land cover 2017 (CNRS, 2017)

In the Super-Mediterranean area (1000 to 1500 m), feathering woods such *as Quercus, Cerris, Ostria, Carpinifolia*, etc. define it. Vegetation is thick in this area as the density of the human population is low. Beyond 1500 m, the *Mediterranean mountain scene* (represented by *Junperus excelsa*, etc.) and the *Oromediterranean scene* are to be found (only *Juniperus excelsa).*
An evergreen scrubland and a garrigue belt characterize the elevations above the Mediterranean area; the highest zones are endemic due to the isolation effects.

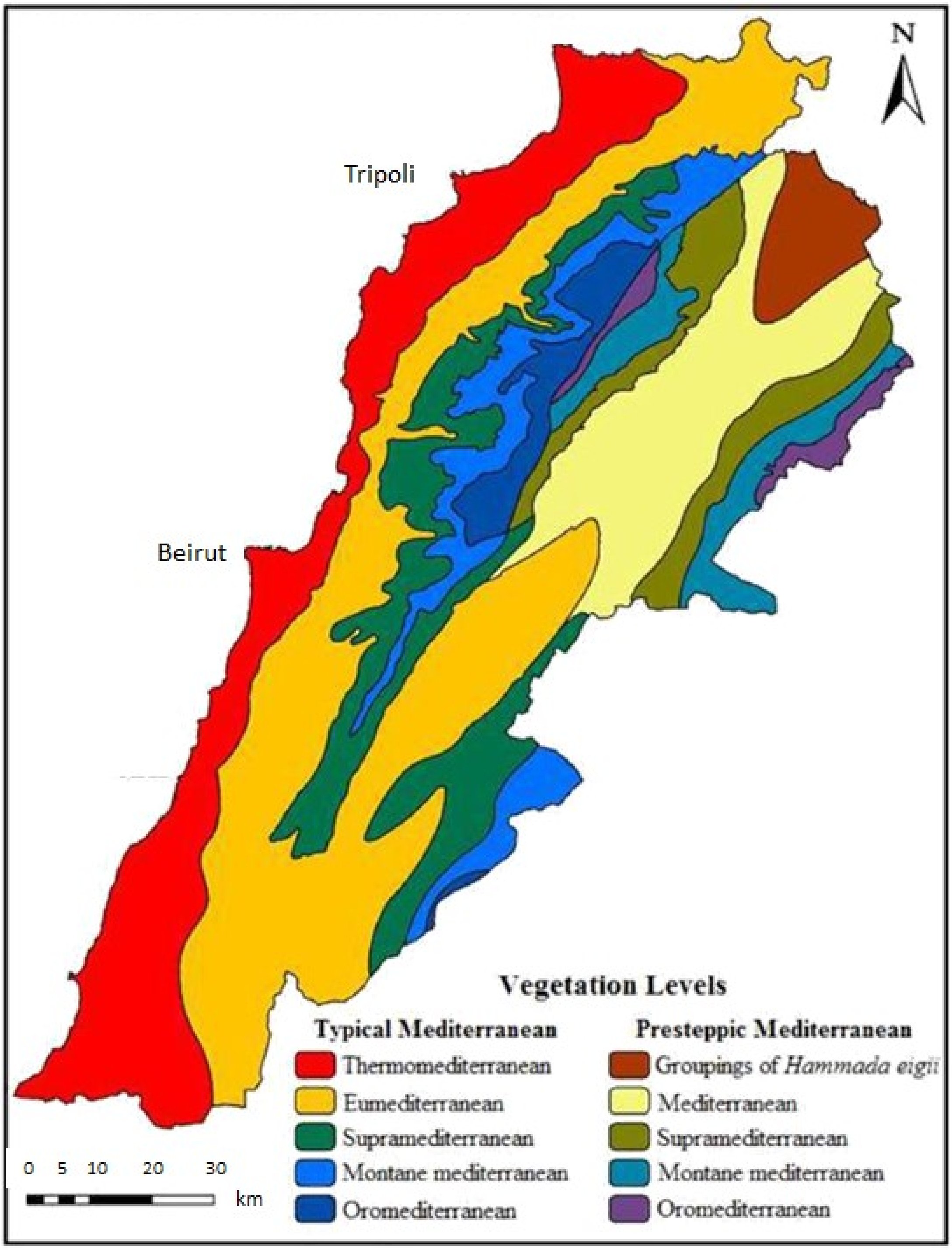

Figure 9: Vegetation level of Lebanon (Abi Saleh and Safi, 1988).

Table 4: Different vegetation groups according to the climate categories (Quezel. 1976).

Thermophilic	wild olive and pistachio scrub wild olive and pistachio scrub
Mediterranean	conifer forests of Aleppo pine, Brutia pine, maritime pine, stone pine, Barbary thuya and Phoenician juniper
Sclerophyllous	evergreen oak forest of holm oak, cork oak, Kermes oak, etc.
Deciduous Forest	zeen oak, afares oak, Lebanese oak, tauzin oak, hornbeam, ash and, occasionally, beech; Mediterranean forests: ecological space and economic and community wealth
Mountain	high-altitude forests of cedar, black pine and firs
Oro-Mediterranean stage	stands of arborescent juniper and thorny xerophytes

The *Mediterranean pre-steppe* (1000 to 1500 m) has grazing paths made mostly of deteriorated garrigue. It is only for Quercus calliprinos environments. *Supramediterranean Pre-stalks* (1400 to 1800 m) of Quercus calliprinos and Quercus infectoria trees are covered. The Juniperus excels, which are the species in the mountain pre-stage (1800 to 2400 m), and the Oromediterranean (>2400 m). According to Quézel, 1976, forest ecosystems may be split into several types of vegetation in ***Table* 4**.

2.4. Threats of Lebanese forest

While the woods and other woodlands in Lebanon cover about 24% of the overall area, the strain and dangers are growing (FAO, 2010). This is particularly true as a huge area of these woods have been cultivated on abandoned farmland, where change in land use/land cover might happen at any given date. Forests confront a number of difficulties, such as (AFDC, 2008): Forestry fires: Climate change is anticipated to impact the present forest in Lebanon (Kelley et al., 2015), Mitri (2009), noted that the influence of human activities in combination with damaging fires should give rise to concern about possibly full tree cover loss (***Figure 10***).

Table 5: bioclimatic zones (Abi-Saleh and Safi 1988)

Zone	Altitude	Dominant species	Observations
Thermo-Mediterranean	0 to 500	*Ceratonia siliqua, Pistacia lentiscus, Pistacia palaestina*	Plant communities in this zone are severely degraded, especially along coastal strip
Eu-Mediterranean	500 to 1000	*Quercus calliprinos, Pistacia palaestina, Pinus pinea, Pinus brutia, Cercis siliquastrum and Styrax officinalis*	Species and plant communities here have been continuously affected by wars, logging, charcoal production and firewood collection
Supra-Mediterranean	1000 to 1800	*Quercus calliprinos, Quercus infectoria, Pinus brutia, Pinus pinea, Cercis*	The vegetation cover is denser due to the reduction of human settlements in recent years
Mountainous - Mediterranean	1500 to 2000	*Cedrus libani, Abies cilicia and Juniperus excelsa*	Zone harbors relic formations of cedar, fir and juniper
Oro-Mediterranean	>2000	*Juniperus excelsa*	Juniper is the only tree species, is accompanied by xerophytic, and dwarf vegetation. Endemism is high due to the effects of isolation
Mediterranean pre-Steppic	1000 to 1500	*Quercus calliprinos*	Forest land is heavily grazed in the pre-steppic zones and the dominant
Supra-Mediterranean	1400 to 1800	*Quercus calliprinos Quercus infectoria*	Forestland is heavily grazed in the pre-steppic zones and the dominant species are a degraded garrigue. In the Anti-Lebanon chain some endemic species are present on western slopes while eastern side is very dry, overly grazed and severely degraded
Mountainous Mediterranean pre-Steppic	1800 to 2400	*Juniperus excelsa*	

Finally, forest fires are the most important contributors to forest degradation and the loss of ecosystems. It is regarded as the most harmful and endangering aspect, which causes a reduction in forest, cover. Wild fire activity is the subject of three types of well: ground fires, surface combustibles, and tree crown fires. The research noted things such as forest fires, in particular, when the woodlands have been subjected to successive forest fires that significantly restrict the likelihood of forest recovery reports, contributes to the total land degradation in Lebanese soil. These three kinds can really occur simultaneously (Faour, 2004). Forest fires remain one of Lebanese forests' major dangers and an important declining element, as seen in ***Figure 11***. According to official statistics published by the MOE, Lebanon has lost 837.96, 206.52, 1851.93 and 1870.54 ha of forests and OWL between the years 2012, 2013, 2014 and 2016 respectively (MOE/UOB, 2012, 2013, 2014 and 2016).

Figure 10: Forest fire Near Quamoua. Taken by camera (2019)

Grazing

May influence forest ecosystems badly. Poorly managed pasture practices contributed to forest cover loss in numerous locations, particularly in central and high mountainous portions of the nation. Goats may be particularly damaging with their desire to climb trees for green foliage. However, if correctly managed, forests can benefit from grazing by reducing combustible biomass and forest ground regeneration.

Charcoal

The over-explosion of forest resources for the gathering and manufacturing of charcoal leads large forest blocks to be fallen. Illegal and abusive falls. The grade charcoal they make is preferred by Oak and Juniper. Like grass, carefully studied and controlled production of wood and charcoal can have good effects on the forest, particularly forest fire reduction.

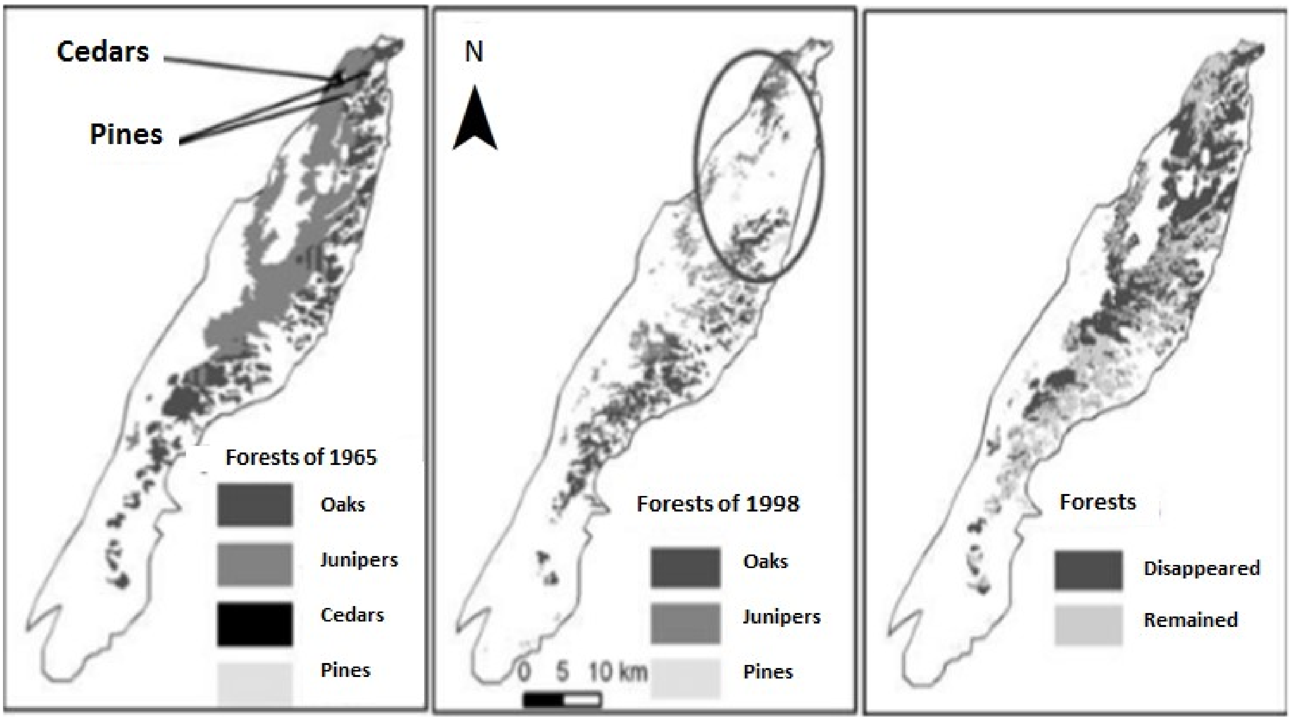

Figure 11: Spatial forest changes on the eastern flank of Mount Lebanon between 1965 and 1998 (Jomaa. et al., 2007)

Climate change

More than one effect is predicted from Lebanese woods. Forest fires are forecast to accelerate forest damage under more dry weather. In the mild winter, a major increase in insect populations was assumed to be caused by the breakout of Cephalcia tannourinensis (Ernobius libanensis) (Nemer, 2018). As species move to environments that satisfy their development needs, the existing distribution of forest species can alter (IDAF, 2009).

Insects and illnesses

Diseases and insects are part of a forest ecosystem that functions. Insect-pest disease outbreaks are uncommon events, which in certain circumstances might be linked to mismanagement. Tannourine cedars were badly damaged by Cephalicia tannourinensis (Ernobius libanensis) (***Figure 12***, ***Figure 13***). Great efforts have been made to control the plague (Nemer et al., 2005). Another important insect pest, Pinus brutia in particular, is a pine procession moth. The bug may defoliate trees seriously and impair their development in years of severe infestation. It causes serious allergic effects amongst humans and animals. The bug is of special importance. Many insects have been blamed for the dramatic decrease in Pinus pinea production and a reduction in the revenue of hundreds of farmers that rely on this tree (FAO, 2015).

Figure 12: Ernobius libanensis male (on the left) vs. female (on the right) by Khalil S. (University of Kaslik 2017)

Figure 13: Ernobius Libanensis attacked summer buds, by Khalil S. (University of Kaslik 2017)

Urban sprawl

The increasing population of Lebanon, warfare that displaced many and the high population density caused a loss permanently of many ideal forestlands along the shore and in the coastal mountains to accommodate dwellings, the industries, and services. (***Figure 14***).

Figure 14: *Cedrus libani* cutting in Ehden Forest. (Taken by camera 2019)

Quarries

The mineral richness of Lebanon is unsustainably exploited, and the mineral and the biological reserves are under considerable strain. Since most quarries are not controlled, they are very commonly utilized to their maximum capacity and then abandoned with little or no rehabilitation work. In addition, abandoned quarries deform landscape aesthetics and ecosystems that have already been under stress in Lebanon, notably in forests, and deteriorate. From 1996 to 2005, the number of quarries rose gradually from 711 to 1278 and dug areas almost doubled by 2875 to 5283 hectares (Darwish et al, 2008). Most of these quarries are in ecosystems of forests and borderlands, known for their great animal and flora variety.

Pollution and insect outbreaks

Thaumetopoea wilkinsoni (Dereix et al., 1999) threatens tree pine in Lebanon, which can attack Pinus brutia and *Pinus halepensis* in particular. In Meten, insects attack all the pinewoods. These wood boring insects have been shown to relate to a dry brown tip symptom of Ernobius sp. (Coleoptera). Insects are being attacked on pine tanks with an expansion, and pinecone collectors in the woodlands are announcing a broad dieback. The reason is species of the woodborer *Ernobius*, which are known to assault weakened or stressed trees (Kawar et al., 1998).

Leptoglossus occidentalis is a new insect plague that might cause direct harm to young cones by rejecting fluids on seed proteins (Nemer, 2015; Nemer et al., 2019).

There are chlorite pines in the Beirut Region, short fresh developments, limited output and numerous trees with dead and malformed crowns. Only the complex and complete effects of air pollution and pollution that Mediterranean conifers are thought to be particularly susceptible may be attributed to an extent of this degradation (Bussotti and Ferretti, 1998).

An insect complex made up of Hymenoptera as the primary pest, *Cephalcia tannourinensis* attacked the wild. Although the *C. tannourinensis* epidemic was limited to the Tannourine woodland, the Bsharre pest was also discovered (**Annex 3**). This plague and other pests may be found in different Lebanese cedar woods but do not seem to be a major risk (Nemer, 1999). Aklersin undulana, Cedrobium laportei, Ernobius lebanesis, Dasineura cederri, Phloeosinus cedri, Cinara cedri, Megassymus schimitscheki, Thaumetopea ispartaensis, Ernobius cedricida (Nemer, 2015; Nemer et al., 2019). The oak woods are extremely sensitive to powdery mildew conditions (fungal disease). All leaves of the tree heal and seldom cause damage or death (Masri et al., 2006). In the spring, the Lymantria dispar or the Gypsy Moth may attack the oak leaves and even whole trees (Masri, et al., 2006). There are few areas of forestry health in Lebanon and effective research is strongly needed.

Cutting and over-grazing

It is estimated that around a million cattle and sheep use forests and damaged mountains for not less than 2 months of each year (FAO, 1998). Consistent overgrazing has avoided forest regrowth and regeneration and has worsened the effects of deforestation. The village settlements in the forest have a low standard of life and restricted revenue production as well as seasonal jobs for agri-pastoral activities. Grazing and cutting vary between regions. The kind of ownership has a huge impact on forest biodiversity sustainability. From this perspective, it is necessary to remediate and take action to preserve and safeguard Greenland from grazing (Darwish, 2015).

2.5. Effect of Climate change on forests

The Mediterranean is a hot place of biodiversity (Myers N. et al., 2000); under constant anthropogenic strain for thousands of years now (Vernet, 1990). The impacts of continuous climate change and pressure are now facing humanity. In the coming century, increased warming and water strains are predicted to take place in the Mediterranean that might harm all ecosystems. In the southern and eastern Mediterranean areas, most of the woods and forests are under threat from reduced moisture availability that may be linked to global warming. Cedar woods are an iconic, but relatively large, yet fast decreasing habitat.

The climate is an important role in Lebanon's fire. When temperatures rise and air moisture and fuel moisture are limited, the number of fires tends to increase in summer. Wildfire ignition and activity are determined by:

- Prevailing circumstances
- Precipitation, relative moisture, air temperature and wind speed, and moisture content (Mitri et al., 2010).

Several investigations have demonstrated that extreme meteorological conditions, such as hot waves, lead to a fire severity and frequency rise. Salloum and Mitri (2014) noted that there was a positive correlation between the occurrence of fire and the variations of mean monthly temperatures and the variation of mean monthly precipitation and a mean monthly wind speed. The duration of the fire season was also observed to be adversely linked to average annual precipitation. In combination with high average temperatures and protracted seasons, an increased likelihood of a fire breakout and illness was found. To be more specific, the growth of the annual average temperature between 1964 and 2011 and the increase of the Summer Days Index (*number of days per annum when a maximum temperature is more than 35°C*) are more important in ***Figure 15***. (German et al., 2011).

The Third National Communication (TNC) predicts that in the hilly inland regions where most of the wooded areas are located, high temperatures will climb to 18° C near the coast of Lebanon by 2040. There are also anticipated substantial rainfall decreases, ranging from 10% to 20%. The annual average relative humidity changes should be small in 2040, with no major change in wind speed or cloud percentage. This is likely to result in a greater fire-frequency range with the forecast temperature increase and the expected precipitation reduction. In the future, the Lebanon risk for fire could be increased mainly if current land use practices do not improve, due to the failure to implement a National Forest Fire Management Plan and especially considering potential climate change as anticipated in the Third National Communication for Climate Risk, Vulnerability and Adaptation (MOE/UNDP/GEF) from Lebanon. Some such extreme occurrences include severe climatic change such as quaternary glacial cycle (Fady, 2005) and land clearance or logging (Robledo-Arnuncio et al., 2004).

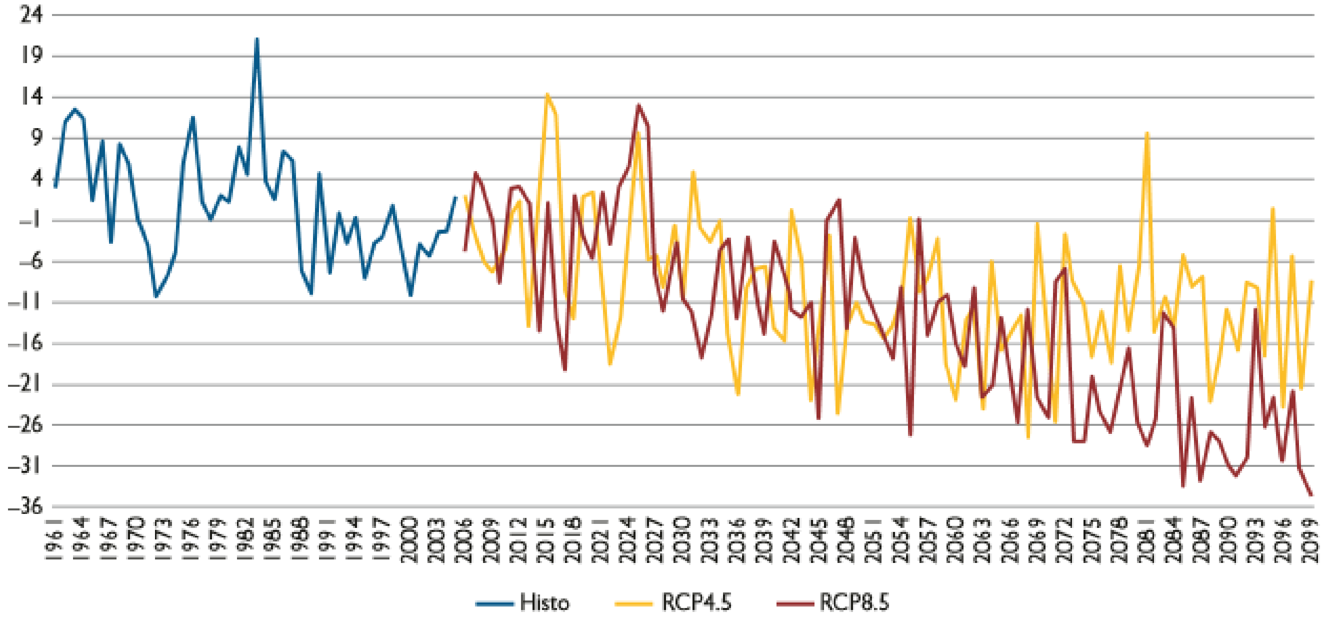

Figure 15: Annual Rainfall Anomaly in Lebanon Compared to the Mean Annual Total Rainfall for the Period 1976–2005. Source (ICBA 9 2017)

Drought, atmospheric systems, impacts and management in Lebanon, International Center for Biosaline Agriculture
Note: The blue line is the model's average for the oldest period, the yellow line is the model's average for the less-severe RCP4.5 scenario, and the red line is the model's average for the more-severe RCP8.5 scenario.

2.6. Environmental law and policies

2.6.1 Role of institutions to protect forest

The forest decline in Lebanon, and particularly in the Cedars region, was mostly due to the loss of canopy cover. Therefore, many public and private sectors (NGOs) have been revising the rules preventing forest decline.

The Government is focusing on the rehabilitation and ending of natural resource degradation of many sectors damaged by conflict. Several lines of government and public agencies contribute to the conservation and fight against land degradation of natural resources shown in ***Table 6*** of the MOA/UNCCD report 2003.

Table 6: Responsibility of the institution to preserve forest (MOA/UNCCD, 2003)

Type of Institutions	Nome of Institutions	Role of the Institution
Public Sector	MOA	-The MOA's mandate is to develop the agricultural sector, at both plant and animal level, to protect natural resources and manage them -The MOA has the mandate to undertake reforestation projects; to protect, supervise and manage the natural resources and to provide assistance whenever necessary. -LARI is a governmental organization under MOA supervision, the role of the institute conducts applied and basic scientific research for the development and advancement of the agricultural sector in Lebanon.
	MOE	It aimed at controlling all forms of pollution, the use of pesticides, deforestation and forest fires, solid waste disposal, protection of fauna and flora, and urbanization. These laws included the protection of natural sites, forestry, etc.
	CNRS	-The center main role involves contributing to scientific needs of the country, notably in securing data and structured information for redevelopment projects and environmental concerns. -The center also helps decision makers on actions and policies of relevance for use of space, remote sensing and GIS emphasizing environmental concerns.
Private Sector	NGO's	-Research Institutions and International Organizations Several NGOs are concerned with issues related to combating desertification. -Another active had implemented a project aiming at awareness raising about the problem of desertification -Another active had implemented a project aiming at awareness raising about the problem of desertification. -NGOs are involved with highly interesting activities in terms of natural resources conservation and reforestation activities ex: LRI, AFDC, LOST, Jouzour Lebanon....
	Research institutions	Like the of AUB, USJ, the Balamand University, the Holy Spirit University, and the Lebanese University… and the private sector are very active in Lebanon: -They are involved in projects dealing with monitoring, managing and accessing the natural resources, the erosion mechanisms and the socio-economic aspects in relation with land use and land degradation. -Several **international organizations** are bringing financial support to assist in the rehabilitation of the natural resources of the country, through capacity building, project implementation and technical assistance. These organizations are World Bank; FAO; GTZ; UNDP; USAID; IFAD; EU; GEF.

2.6.2. National legislation policies and strategies

The Ministry of Agriculture is responsible for forest management. A comprehensive assessment of the protection of the forests in Lebanon and biodiversity and biodiversity has been used in 2009, according to the National Report of the USAID forest and biodiversity financing. A quick review of national legislation, regulations and policies of Lebanon is shown in ***Figure 16***.

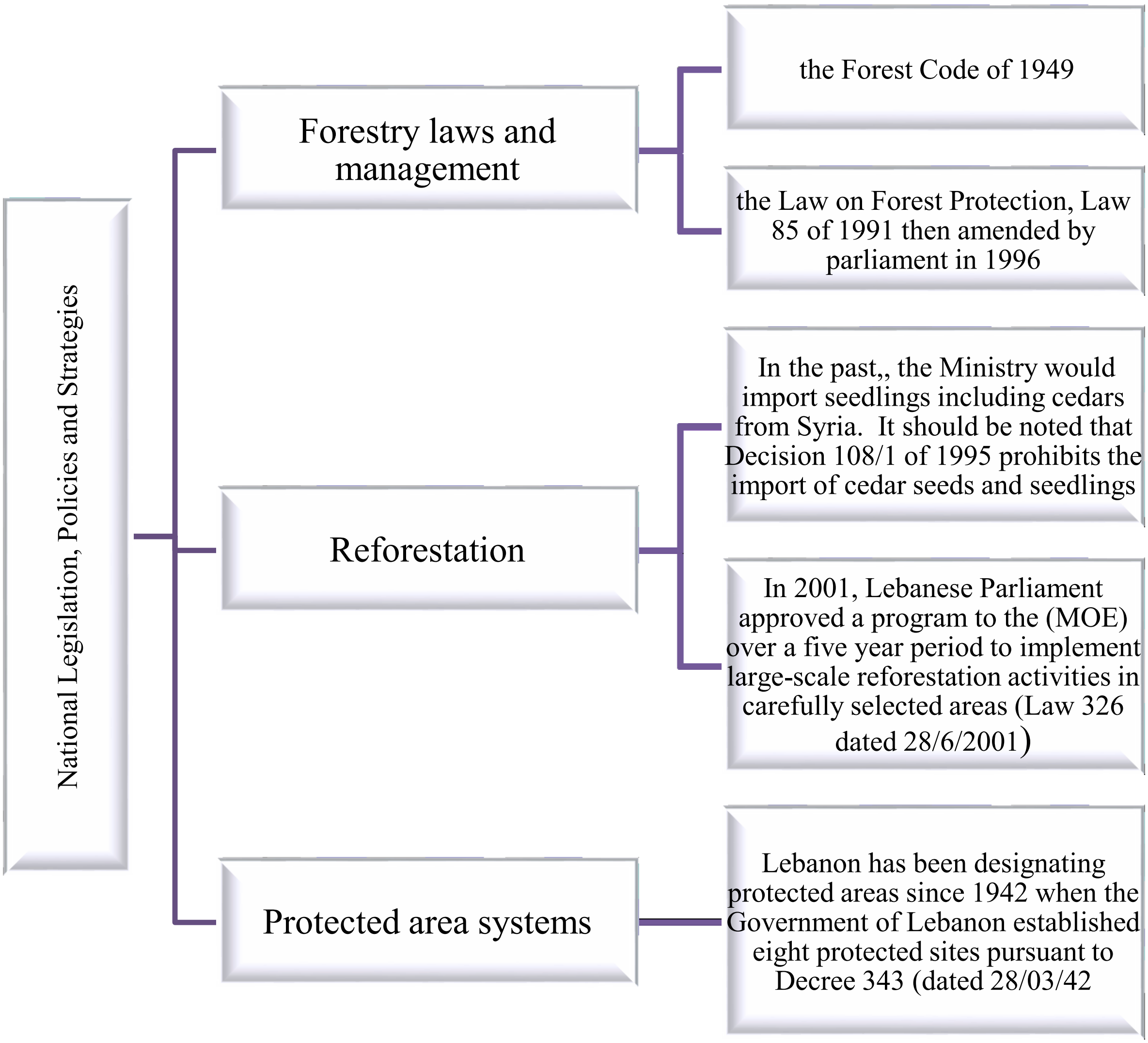

Figure 16: National legislation, policies and strategies (USAID, 2009).

Apart from the Lebanese Government, various laws, decrees, and ministerial policies are now being made on forestry preservation and management decisions. A national strategy for forests is developed in Lebanon.

Act No. 558 of 24 July 1996: All coniferous woods were deemed safeguarded by statute No. 558 (state owned and municipality-owned forests) the guarded Forest legislation stipulates the establishment of a Rural Development and Natural Resources Forest Protection Service at MOA

(***Figure 17)***. It also formed the foundation for the identification and administration of protected areas, financial aid, supervision, operations, violations, and citations:

- Afforestation/Reforestation
- Regulating hunting
- Grazing
- Geographic zoning of forest land
- Maintenance of forest cover.

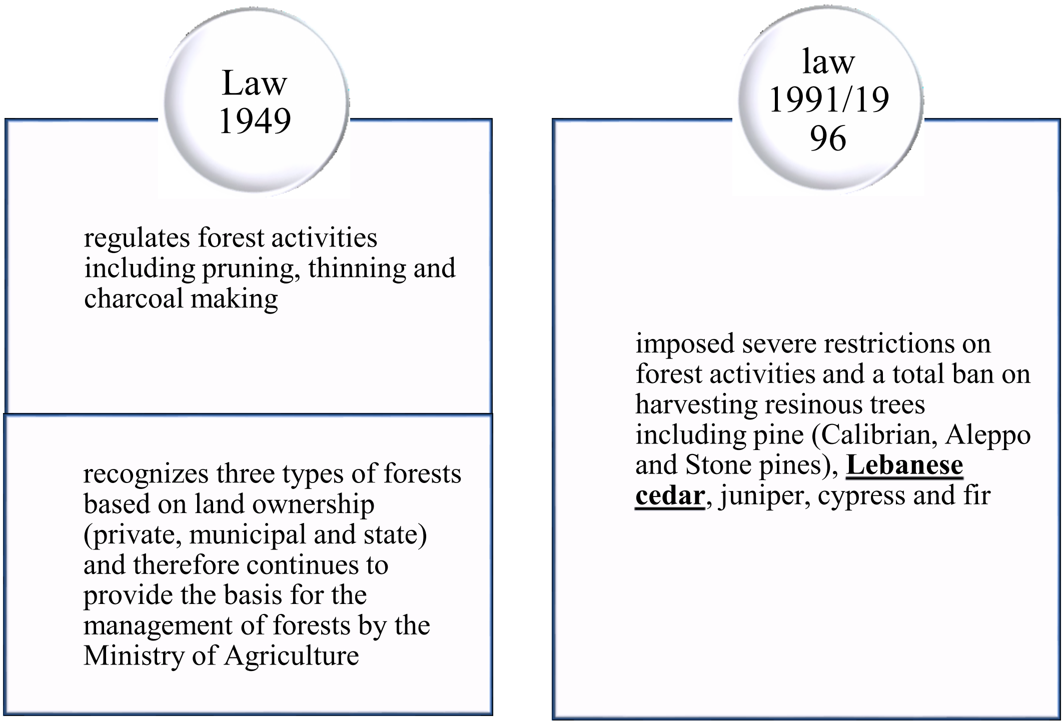

Figure 17: Law approved by MOA and MOE

2.6.3. Law and region of protected area

In accordance with Decree 343 (28/03/42), the Lebanese government has established eight protected sites (**Annex 4**). Early preserved sites ranged from urban parks (Horsh Beirut), spring (Nabaa el laban), woodlands (Mrouj oak forest and Bcharre cedar), and historical monuments (temple of Baalbeck). A few ministries since 1942, including the Ministries of Tourism, Agriculture, Culture and Environment, have designated protected areas. (***Table** 7*)

In June 1992 in Rio, de Janeiro Lebanon signed the CBD at the Earth Summit (***Figure 18***) in 1994; the government established its NBSAP following its ratification (Law 360/94). Among many stated objectives, it was designed to continue the preservation and management of the system of protected areas in natural and seawater conditions, and establish an equitable ecosystem for natural development by plants and animals. (Anonymous, 1998) with an aim of expanding and maintaining the system of protected areas in terrestrial, marine and freshwater environments. Major land biodiversity management objectives describe the adoption and local participation of methods leading to sustainable usage.

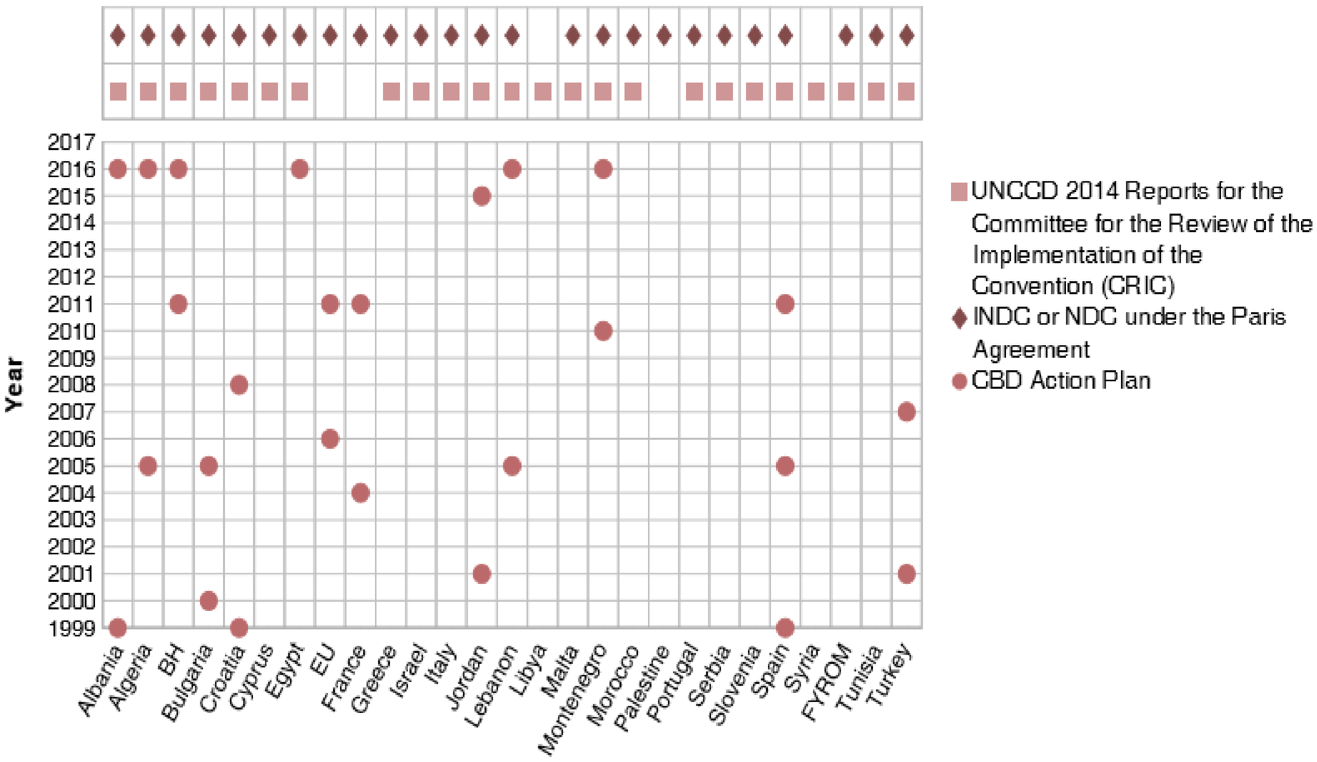

Figure 18: Mediterranean countries that have ratified all the main international conventions and agreements and dates (when available) State of Med. Forest 2018.

On the other hand, CBD articles, the integrated approach to ecosystems and natural resource conservation have been mainstreamed by this nation, with the prospect of sustainable development. Therefore, 90% of the Hima population in Lebanon may work on this choice in ***Table** 7* ,Hima and the Cedrus Lebanon natural reserve.

Table 7: Laws and Hima of *Cedrus libani* by (MOA, MOE and Ministry of touristic)

Hima and nature reserves of Cedrus	Law/Decision
Horsh Ehden Nature Reserve	Law no. 121 of 1992
Al Shouf Cedars Nature Reserve	Law no. 532 of 1996
Tannourine Cedar Forest Nature Reserve	Law no. 9 of 1999
Bentael Nature Reserve	Law no. 11 of 1999

Karm Chbat Forest Nature Reserve	Ministerial decision no. 14 of 1995
Al Kammoua Area (Akkar)	Decision no. 19 of 2002
National Hima from Maaser Al Shouf to Dahr El Baydar	Decision no. 127 of 1991
National Hima in Al Kammoua mountain (Akkar)	Decision no. 165 of 1991
Tannourine, Hadath El Jebbe, Jaj and Al Arz forests	Decision no. 499 of 1996
Cedar forest in Swaysi area (Hermel)	Decision no. 587 of 1996
Cedar, Shouh, juniper forest in Kammoua (Akkar)	Decision no. 588 of 1996
Cedar, Shouh and juniper forest in Karm Chbat (Akkar)	Decision no. 589 of 1996
Cedar, Shouh, juniper, oak, ofis, and malloul forest in Bezbina (Akkar)	Decision no. 591 of 1996
Cedar, Shouh, juniper, oak, ofis, and malloul forest in Ain AlHokaylat and AlKeif Kirnet and shalout (Al Diniyé)	Decision no. 8 of 1997
Cedar and juniper forest in Jurd Al Njass – Al Arbaen mountain (Al Diniyé)	Decision no. 9 of 1997
Cedar in Sfiné village (Akkar)	Decision no. 10 of 1997
Cedar, Shouh, juniper forest in Marbine - Jhanam Valley (Akkar)	Decision no. 11 of 1997

3. Afforestation and Reforestation activities

In 2006, the FAO presented two reforestation definitions, land forested during the last 50 years, but replanted with one species (often imported), for example, most wood or planting pulp. The second is built on land which in the last 50 years was forested earlier, but renewed with the same crop (or indigenous species) as before, e.g., lumber plantations, but far less frequent than before.

The forest fires constitute a special regional concern for the Mediterranean forest ecosystems, as mentioned at the start of the Agadir Declaration, which require specific regional solutions, such as joint monitoring activities, which are supported by regional cooperation declarations in forestry policy. A network of EU and other Mediterranean Member States, including Algeria, Lebanon, Morocco, Tunisia and Turkey, may benefit from new collaborations in the Region and the European Forest Fire Information's System (EFFIS). (Mediterranean Forestry, State 2018).

A regeneration strategy can be based on IUCN's Guidelines on Forest Restructuring and the Society for Ecological Conservation's Recommendations (IUCN, 2007). It has concentrated on enhancing the varied nature of forests and tree crops by increasing the number of drought-tolerant plants, restoring forestry-heterogeneity settings and breaking down artificial, disrupted and/or abandoned ecosystems. In addition, it is necessary to integrate several life strategies for increasing resilience (such as Quercus Spp, Arbutus Spp, etc.) and restoring firebreak and erosion riparian plants.

Forest management is a duty of the Agriculture Minister of Lebanon (Department of Forests and Natural Resources). In the late 1960s as well as in the mid-1970s Lebanon has led nation-wide replant-building initiatives called the Green Plan; a vast quantity of plants and seeds have been planted in vast parts of the country. Whilst now the Green Plan remains a semi-autonomous agency, its scope and purpose have shifted from reforestation to land restoration. Lebanon spearheaded a nationwide restructuring project dubbed The Green Plan both in the late 1960s and mid-1970s; in several areas of the country a huge number of plants and seeds were plant. While the Green Plan remains a partially independent organization, it is currently shifting its scope and aim from reforestation to land recovery. The Department of Forests and Natural Resources continues to participate in small scale replanting notwithstanding this shift. An anticipated 200,000 seedlings in nine plant nurseries around the country were supplied in 2008. The Lebanese Parliament supported in 2001 a 16, 7 million $ program for upgrades of significant forestry practices in carefully selected regions to the Ministry of the Environment (MOE), over a five-year period (Law 326 dated 28/6/2001). This is how the MOE defined the NRP and the Phase 1 (2002-04), two (2004-06) arrangements by contracting commercial nurseries to collect seeds, supply, and transplant plants on municipal-government land and to provide a water system and replacement for two years. MOE planted 305 hectares of municipal lands during its startup phase (2002-06), which spread across 23 locations, using species of autochthonous timber. The lack of cooperation between MOE and MOA hindered the effort.

Recently, the MOA, in accordance with the NRP – The '40 million trees program, also started a nationwide campaign in 2014. Finally, this initiative will design 40 million forests on 70,000 hectares of public property in the next 20 years, raising the cover of forests from 13 percent to 20 percent of the whole area of Lebanon (MOA, 2015). Fire wise–Lebanon is a joint effort, inspired by the Fire way-US Program under a Lebanon Reforestation Initiative. It aims to enable local communities to work together to prevention and decrease the dangers of wildfires that adversely affect local communities in economic, social and environmental terms. Based on factors including high fire danger and socio-economic and environmental importance, sites have been selected (State of Mediterranean Forest, 2018).

While restoration takes large amounts of money, policies, forestry frameworks and programs in Lebanon remain the only chances to exploit land degradation, such as the NARP, the Lebanese 40 Million Trees Program. Blueprint. The Ministry of Agriculture in Lebanon has developed this Program (NARP), which seeks to expand forest cover from 13 per cent to 20 per cent of Lebanon's total land over 20 years, with the support of FAO. This objective is to increase the forest cover by 7 percent through a forestry plantation program of 40 million trees and promote sustainable forest and other plants (MOA/CNRS, 2018).

Some important projects outlined in MOA/CNRS 2018 study, for example, have already been begun and implemented to resolve partly or wholly the restoration of forest landscapes (***Figure 19***):

- The Smart Adaptation of Forest Landscapes in Mountain Areas (SALMA), the FAO's five-year MOA sponsorship program. The main aim of the program is to restore forests up to 1,000 hectares and to manage another 1,000 ha.
- The Forest Landscape Restoration Mechanism (FLRM) aims to foster national efforts targeted at enhancing forest protection and the natural environment, supporting sustainable resource funding systems and improving the regulatory framework controlling natural forests, such as forests.
- Project FAO Technical Cooperation Protocol to enhance MOA ability for project management, production and reforestation standard rescue seedlings and capacity strengthening in planting and natural forest management.
- The project PARSIFAL, financed by the French Development Agency. This initiative aims to aid vulnerable communities by restore a range of goods and services to no less than 700 hectares of natural land.
- The third phase of the USAID-funded initiative has finally arrived at a Lebanon Reforestation Initiative (LRI). During the first two phases, about 800 hectares of forests were planted and supported by the local network of natural forest trees and shrub producers. (***Figure 20***, ***Figure 21***).
- GEF-funded and conducted under the UN Development Program is MOE project The Save and Restore Lebanon's Wood (UNDP). In Lebanon, it aimed to promote forestry efforts and methods. In the following two decades, MOE helped develop a management system to restore damaged forests by piloting novel planting methods to improve survival of plantation and disseminate technology at lower cost over the next two decades.

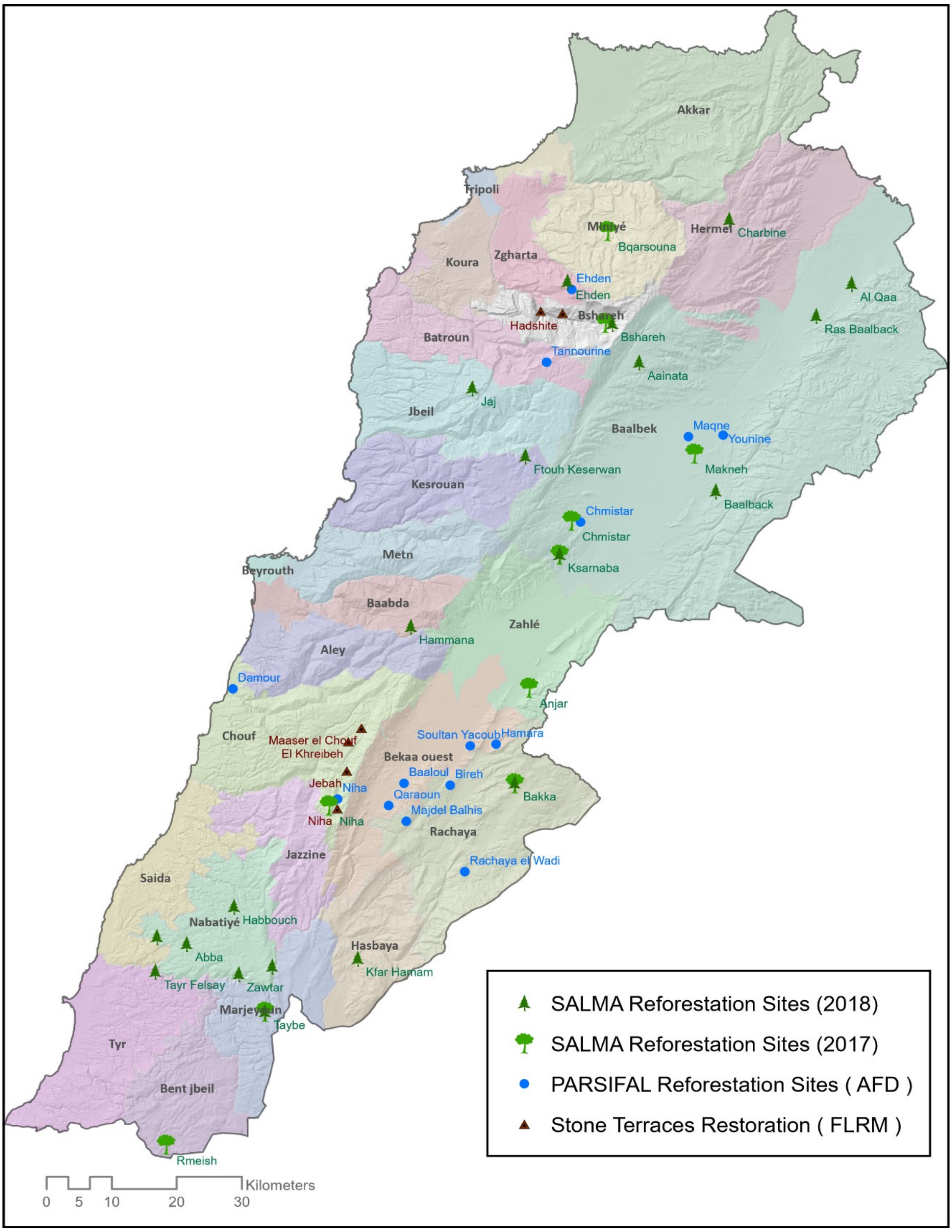

Figure 19: Planned and ongoing restoration activities (MOA/CNRS, 2018).

Figure 20: Reforestation of *Cedrus libani* near Ehden Forest planted by Mouawad Foundation (Taken by camera, 2019)

Figure 21: Region Bcharri near Cedars of God planted by NGO's local (Taken by camera, 2019)

4. *Cedrus libani* species in Lebanon

The FRA 2005 study detailed the Lebanese forest area, which estimates that 13.3 percent (139,376 hectares) of total forest, area is broken up into three subcategories (level 2): coniferous, broad-leaved and mixed forests.

In Lebanon, wildlife forests account for 56.6% of the total forest area. Lebanon's (78,887 hectares). Coniferous woods make up 32.2% of the forest area in the second biggest category (44,879 hectares). Mixed forest, defined as coniferous trees and wide-flowing trees containing at least 25% (15,610 hectares) accounts for 11.2% of the total forest area. Coniferous forests are found primarily in the Mediterranean subtropical mountain ranges. They have been used for wood consumption for years, and their area is said to have shrunk dramatically. ***Table 8*** in FRA 2010 and ELARD (2010) represents the major forest species in Lebanon. Oak (41.6%), pine (20%) and junipers are the main forests in the Lebanese area (8.5%). Cedar woods account for 1.6% of the total area of the forest. The fir woods (1.2%) and the cypress (0.24%) form a niche in the mix of cedar, juniper and pine coniferous forests. A large part of the mixed coniferous and wider woods (26.56%). Riparian forests occupy 0.04% of the total Lebanese forest cover. In Lebanon there are, according to the NFA, 45,000 hectares of coniferous forests, mostly pine groves, protected coniferous stands and reforested regions. (NFA, 2005). *Cedrus libani* are 4.4% coniferous (***Figure 22***), and an estimated 43,657 hectares of coniferous woods.

Table 8: Forest type distribution in Lebanon (FRA, 2010)

Forest type	Forest cover %
Oak	41.6
Mixed forest	26,52
Pine	20.3
Juniper	8.5
Cedar	1.6
Fir	1.2
Cypress	0.24
Riparian Forest	0.04

The coniferous forest, according to the species makeup of the trees, is separated into distinct forests. The other pine forest (Pinus brutia and Pinus halepensis) is the most important of the coniferous forest types, accounting for 17,952 ha of the total coniferous forest area. The coniferous forest is made up of 10,502 ha of Juniper Forest, 7943 ha of Pinus pinea Forest, 2019 ha of Cedar Forest, 1257 ha of Cypressus Forest and 5206 ha of mixed coniferous forest. (NFA, 2005). (***Figure 22***)

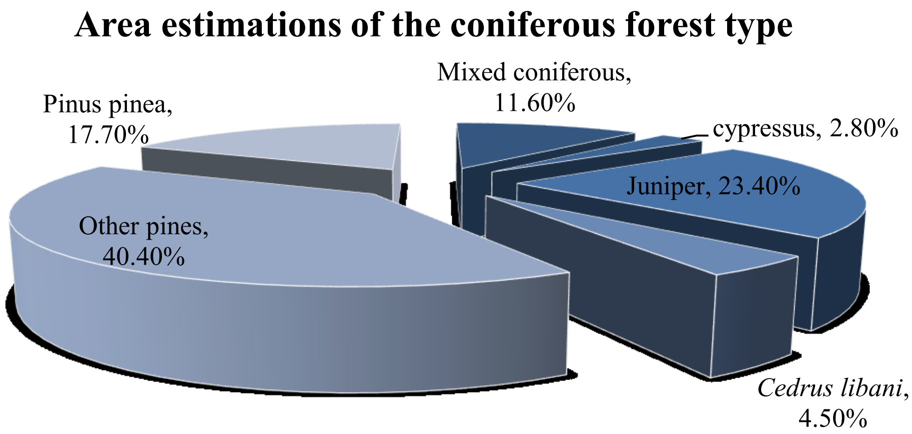

Figure 22: Area distribution for coniferous type (FRA 2005)

4.1. Ecological distribution and status

For the early civilizations of the Near East and Nile, Cedar's woodland was a major timber supply from the times of the Phoenicians who used it to build a ship, construct a temple and so on, and who made a prosperous business exporting cedar wood to Egyptians. These wood resources from The Assyrians and later the Romans made use of Lebanon. During the 1914-1918 war, the remainder was mostly exploited and destroyed for rail fuel. Dr. M.W. Mikesell is now conducting research on the history of the cedar woods (University of Chicago). Historically, for shipbuilding and constructing temples the wood has been utilized extensively. The genetic diversity of cedars in Cedrus Lebanon is the highest among all cedar populations (Scaltsoyiannes 1999; Bou Dagher Kharrat, 2001) and Cedar woods presumably covered huge portions of the Near Eastern Mountains at one point (Nahal, 1962) but real data is not available.

Figure 23: Old tree of *Cedrus libani* cutting in Ehden forest. (Taken by camera, 2019)

In Lebanon, the end of the conflict resulted in mountain resorts and summer resorts pursuing land developers. The abiotic (e.g. wind speed, terrain, temperature) and biotic influences allow trees to spread from boundaries at various distances (i.e. plant competition, grazing, and deforestation), (Fordham, 1977), ***Figure 23***.

Cedar spreads in the Mediterranean slopes of Mount Lebanon over an ongoing stretch from 1400 to 2000 m a.s.l., (***Figure 24***). The cedar stands are restricted to places near the west slope of Mount Lebanon towards the Mediterranean Sea, where fog and nude balance evaporation in summer. (Beals, 1965; Mikesell, 1969; Khouzami and Nahal, 1983; Talhouk et al., 2001).

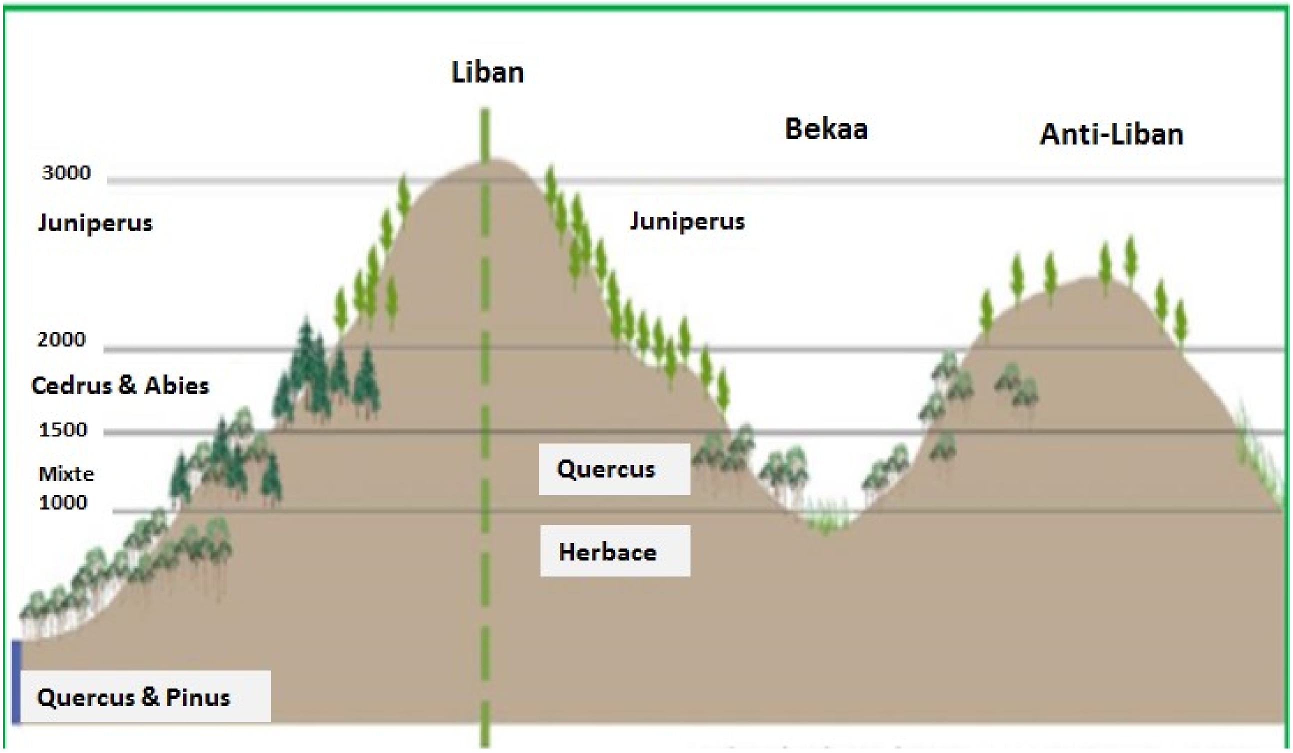

Figure 24: Coniferous situation above sea level in the mountains (M.E. de Vaumas and P. Mouterde)

The use of decorations manufactured from cedar wood (Khuri and Talhouk, 2000) in Lebanon is restricted, but protection is provided to the trees (***Figure 25***). Lebanon cedar is one of four Cedrus species (Boydak 2003; Sattout and Nemer 2008). Sattout et al. reported in 2006 that cedar woods in Lebanon provide refuge for a wealth of biodiversity and are major mountain relic ecosystems with a wide range of unique, uncommon, and endangered species and economical potential. Lebanon's cedar is a light and drought resistant species but can also be maintained at a young age in partial shadow circumstances, it also grows long (over 1000 years old) and reaches amazing dimensions and appearances (El-Hanna et al. 1999; Boydak 2003). Endemic or sub endemic to the Mediterranean basin is the genus Cedrus (SETS, 2007). In past times, these woods, formerly spanning the eastern and the western mountain ranges, supplied valuable lumber to the region. The old methods have left the country with only twelve woodland remains spread throughout Mount Lebanon. Although internationally known as flagship species and cultural, religious, and historical attractions, these woods garnered minimal international conservation money (***Table 9***). Along the coast, are present many conifers woods (cedar, Cyprus, fir, juniper and pine), or deciduous trees (carob tree; European hop-hornbeam; manna ash; oaks; pistachio tree). Woods and forested regions (easterly woods) have formed, as well as semi deciduous ones (*Aleppo oaks*) and evergreen ones (*Palestine oaks*) (Abi-Saleh, 1978; MOA and FAO, 2005). They occupy just 0.86% (1135 hectares) of Lebanon's total forest cover (El-Khoury and Bakhos, 2003). Their estimated area before 5000 years of operation was 500,000 hectares (Alptekin et al., 1997).

Figure 25: Bcharri Forest cedars, Souks (Taken by camera, 2019)

The first studies by Beals (1965) on natural reserves revealed that (***Figure 26***). The current distribution of cedar-associated flora is limited to twelve areas, from north to south.

Table 9: Importance value given to various attributes of cedar forests percentage (Sattout. et al., 2006)

Reason	Very important	Moderately important	Slightly important	Not important at all	Do not known
Biodiversity	71.5	15.6	7.9	3.4	1.6
Wood products	10	10.6	12.2	63.1	4.1
NTFPs	47.5	23.7	15	12.2	1.6
Landscape	83.1	11.9	2.5	1.25	1.25
Symbolic and cultural	60.3	19.4	10.6	8.7	1
Recreational	58.75	26.5	10.3	3.75	0.7

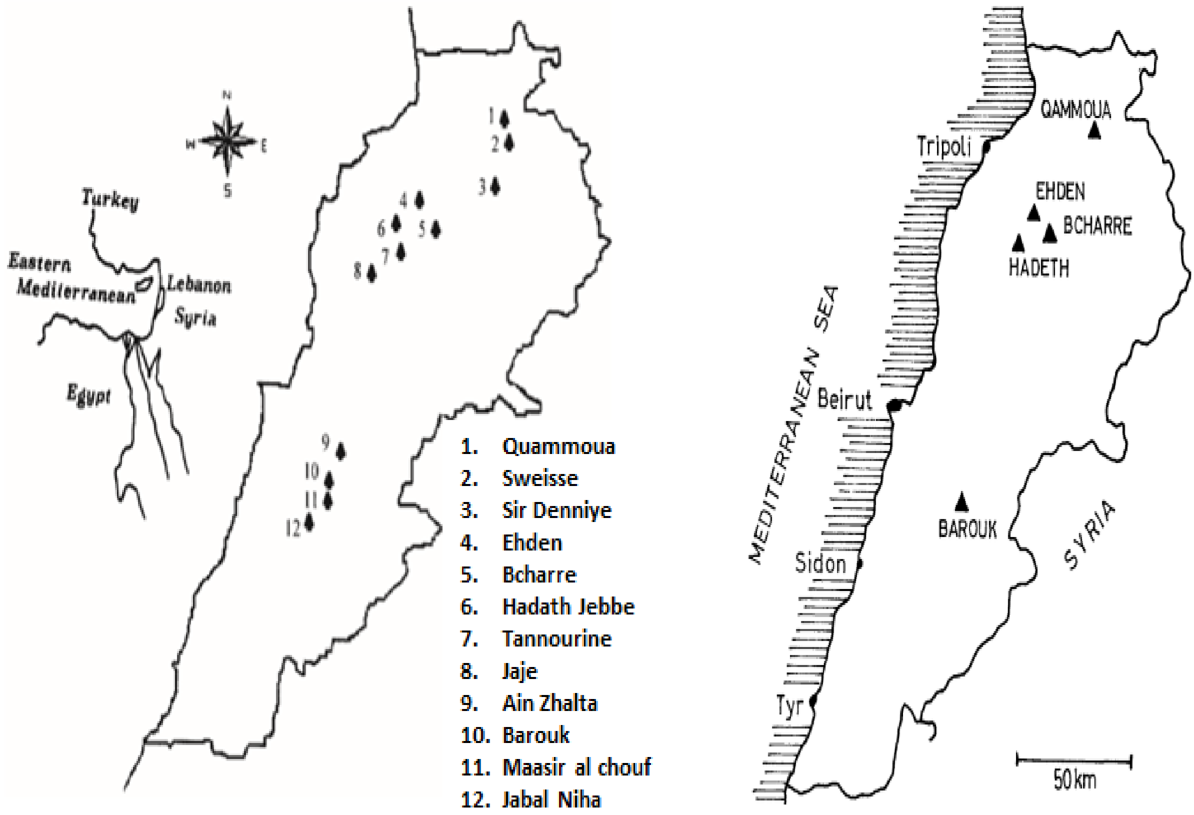

Figure 26: 1: Map of Lebanon, Major cedar forest remnants (Beals, 1965).2: Map showing the geographical of the fragment population of *Cedrus libani* (Khury et al., 2000)

These areas include Jabal Qammoua Forest, Wadi Jahannam for Akkar, Ain Zhala/Bmohrain, Barouk, and Maasser el Chouf Mountains in the Jubail Mountains, Ehden, Bcharre, Tannourine-Hadeth, and Jeij. Most of the latter are pure cedars; however, half of them is less than 50 hectares. They are in IUCN CPD site SWA 17 (Davis et al., 1994). (***Table 10***). The defined sub-population (Khury et al., 1999) is made up of 15 divided stands (***Figure 26***).

Table 10: Forest of *Cedrus libani population* (Khouzami, 1994)

Name of forest	municipality	Elevation(m.s.l)	Area (ha) 1965	Area (ha) 1988	Land tenure
Qammoua	Akkar	1400-1900	378	269	National government
Sweiss, al hermel	Akkar	1500-1750	312	273	National government
Ain mraaj	Akkar	1400- 1750	44	44	National government
Al Najas	Akkar	1600- 1750	17	17	National government
Seer el Donniye	Akkar	1500- 1800	632	565	National government
Sawaqi	akkar		7	0	National government
Ehden	Zgharta	1350-1800	225	225	Local government, nature reserve
Bcharre	Bcharre	1950	11	11	Local government, Religious holdings
Hadath Jebbe & Tannourine	Bcharri-Batroun	1200-1850	589	547	Local government, Religious holdings
Jeij	Jbeil	1500-1800	50	50	Local government
Bmohrai & Ain Zhalta	Shouf	1100- 1700	128	104	Local government, nature reserve
Barouk	Shouf	1500- 1700	171	185	Local government, nature reserve
Dahr al Arez	Shouf	1750	4	4	Local government, nature reserve
Jiwar al abhal	Shouf	1750	2	2	Local government, nature reserve
Maaser el shouf	Shouf	1400- 1650	12	16	Local government, nature reserve
Jabal Niha	Shouf	1700	1	1	Local government, nature reserve

According to Davis et al., 1994, more than half of which have an area of occupancy of less than one km^2 and are in a state of severe degradation. The second distribution by (Baltaxe, 1966; Khouzami and Nahal, 1983; Bariteau et al., 2000) only 12 scattered remnants (***Figure 27***) survive of the once extensive stands of cedar, fir, and juniper. The actual AOO of *Cedrus libani* in Lebanon is 22 km2 (Talhouk, 2001). Today in Lebanon, most of *Cedrus libani* forests cannot expand any higher because they are already located at the summit of mountains. Only Bcharre (***Figure 28***), Ehden and Tannourine/Haddath al Jibbe have higher altitudes. Fady et al., (2008) show that cedars from Tannourine/Haddath al Jibbe have a high genetic diversity, as suggested by Cheddadi et al., (2009).

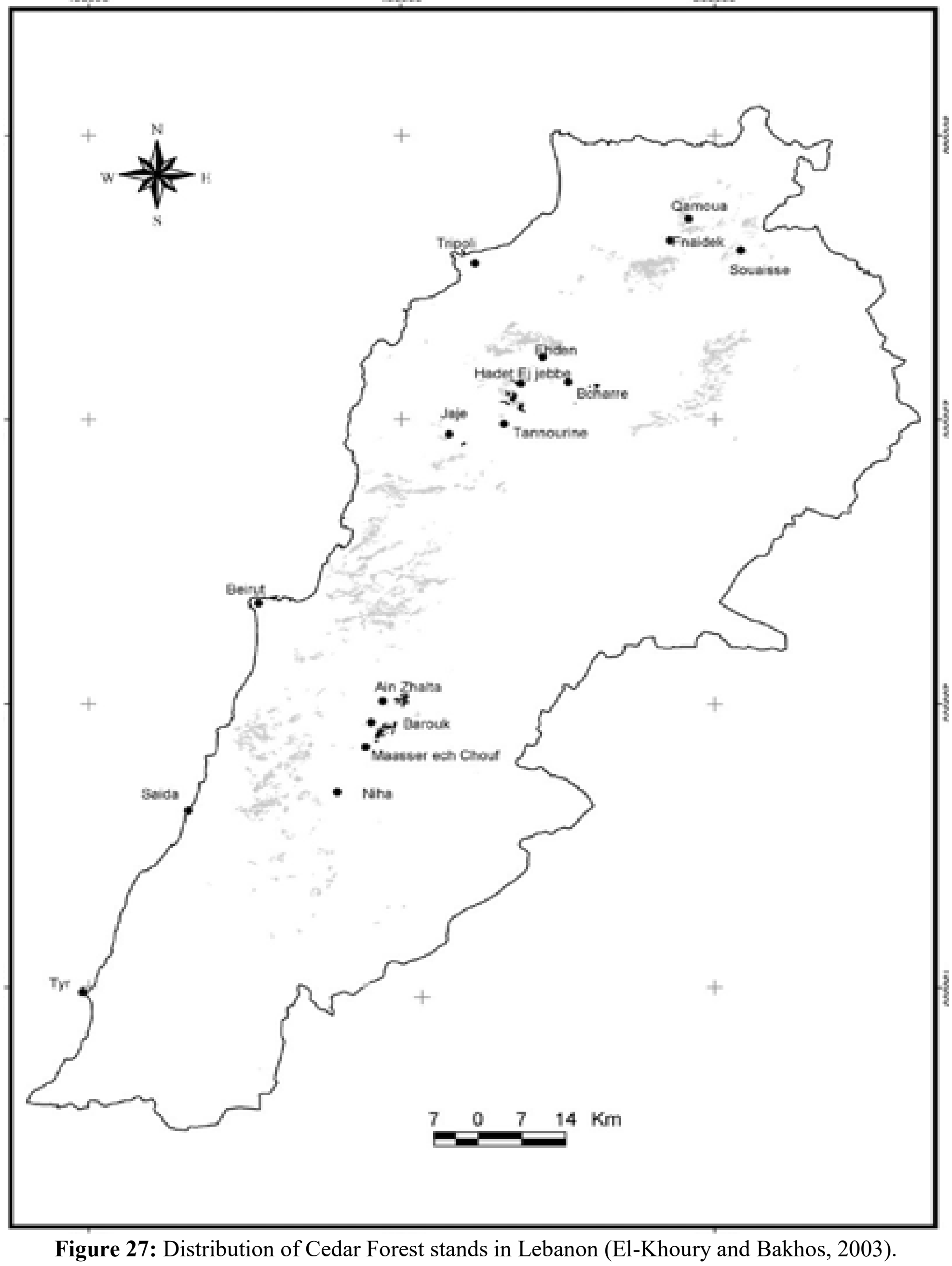

Figure 27: Distribution of Cedar Forest stands in Lebanon (El-Khoury and Bakhos, 2003).

Figure 28: Bharri, Cedars of God, (Taken by camera, 2019)

4.1.1. Biological value for *Cedrus libani*

The *Cedrus libani* occurs amongst species listed in IUCNT 1983, and Hilton-Taylor (2000), as a lower-risk and near-threatened taxon, but cedar is categorized as a threatened or on the path of extinction by national records (Khouzami et al., 1996). Lebanese cedar woods are shelters of wild plant life and home for species of flora which comply to CITES standards, such as Cyclamen coum (Mill), and to Sternbergia clusiana, (Ker Gawl) ex Sprengel, in compliance with CITES guidelines. Cedar woods in Lebanon have an estimated range of plant species between 500 (Tohme et al., 1999a, b) to 1030 (Semaan and Haber, 1998). National surveys in mid-1990 on plants, birds, mammals, amphibians and reptiles included 2.9% endemic, 2.6% endangered and endangered, and 4.43% rarity species (***Figure 29*** and ***Figure 30***). The 30.47% and 8.07% of economical plant species are relevant birds breeding species (Khouzami et al., 1996).

Figure 29: Forest Ehden, biodiversity (Taken by camera, 2019)

Figure 30: Forest Ehden, biodiversity (Taken by camera, 2019)

4.1.2. Biomass of *Cedrus libani*

Accomplished by the National Forestry Program (NFP), various variables might damage the forest biomass, such as species abundance, biomass production capacity within a period, exploitation, fire events and decomposition rate. We discover a considerable biomass of cedars and juniper stands despite the sizes of the stands are modest as shown on ***Table 11***.

In the forest of Lebanon, the stock of live biomass and carbon is mostly low. This has to do with the forest and the mismanagement, because many natural species of forest are not recognized as a reserve and can be destroyed by everyone. This fact helps to reduce strain on forest resources in other areas that contain fruit trees, which account for a substantial proportion of the overall increasing biomass and carbon stock.

Table 11: Calculation of living biomass of *Cedrus Libani* forests (FRA, 2005)

Type	GS (million)	AGB (million tons)	BGB (million tons)
Cedrus Libani	0.31	0.16	0.04

AGB Aboveground biomass (tonnes)
BGB Belowground biomass (tonnes)
GS Growing stock (volume) over bark (m^3)

4.1.3. Taxonomy of *Cedrus libani*

The Lebanese Cedrus belongs of the Pine Family (Pinaceae). The cedar is single, and it bears unisexual flowers with the same plant, both male and female (***Table 12***). The men are solitary, erect, about five cm long and appear at the end of short shoots. The female cones are crimson and smaller and can be found at the ends of the dwarf shoots alone. They are big in form and break up when grown, while still fixed to the branches. In the second year, female cones mature for the whole development time of around 17 to 18 months (***Figure 31***). Young cones are bright green, adult dark brown cones (***Figure 32***). The tree branches are often upright or scattered. The ancient trees are generally split into many rough, upright branches; the secondary branches are horizontal and occasionally spread far from the trunk.

Figure 31: Hadath Jebbe, cone of *Cedrus libani* Taken by camera, 2019)

Figure 32: Forest Tannourine Cedars, Female cone (Taken by camera, 2019)

Depending on the density of the stand the tree shape, especially the shape of the trunk. The *Cedrus libani* grows straighter on a high-density stand (***Figure 33***); whereas the *Cedrus libani* develops, it is lower horizontal branches and distributes them on vast distances on a low-density stand when they grow.

Figure 33: Old Tree of *Cedrus libani* in Ehden Forest (Taken by camera, 2019)

The Lebanese cedars is more numerous and well designed in north-facing paths, where radiation has less influence, but also flourishes in the wetter conditions on the side of the mountains due to the predominant rainy breezes. These slopes face the sea in the Mediterranean. Snow from winter is a significant water source in spring (***Figure 34***). Annual precipitation is generally above 1000 millimeters in Lebanon where woods of Cedrus exist.

A widespread soil erosion throughout Lebanon may have made the species more susceptible to meteorological conditions and may have limited the quantity of cloud formation through plant denudations. Shade tolerance is usually minimal; all of live cedars require plenty of sunshine. Cedrus generally forms clean, relatively open woods, with low undergrowth of low-shrubs grasses, but is intermingled with other conifers and oaks as well. (***Figure 35***) (Masri. 1995).

Figure 34: Snow on Ehden forest naturel *Cedrus libani* (Taken by camera, 2019)

Figure 35: Shrubs and new Cedrus regeneration in Ehden forest (Taken by camera, 2019)

Table 12: Taxonomy of *Cedrus libani* (IUCN 2013)

Taxonomy	
Kingdom	Plantae
phylum	Tracheophyta
class	Pinopsida
order	Pinales
family	Pinaceae
order	Pinales
Taxon name	*Cedrus libani*
Common name	Cedar of Lebanon, Lebanon Cedar, Cedre du Liban
Taxonomic source	Farjon, A 2010 Handbook of the world's conifers, Koninklijke Brill, Leiden.

4.2. Stakeholder status of collaboration

The participants in sustainable cedar forest management plans in Lebanon are the MOE, the MOA and the MOIA, the Municipalities, the private sector (Eco tours and businesses with nature), the NGOs, academic institutions (woodworking workers), the plant collectors (plant workers) and the communities and all community members, the main beneficiaries are communities and non-governmental bodies, respectively (***Table 13***). The ones allocated for the employment of local rangers and those from woodcraft micro-industries in Bsharre village and from the donation fees collected at the entrance to the cedar nature reserves of Al-shouf, Bsharre and Ehden.

4.3. Description of *Cedrus libani* Forest

4.3.1. Characteristic of *Cedrus libani Ain Zhalta*

Shouf biosphere contains the *Shouf Cedar Nature Reserve* and the *Ammiq Wetland*, and 22 communities with 70,000 inhabitants in the core and buffer area of the reserve. The SBR comprises of a core zone, a buffer area, and a transition area for their various purposes. The *Shouf Biosphere Reserve* altitude varies between around 1000 m to 2000 m. Jabal el- Barouk is situated on the southernmost edge of the cedar growing range, on the slopes of the central section of the Mount Lebanon chains.

Table 13: Responsibilities and revenue sources of all stakeholders of the cedar forests in Lebanon (Sattout et al., 2008)

Stakeholders	Responsibilities	Rights	Revenues
MOE	Management of cedar forests declared as nature reserves	Supervision of conservation priorities and activities	International funds annual budget allocation
MOA	Protection and management of all remaining cedar forests	Control access to forest and activities (hunting, grazing and wood cutting)	Penalties collected annual budget allocation fees from hunting and grazing permits
MIA	Allowance for entrance fees	Supervision of donation fees	None
Academic and research institutes	Scientific support for management strategies and conservation policies	Giving guidelines for management strategies and conservation policies	International funds
GAC	Elaboration of management strategies	Develop plans of activities	None
Municipalities	Implementing laws for the protection of forest on communal land	Control access and activities in communal forests	None
NGO's	Implementation of management strategy	Control access and activities in the reserves	Donation fees amenity service
Local communities (including herders and hunters)	None	Collection of wood and NTFPs	Cedar wood handcrafts and local products

It has Cedrus Lebanon's largest self-generating stand. Jabal el-Barouk is made up of three neighbouring but independent stands, each spanning around 3509 hectares of cedar, on common land in the various communities (***Figure 36***).

However, the wooded area covered just 216 hectares, approximately 8.6% of the 3509 hectares (Rania, 1995). The woods of Shouf Biosphere (SBR), together, account for around 25 percent of the surviving *Cedrus libani* in Lebanon (***Figure 37***). This makes the SBR an essential place to conserve and spread the cedar tree throughout time. (IUCN Europe, 2020).


Figure 36: Shouf biosphere forest, *Cedrus libani* (Taken by camera, 2018)

According to the IUCN 2020 report, the Cedar Society (ACS), major village officials and independent environmental experts, is under the jurisdiction of the Lebanese Ministry for the Environment (MOE) to manage the SBR through the designated Protected Areas Committee (APAC), which includes its own components. APAC connects with the management team of the reserve, which works with management and planning day-to-day of the reserve. Furthermore, Bird Life International has highlighted Jabal el-Barouk as an important bird zone. (Beals, 1965).

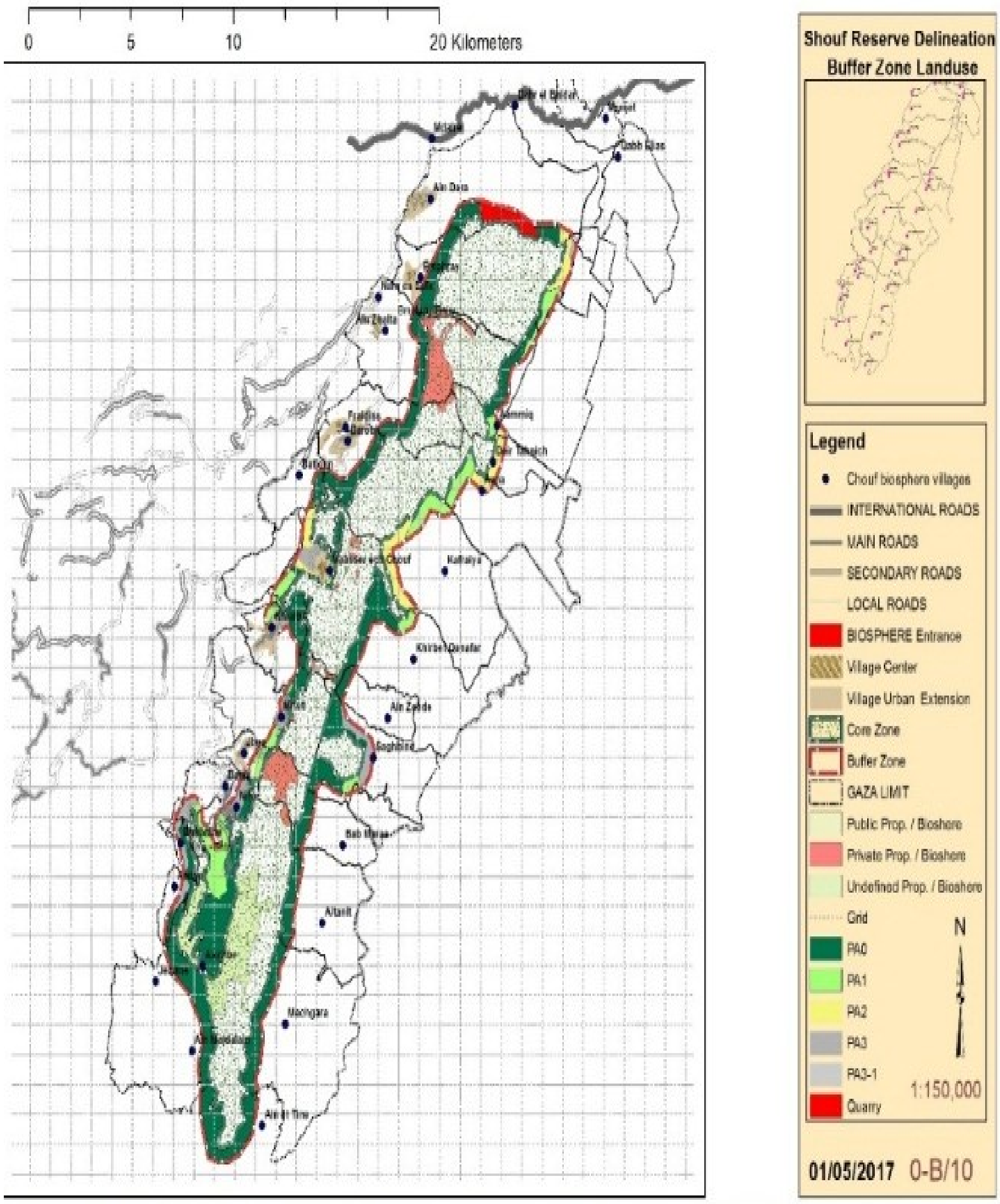

Figure 37: Map of Shouf biosphere forest (Shouf biosphere report, 2018).

4.3.2. Characteristic of *Jabal Barouk forest*

Jabal Barouk is 1940 m higher and much higher than the western mountains, which are 1100 m higher locally. It is made up of three neighbouring but independent cedar stands: Maasser al-Chouf, Ain Zhalta and Arz el-Barouk. A total of only 216 hectares is covered with woodland. Jabal el-Barouk has an interesting, vital history with respect to cedar management (Rania, 1995). The forest of today is located on west west and northwestern slopes and stands of roughly 1500 to 1800 m on the Jabal Barouk Massif on the eastern border of the Lebanon range, next to Ain Zahalta and Barouk. The Barouk Mountain in whole is cavernous calcareous, according to Rania 1995, with several surface

characteristics, such as the do lines, which indicate the cavernous formations behind the mountain range. The woods are made on Kesrouane calcareous red yellowish soils (Jurassic).
Surface horizons pH varies mostly from 6.4 to 7.6. The litter layer was 0-10 cm high with Cedrus and Quercus (in Barouk) leaves. The litter layer was varied. Sometimes there was a black layer of breakdown up to 3 cm deep and fungal mycelia was abundant. The soil, reddish, locally has an overall thickness even greater than 100 cm and has a coarse texture for sands and gravels. Watershed precipitation is the source of both surface and groundwater stream flows. The roots of the trees entered a fractured calcareous area. Of the large trees in Barouk, five are estimated to be between 375 and 440 years old.
The older trees were strongly distorted, probably to avoid the use of wood (***Figure 38***). They were typically made up of two or three bolts that branched near the ground.

Figure 38: Forest Stands of Barouk, near forest *Cedrus libani* (Taken by camera, 2019).

These were younger at Ain Zahalta (120-200 years) and typically considerably straighter. ***(Figure 39)*** (Beals, 1965). Cold winters with regular precipitation like snow and severe summers with extended physiological dryness define the climate of the region (Rania, 1995). By spreading deep roots, the cedars have adjusted to the heat and drought in the area. The only significant natural spread of this tree in Lebanon is through the abundance of seeds every three years. One of the few regions left in Lebanon was bigger birds like the wolf and the wild boar and where the stem and the mountain gazelle may still be recovered. Thus, winter and summer moisture off the Mediterranean Sea benefits practically completely. (Beals, 1965).

Figure 39: Old cedar forest of Barouk and Ain Zahalta, (Beals, 1965)

1: old cedar forest at Barouk on very shallow soils, showing deformed trees
2: younger and less disturbed cedar forest in Ain Zahalta

4.3.3. Characteristics of *Tannourine and Hadeth jebbe* forests

According to Rania (1995), about 200 ha of forest, 85 ha of which may be considered closed, are situated on the Jabal Maroune and Jabal Es Sair slopes, 1550 to 1800 m, between the Hadeth el Joube and Tannurine and Tahta towns, and much of the wooded land is on the west and north slopes. Cedars Tannourine reserve (***Figure 40***), at heights between 1300 and 1900 m a.s.l., with a latitude of around 34° 12′ to 34° 15″ and a longitude between 35° 54′ and 35° 56′ (SETS 2007, ECODIT 2009). Is one of the richest biodiversity woods in the region: 299 plant species inventoried, of which 55 are unique and represent over 50% of the total endemic plant species found in Lebanon, one of the relics of the ancient cedar forest is the Tannourin Forest. The primary and prominent species of Lebanon cedar is 90% density compared to TCNFR (Mitri and El Hajj, 2008). Limited logging takes place on the Tannourine side (Beals, 1965) on calcareous, sandy and volcanic soils (***Figure 41***), the TCFNR Tannourine Cedars Forest Reserve is distributed across 1.5 km^2 on the north eastern and south-western panes, (SETS 2007, ECODIT 2009). In addition to the cedar trees, the forest has occasional species of trees, shrubs, or plants, (***Figure 42***) such as *Juniperus excelsa, (L) Juniperus. Oxicedrus (L), Cupressus sempervirens (L). Quercus cedrorum (Kotschy), Berberis libanotica (Ehrenb), Prunus ursina (Kotschy), and Pirus syriaca (Boiss). Q. cCerris (L*), (SETS, 2007, FAO 2003).

Figure 40: Tannourine Cedars Forest (Taken by camera, 2016).

According to (Beals, 1965) *Cedrus libani* grow more quickly than on sandstones in the calcareous substrate In Hadeth trees on sandstone were more deformed by wind than trees on calcareous soils that were similarly exposed. Moisture in the soil probably influences wind resistance. However, in these conditions, Cedrus survives. The appearance and under storage of these woods are much different from those of calcareous forests. These stalls are prone to heavy grassing and browsing because to their relative openness and therefore weedier grasses-Medicago, Trifolium spp., Eryngium, and Scabiosa-than other woods. Vegetation on sandy soils is prone to degrade faster with the same amount of grass than calcareous soils. To the North, fir may replace a cedar, although cedar forest may have been the climax vegetation for many parts of the Lebanon region on the north and west slopes between 1400 and 1800 m. On reddish grounds on the calcareous Kesrouane are the Tannourine cedars and several of the Hadeth. Some Hadeth cedars are located on silica soils derived largely from Nubian sandstone Cretaceous. The organic layer, leaves, branches, with different degrees of degradation varied by less than 2 centimetres, yet sometimes by 20 centimetres. In the soil sections in the Tannourine wood, the mineral horizons can have thicknesses even greater than 100 cm.

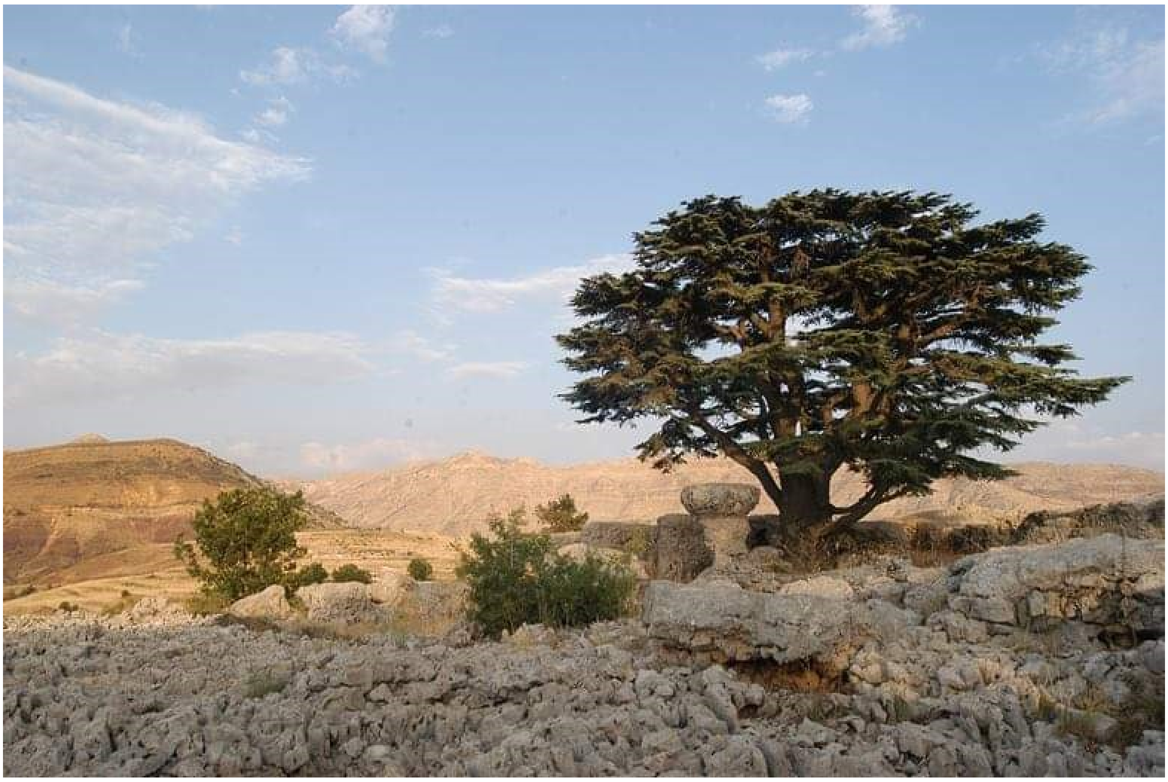

Figure 41: Tree of *Cedrus libani* on Tannourine forest (taken by camera, 2019).

The pH range of calcareous soils was between 6.5 to 7.6 in red sandstone soils were 5.2 to 6.6 and sandstone soils were 6.2 to 7.0. The five big trees near Tannourine have been aged between 210 and 300. The trees on the sandstone had been far smaller, the biggest around 120 years old, and obviously their development was considerably less than that of calcareous cedars. **Annex 5**. (Beals, 1965).

Figure 42: Endemic plant species, reptiles, birds, on Tanourine forest (Taken by camera, 2019)

Annual rainfall was generally between 1000 and 1200 mm, with little rainfall in late-summer dryness between June and August. The average temperature recorded in January is 3 °C and the minimum reported average temperature in August is 18 °C. Snow cover generally lasts 15-30 days from November to March.

4.3.4. Characteristic *Ehden* Forest

Ehden Woodland is around 140 hectares of closed, well-preserved forest situated in the northeast of Ehden town. The woodland of Ehden is the wealthiest place in Lebanon (Mouterde, 1954). Sheep and goat grass are extremely little (Rania, 1995). In the Ehden mixed woods, where Cedrus is abundant, sapling densities are very low, while cedar saplings are practically nil in pure cedar forests (***Figure 43***) (Beals, 1965).

In 1992, the woods of Ehden and Shouf became natural reserves. There is little cedar breeding within the *National Heritage Sites* designated by Lebanese government (Tohme, 1996).

On the Sannine claystone (Cretaceous), on the northeast of Ehden (***Figure 44***) which slopes from NNW to E, there was generally a litter layer 1-5 cm in depth.

Figure 43: Ehden forest, *Cedrus libani* (Taken by camera, 2019)

On the Sannine claystone (Cretaceous), on the northeast of Ehden (***Figure 44***) which slopes from NNW to E, there was generally a litter layer 1-5 cm in depth, which significantly reduces the effects of erosive processes. The soils present, despite having a discrete superficial stonyness, have a greater depth than in similar situations for lying, thanks to the presence of the aforementioned litter.

Figure 44: Ehden forest, sands between *Cedrus libani* (Taken by camera, 2019)

The cedar in the forest, like in Ehden, is enough for the reproduction of hardwoods but where cedar forms are virtually pure, is not (***Figure 45***). Still, in openings, cedar copying occurs. Perhaps disasters like fire and illness were crucial for the forest regeneration when the woods were widespread. (Beals, 1965).

Figure 45: Ehden forest pure of *Cedrus libani* (Taken by camera, 2019).

4.3.5. Characteristic of *Jabal Qammoua* forests

The Jabal Qammoua is a vast, hundred-hectare woodland. It is extremely degraded, with forests closed about approximately 30 hectares. The Cedrus, Abies cilicica (Antoine & Kotschy) and Juniperus sp. are a combination of species with Abies dominates northwest and northwest slopes. In the Jabal Qammoua, forest there is a large number of goats, which damage both the emerging plants and the most accessible parts of the canopy. To these must be added the indiscriminate cutting for firewood. The degraded situation is considerably aggravated during the conflict, (Beals, 1965). This forest is characterized by a level of humidity and / or higher temperatures, for example on its side compared to other areas with cedar woods. (Beals, 1965). it is evident the proliferation of the oak and cedar scrub in the Qammoua area is due to the excessive grazing to which it is subject.

4.3.6. Characteristic of Bcharre cedars Forest

The Bcharri cedars forest shown by ***Figure 46***, known as the Lord's cedars (*Arz e-Rab*), are protected from the Maronite Patriarch in various degrees. In the late 1870s the governor general of Lebanon, Rustaum Pasha, built a stone wall around the grove, part of which, after the reporting of Hooker in the 1860s, was supported by Queen Victoria. The grove is currently preserved by the efforts of the local people and a directive on ministries (Tohme, 1996). It has also just been identified as part gorge of a Wadi Qadisha, one of World Heritage Site. Moreover, the literature frequently says that it is the last cedar forest remains in Lebanon. The Society for Nature Protection in Lebanon has nominates Bcharre cedars as a World Heritage Area (Rania, 1995).

The stand is modest but contains the oldest and biggest known examples of cedar (Beals 1965). It is the highest altitude grove, 1950 a.s.l., and is located at the natural cedar altitudinal limit. It is one of the few remaining ancient growth forests. Everything has burned in Lebanon after the conclusion of the recent conflict (1974-1990) and cedar has been at the centre of passionate attempts to save the environment. The oldest and biggest specimens of *Cedrus libani* are on this famed seven hectares stand. (**Figure** *47*). Some of them are more than 1000 years old. (Rania 1995).

Figure 46: Bcharre forest, Cedars of God (Taken by camera, 2019)

It is the most accessible stand and was thus most disturbed, even if it has been preserved from complete destruction as a holy sanctuary. A stall around the stand was set up to maintain the goats in ***Figure 48***. However, the enclosure keeps the numerous human visitors in, inflicting grave damage. Very little has remained from the original vegetation. The replication is limited, mostly to outside sections of the enclosure. There is little cedar. (Beals, 1965).

Figure 47: Old *Cedrus libani* height 28 m at Bcharri forest (Taken by camera, 2018)

Figure 48: Barrier around forest Bcharri, *Cedrus libani* (Taken by camera, 2019).

Guinier (1954) explored this topic and a stronger control over tourism usage of the Sannine calcareous stand established. This is because popular literature typically says it is the final residue in cedar woodland, because the booth was so much troubled. (Beals, 1965).

4.4. Climatic zone for *Cedrus libani*

However, while vegetation relies on a broad variety of environmental variables, it is determined that the distribution of the world's main forms of vegetation is strongly connected and regulated by climate and environment factors (Woodward, 1987; Woodward and Williams, 1987; Stephenson, 1990). Climate variables and limitations including measuring rainfall, temperature, evaporation, radiation, and relative humidity are affecting the physiology of plant species and are recognized as the principal abiotic factor determining the geographic range of plant species (Hengeveld, 1990). Scientists have tried to determine exactly what climate elements are influencing the spread of vegetation. However, a criterion for vegetation distribution and categorization has not been universally recognized as a standard (Stephenson, 1998). The influence of the numerous environmental variables is not equal, however, and there is a constraining climate factor in each location, which mostly affects vegetation (Kutiel et al., 2000). Increased temperatures are a crucial element in the growth and survival of forests. Access to water due to precipitation, mountain snowfall and the ability of the land to hold water are key characteristics in this sector (MOE/GEF/UNDP, 2011). Abi-Saleh and Safi (1988) simulated and adjusted both the previously developed bioclimatic and vegetation associations to match the Lebanese circumstances, therefore creating a map of Lebanon's bioclimatic areas and amount of vegetation shown in ***Figure 49*** (Safi and Abi-Saleh, 1999). Cedar woodland is present in areas that are precipitated at least 800 mm annually, according to Basbous (1954) and Pabot (1959), however, there are few data. Pabot is 1100 mm high. Most of this occurs in the form of snow from October to May (***Table 14***). Snow may easily reach a depth of 1 m in the forests and can linger until May in protected areas (***Figure 50***). The increases of atmospheric CO_2 and temperature, and the water stress predicted by several GCM outputs (IPCC, 2007) within the next century, may lead to an expansion of xeric vegetation in the Eastern Mediterranean region. Through height and the channelling of humid air through mountain valleys, the warm dry Mediterranean summers are much improved (**Annex 6**). Although rainfall is infrequent, the woodlands are regularly drenched in the afternoon during the summer. The nebula can condense on trees and run down to the earth. Because today's forest residuals are only at locations, where the clouds are more prominent, historical forest occurrence in other areas involves certain environmental modifications. The widespread soil erosion across Lebanon can make the forest species more sensitive to air conditions and may have reduced the number of cloud formation caused by vegetation denudations (Beals, 1965).

The cedar is likely to be less heat sensitive than fir since it descends to lower heights (Nahal, 1962) and since it has more southern geographical boundaries than the fir.

According to Beals (1965), *Cedrus libani* occurs in general on the drier northeast and east paths, is also present on west and slopes, while the eastern slope is apparently too dry for Cedrus to replace Quercus woodland. Finally, soils are well drained and usually calcareous although in Lebanon trees do occur on sandstone formations (Talhouk, 2001).

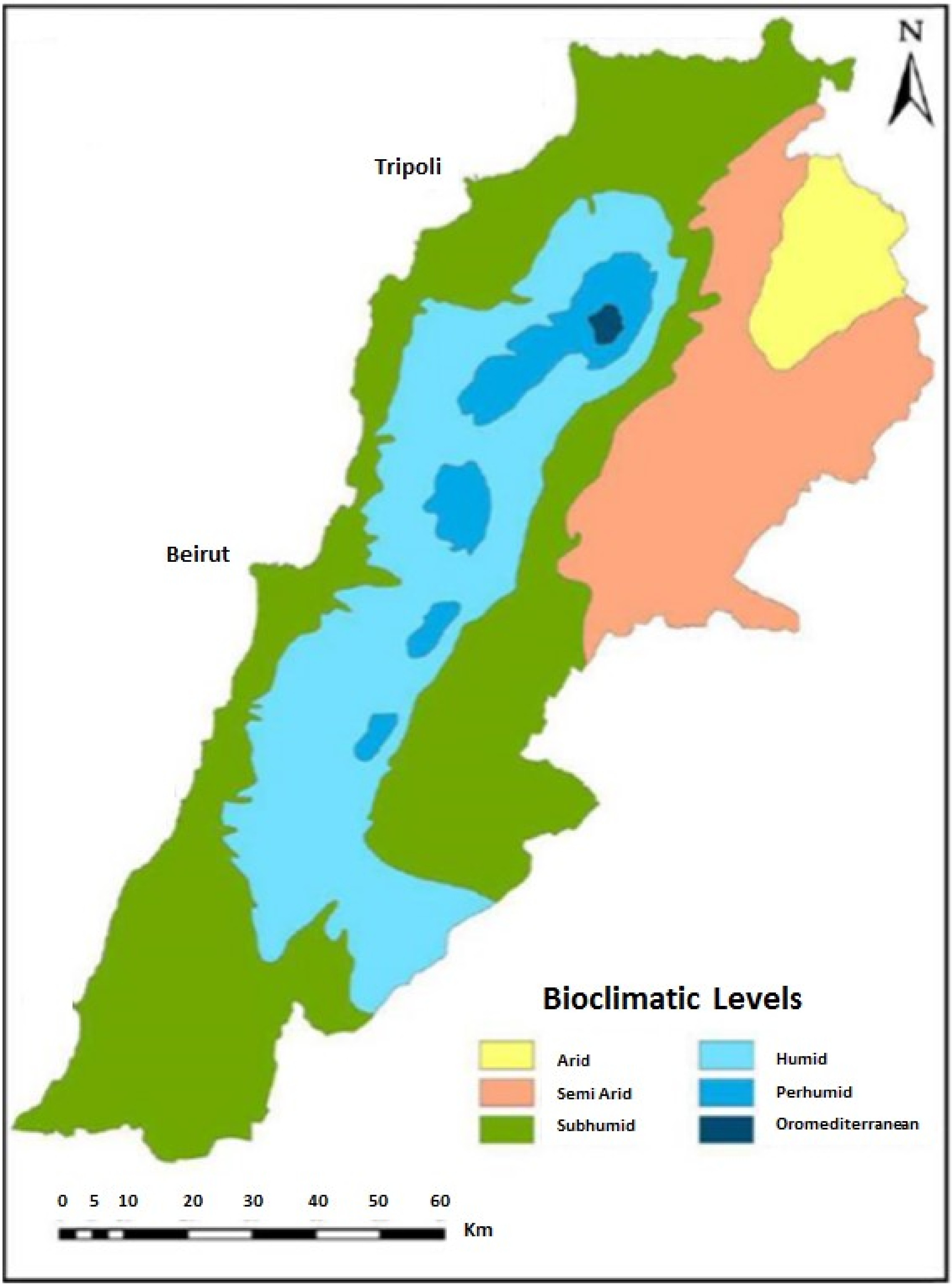

Figure 49: Map of bioclimatic level (Safi and Abi-Saleh, 1999).

Figure 50: Bcharri Cedars, snow of February (Taken by camera, 2019)

Table 14: Climatic boundaries used as input for *Cedrus libani* simulations (Laurent et al., 2008)

Climatic boundaries	Tmin	Tmax	Wmaxg	Sw	Gdd5
Cedrus libani	-16	4	0.5	0.03	1.700

Tmin: minimum absolute temperature threshold by the species (temperature threshold below which "cold" stress occurs)
Tmaxg: maximum mean temperature of the coldest month and tolerated by the species.
Wmaxg: maximum soil water content during the driest month allowing germination of the species
Sw: minimum soil water content
Gdd5: minimum values of growing degrees days above 5 °c (i.e., mean of the temperature exceeding 5 °cover the year, for the species to complete their vegetation cycle).

4.5. Problems and threats affecting some forests of *Cedrus libani*

The primary changes in land use that contributed to the deterioration of natural forests and forests include deforestation, quarrying and urbanization. Vanishing woods were previously referenced in 1st century B.C. and since they continued in history, they are now believed to be the remains of more than 500,000 ha of post-glacial forests with the present 2000 hectares of spotty cedar woodland in Lebanon (Alptekin et al. 1997).

This was particularly apparent during the civil war, when forest protection and land-use control were practically non-existent (Abi-Saleh et al. 1996; Nasr et al. 2009; Darwish et al. 2010a). Forests with big trees are rare and very scattered, particularly on Mount Lebanon's west crest (Talhouk et al. 2003). Since the creation of the Minister of Environment soon after a civil war, some contiguous woods (coniferous and broadleaved) are currently protected by law under natural reserves (Abu-Izzeddin, 2000). However, there is a dearth of efficient conservation management systems for most forests and other forest types beyond these protected areas (Sattout et al., 2005). In Lebanon, the conversion of land and habitat fragmentation continue to jeopardize forest ecosystems and biodiversity (Talhouk et al., 2005). During Ottoman rule in Lebanon (1917–1918), the forests were demolished to build the Aleppo–Baghdad railway, and to fuel the trains in and after the First World War, continued unregulated cedar cutting for the production of coal for domestic and industrial uses. (Chaney and Basbous, 1978).In 1965, the entire surface area of Lebanon covered by the cedar forest was 2.593 hectares, surface which in 1988 was 2323 hectares (Khouzami, 1994), with a decrease of 270 hectares during these 23 years.

The amount of deterioration of habitat caused several critics to fear for the cedar future (Paule 1975). The trees were already quite diminished and scattered, beginning to visit the Lebanese mountains (Aziz, 1996). Cedar forests are present only in Lebanon and Syria where forest degradation has long been in danger. Only 5% of the natural forest exists now in these two nations (WWF and IUCN, 1994). Land abandonment has in some sections of the nation led to natural regrowth. Although forest and biodiversity in Lebanon still confront various risks and difficulties, despite their forest coverage that exceeds the global average of FAO, 2011. Dating from the beginning of the 18th and afterwards being used for wood production in the European Mediterranean area, the Lebanon cedar was introduced to European horticulture. It is nonetheless anticipated to focus on the wildlife in the Levant to manage the protection of this species effectively. A more integrated and more coordinated strategy, like in Turkey, is also necessary in Lebanon and Syria. Special care is needed to preserve historic wildlife stands, likely to be lost as natural deaths and regenerations are significant genetic material sources for reforestation and habitat restoration (Khuri and Talhouk, 2000).

Since ancient times, its wood has been highly valued for its long-lasting qualities, density, colour and resistance to decay. For instance, it was a choice of wood for royal tombs in the Middle East (Rogers and Kaya, 2006). Its native habitat in the Lebanon highlands has had a significant human effect throughout the years. Intensive logging was documented in the third millennium B.C. for shipbuilding, construction, and land clearing in the agriculture (Talhouk et al., 2001).

4.5.1. Problems affecting the cedar forest of Bcharri

The problems affecting this forest are many, as are the causes that generated them:
-reduced soil fertility in macro and micro elements, which manifests itself with evident needle's damages, very poor cone production, less resistance to phytopathologies, increased presence of tunnels and mines on desiccated branches and dead trees caused by borers;
- the high density of the most recent plants, 4-5 trees / m^2, which involve a competition for light, nutrients, water, is the cause of their reduced development, in biomass;
- severe engraving performed by visitors on bark of trees and huge wood cutting left for fire setting during visits (***Figure 51***, ***Figure 52***).
- Among the pathogens were observed, the fungal formations of Armillaria sp, Botryodiplois sp, as well as the widespread presence of Parasyndemis cedricola (Masri, 1995) whose larval forms cause serious damage to the leaves and buds.

4.5.2. Problems affecting *Jabal Barouk and Ain Zhalta* cedar forest

The 1975 reforestation project ceased at the beginning of the conflict, as stated by Rania in 1995. *Jabal el-Barouk* is not allowed to live in people and pastures (estimated to be 2,000 goats between May and October) have been banned in the forest. Ain Zhalta was taken over by the Israeli army in 1982. Among many other things, the Israeli occupation of Arz *Ain Zhalta* caused the conflict to expand to the cedar forests, leading some cedars to be damaged and deadly. More importantly, due to intensive compaction from its heavy gear and road building, the Israeli army inflicted practically permanent damage of about 5% of the cedar woodland. One of Arz *Ain Zhalta's* main highways is utilized as a site for the surrounding communities. Trash is dropped by the cargo and then burnt frequently for more waste. In addition to attracting insects and perhaps diseases, garbage can be detrimental for trees, it can also spread to the forest itself. Until date, the fires have not interested to the peripheries of the forest, but the use of fire to eliminate garbage on the outskirts of inhabited centers near the forest represents a very high risk factor. Cedars have been afflicted in *Arz el-Barouk* with what is supposed to be a fungal illness and have soil erosion (**Annex 7**). The principal symptoms are stag heading[1] and crown defoliation. (Masri, 1995).

[1] Stag heading may be a physiological stress reaction and not always a fungal or infectious illness sign

Figure 51: Dead cedar trees, Bcharri Forest (Taken by camera, 2019)

4.5.3. Problems affecting *Tannourine cedar* forest

A new bug (*Cephalcia tannourienensis, Chevin*) endangers the Lebanese cedar woods. The *Tannourine* Cedars Forest Nature Reserve, one of the largest cedar woods in Lebanon, was originally found in 1997. It is the most important natural forest. This insect's larvae feed on cedar trees and induce defoliation, which can kill woods in the event of a serious infestation (Nemer, 2008). The adults emerge and fly from mid of April to mid-June based upon the life cycle of this insect, laying their eggs on the cedar tree needle buds. Then, in the months of June and July the eggs hatchery, larvae travel through three instars before wintering in the soil. The larvae eat the needles of the young cedar buds during their development (SETS 2007, Nemer et al., 2007). During the spring and early summer, the feeding of larvae on the young shoots infers the serious damage caused by cedar Web-Sawfly and its possible effect on growth in cedar. The cedar moth (*Thaumetopoea libanotica, Kk and Talhouk*) weakens the Lebanese woods of Shouf. Finally, we remind you that also for this forest there are the problems common to cedar woods: urban development, selective cuts to the craft industry, and serious harm to winter sport and goat pasture activities (Khuri and Talhouk, 2000).

Figure 52: Bcharri Cedar broken by lightning and thunderbolts (Taken by camera, 2019)

4.6. Review of related literature

There were several, studies on Lebanese cedars, some of which need to be described in ***Table 15***.

Table 15: Articles contained Lebanese Cedars.

Author	**Article aims**	**Region Site**
Beals E.W. 1965	Description of the remnant cedar forest of Lebanon	Lebanon
Alpektin C.U. 1997	Le cèdre de turquie : aire naturelle, insectes ravageurs, perspectives d'utilisation pour les reboisements en france	Turkey
Masri. 1995	The Cedars of Lebanon: Significance, Awareness and Management of the *Cedrus libani* in Lebanon	Lebanon
Boydak M. 1998	The effect of prescribed fire on the natural regeneration success of Lebanon cedar (*Cedrus libani* at Antalia-Kas locality	Turkey
Khury S. et al., 20000	Conservation of the *Cedrus libani* populations in Lebanon: history, current status and experimental application of somatic embryogenesis	Lebanon
Boydak M. 2002	Regeneration of Lebanon cedar (*Cedrus libani* A. Rich.) on karstic lands in Turkey	Turkey
Ünal Akkemik 2003	Tree rings of *Cedrus libani* at the northern boundary of its natural distribution	Turkey

Carus S. and Avci M. 2005	Growth Loss of Lebanon Cedar (*Cedrus libani*) Stands as Related to Periodic Outbreaks of the Cedar Shoot Moth (Dichelia cedricola) Serdar Carus	Turkey
Kayihan G.C. et al., 2006	The genetic structure of *Cedrus libani* a. rich seed stands determined by random amplified polymorphic DNA markers	Turkey
E. J. Sattout et al., 2006	Perspectives for sustainable management of cedar forests in Lebanon: situation analysis and guidelines	Lebanon
E. J. Sattout et al., 2007	Economic value of cedar relics in Lebanon: An application of contingent valuation method for conservation	Lebanon
B. Fady et al., 2008	Genetic consequences of past climate and human impact on eastern Mediterranean *Cedrus libani* forests. Implications for their conservation	Lebanon, Turkey
Anthony S. Aiello and Michael S. Dosmann. 2008	The Quest for the Hardy Cedar-of-Lebanon	Turkey
M. Ducrey et al .2008	Variability in growth, carbon isotope composition, leaf gas exchange and hydraulic traits in the eastern Mediterranean cedars *Cedrus libani* and C. brevifolia	Mediterranean
L. Hajar et al., 2010	Distribution of *Cedrus libani*, past present and future	Lebanon
Aertsen W. et al., 2010	Comparison and ranking of different modelling techniques for prediction of site index in Mediterranean mountain forests	Turkey
Caliskan B. et al., 2009	Pollen characteristics and in vitro pollen germination of *Cedrus libani* A. Rich.	Turkey
Sabatier S. et al., 2003	Intra- and interspecific variations of polycyclism in young trees of Cedrus atlantica (Endl.) Manetti ex. Carrière and *Cedrus libani* A. Rich (Pinaceae)	Turkey and Lebanon
Ruiz et al., 2016 (IUCN)	Taxonomy of *Cedrus libani*	Mediterranean
Messinger J. et al., 2015	*Cedrus libani*: A promising tree species for Central European forestry facing climate change?	European
Guner S.T. et al., 2016	Effects of seedbed density on some morphological properties and nutrient status of two-year old taurus cedar (*Cedrus libani* a. rich.) seedlings	Turkey
Yazici N. and Bilir N. 2017	Aspectual Fertility Variation and Its Effect on Gene Diversity of Seeds in Natural Stands of Taurus Cedar (*Cedrus libani* A. Rich.)	Turkey
Bassil S. et al., 2018	Stand structure and regeneration of *Cedrus libani* (A. Rich) in Tannourine Cedar Forest Reserve (Lebanon) affected by cedar webspinning sawfly (Cephalcia tannourinensis, Hymenoptera: Pamphiliidae)	Lebanon
Abeer Ibrahem et al., 2020	Assessment of the suitable habitat of the naturel regeneration of *Cedrus libani* in Slenfeh Syria	Syria

Chapter II

Materials and methods

1. Study area and field visits

According to its small area 10,450 km^2, Lebanon, located on the eastern shores of the Mediterranean Sea, extends between latitude 33.1˚ to 34.5˚ and longitude from 35.1˚ to 36.2˚. It represent a high complex geomorphology and landscape. The ***Figure 53*** and ***Table 16*** below show the visited Cedrus sites.

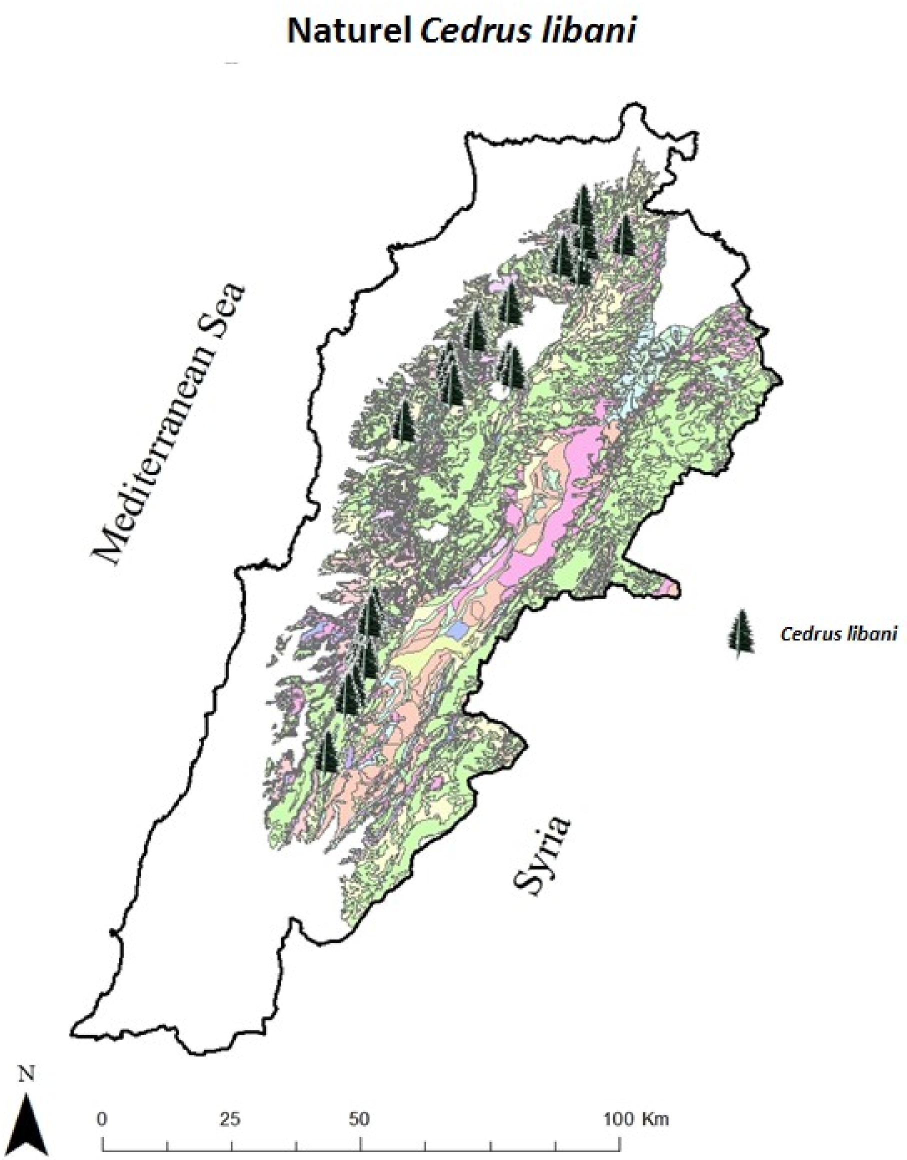

Figure 53: location of naturel *Cedrus libani*

Table 16: Coordinate of naturel *Cedrus libani*

	SITE	ALTITUDE m a.s.l.	latitude	longitude	COORDINATE WGS-84
Mogareb	1	1876	34.40858552	36.20235638	37N 242850 - 3811010
	2	1847	34.41081013	36.20857979	37N 243429 - 3811241
	3	1847	34.4109745	36.20867222	37N 243438 - 3811259
Baydruth	4	1772	34.45627353	36.22576276	37N 245147 - 3816241
	5	1772	34.45693751	36.22602373	37N 245173 - 3816314
Kammoua	6	1488	34.47727234	36.21802461	37N 244500 - 3818590
	7	1525	34.47324798	36.22022637	37N 244690 - 3818138
Bcharre	8	1984	34.24576824	36.04805031	37N 228137 - 3793350
	9	1940	34.24464259	36.04996747	37N 228310 - 3793220
	10	2160	34.23607598	36.06108746	37N 229307 - 3792240
Horsh Ehden	11	1415	34.31079148	35.98262146	36N 774477 - 3800646
	12	1465	34.31096691	35.98614728	36N 774801 - 3800675
	13	1620	34.30352533	35.9826576	36N 774504 - 3799840
Haddath Jebbe	14	1462	34.24888812	35.92447584	36N 769322 - 3793623
	15	1657	34.22718108	35.92828269	36N 769742 - 3791225
Tannourine	16	1790	34.21026129	35.93167886	36N 770109 - 3789357
	17	1652	34.15103032	35.82754443	36N 760694 - 3782515
Ain Zhalta	18	1265	33.74589634	35.71632991	36N 751628 - 3737297
	19	1470	33.74267205	35.72354482	36N 752306 - 3736957
	20	1660	33.74222418	35.73685803	36N 753541 - 3736940
	21	1745	33.73802535	35.73512754	36N 753393 - 3736470
Barouk	22	1535	33.69901164	35.70174738	36N 750413 - 3732061
	23	1720	33.68983893	35.70316414	36S 750571 - 3731047
	24	1718	33.69042442	35.70730234	36S 750953 - 3731122
Falouga	25	1580	33.82649763	35.75310943	36S 754797 - 3746328
	26	1575	33.82662375	35.75311347	36S 754875 - 3746342
Hammana	27	1510	33.80804934	35.74395387	36S 754004 - 3744259
	28	1500	33.81069986	35.74476214	36S 754071 - 3744555
Massour el Chouf	29	1740	33.67262094	35.69359975	36S 749735 - 3729114
	30	1790	33.6755103	35.69339875	36S 749707 - 3729434

2. Land Evaluation for *Cedrus libani* implant

2.1. FAO Framework for land evaluation

The Framework of FAO land evaluation is divided into four levels of assessment ***Figure 54***:
- *Order*. There are two orders, *Suitable* (S), and *Not Suitable* (N). They lie in the order S lands on which prolonged use of the type under consideration is likely to generate benefits that justify the inputs without unacceptable risk of harm to land resources. Order N as land with characteristics that tend to limit long-term usage of the type under consideration (MacRae and Burnham 1981)[2].

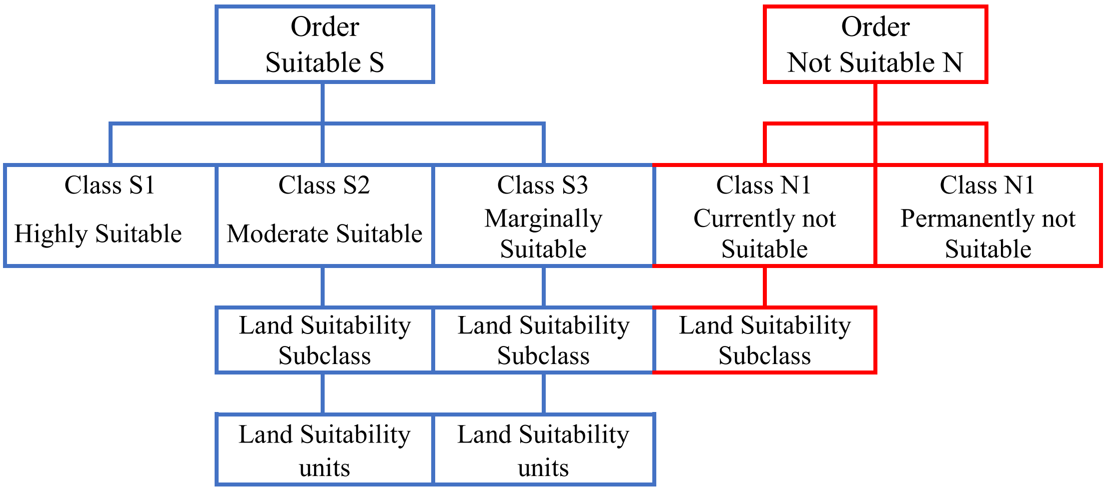

Figure 54: The FAO Framwork for Land evaluation model levels

- *Land Suitability Class*. Various classes in each order allow you to determine the degree of constraints for the crop or for studio use. The Framework recommends the use of three classes from S1 highly suitable to S3, marginally suitable. For order S and two classes N1 currently not suitable, for land having limitations which may be surmountable in time, as economic conditions change or as technical knowledge progresses and N2 permanently not suitable for land having limitations so severe to preclude any possibilities of successful sustained use of land in the given manner[3].
- *The subclass* is indicated with a letter suffix to the class symbol. Contrary to the Land Capability, classification, which establishes them a priority, the number and nature of limitations, must be specified for each assessment. It is possible to use two suffixed letters only if there are two limitations of equivalent severity.

[2] Mac Rae. and Burham, page. 50
[3] Idem, page 51

- *Land Suitability units*. This level are most use at the farm planning, as it allows you to specify production characteristics or in minor aspects of their management requirements. The Land Suitability Unit is indicated with an Arabic number suffixed to the subclass symbol.
Based on the global classification of land suitability framework done by FAO, our research proposed a new suitability model that is described in the next chapter.

3. Land evaluation for *Cedrus libani* reforestation: Vocazione colturale specifica (VCs)

3.1. Introduction

The reference model for assessing susceptibility to reforestation is the Land Evaluation for Forestry (FAO, 1989). Madrau et al., 2006 and Cossu, 2019 respectively proposed a model for assessing the susceptibility of territory to the planting and conservation of cork oak (*Quercus suber L.*) and the association of cork and olive trees. Typical use destinations of the hilly areas of Sardinia. The models they propose are derived from that of the *Vocazione Colturale specifica* assessment (VCs) (Danuso et. 2001). The methodology of this work will be based on the proposed model of madrau and cossu 2019.

3.2.VCs Model

The VCs for each of the proposed use is obtained from the weighted sum of 5 of normalized variables (from 1 to 0) multiplied by the vocation irrigated normalized.

$$VC = Pi * (Pp+Pt+Ps+Pr+Pf)/5$$

In accordance with the Authors, the score of the factors considered, must be normalized as a function of the greater or lesser influence that these have in the intended use of the object of evaluation.
The result is expressed as a vocational class. In the original model, it is proposed the following four classes of decreasing suitability.

- *Poorly suitable*
- *Medium suitable,*
- *Suitable*
- *Very suitable*

Similarly, to other susceptibility assessment models, the number of classes can be reduced or increased according to the specific characteristics of the intended uses.

3.3. Data collection and parameters description

In our research, the following vocational evaluation model is proposed for medium scale of detail, based only on characteristics of the territory and soil deriving from the DEM and the available pedagogical maps. The following part will describe the parameters used to develop the model:

i. *Elevation.*

Based on the literature review (Evcimen, 1963; Saatcioglu, 1976; Boydak, 1986, 1996, 2003; Atalay, 1987; Quezel and Medail 2003; Khouzami, 1994), the optimal altitude for *Cedrus libani* is between 800 and 2100 m a.s.l.

Similarly to what proposed by Madrau et al., and Cossu (cit.) for the cork and olive tree land suitability model, it is possible also consider mid-hill altitudes, 500 - 800 m, as suitable for regeneration if on slopes exposed from N to NE, capable of avoiding conditions of prolonged aridity conditions. Even on high hill situations, from 2100 to 2500 m, they can be considered compatible with the ecology of the cedar if exposed to the southern slopes capable of avoiding air temperatures below -5 ° C for excessively long times.[4]

The data relating to the two morphological characteristics, elevation and slope exposure were obtained in ***Figure 55*** with the *Reclassify* function (3D Analyst) from the processing of the DEM available on the Nasa Shuttle[5] website.)

[4] Boydak (cit.) points out that in the Taurus mountains *Cedrus libani* occurs generally between 800 and 2.100 m elevation, but it can be found at lover (500 -600 m) and higher (2400 m) elevation as small populations or small group and individuals.

[5] NASA Shuttle Radar Topography Mission Global 30 arc second https://doi.org/10.5067/MEaSUREs/SRTM/SRTMGL30.002

Figure 55: Digital Elevation Model study area

ii. Rainfall

To determine the classes of influence of the average annual precipitation, the map produced by the CDR - SDATL (2003) at the scale of 1: 200,000 shown in ***Figure 56*** was used. From this map, a first layer was created relating to the completely Lebanese territory, from which it was obtained, following the same criteria adopted for the soil map, that relating only to the altimetry range above 500 m a.s.l. The proximity of the reliefs of the chain of Mount Lebanon limits the rainfall classes below 700-800 mm/year to almost all of the territories of the governorates of South Lebanon and to part of that of Nabatiya. Another governorate concerned is that of Baalbek-Hermel, where rainfall of less than 200 mm/year is recorded in the Orontes valley. On both sides of the Mountains of Lebanon, it is possible to observe how rainfall ranges above 800 - 900 mm affect areas of limited extension, highlighting how rainfall is strictly correlated to altimetry.

The rainfall range > 1400 mm/year is limited to the highest altitudes of Quornet el Sawda, while that of 1300 - 1400 mm/year affects the area of Harf Sannine and the northern slopes immediately downstream of Quornet el Sawda.

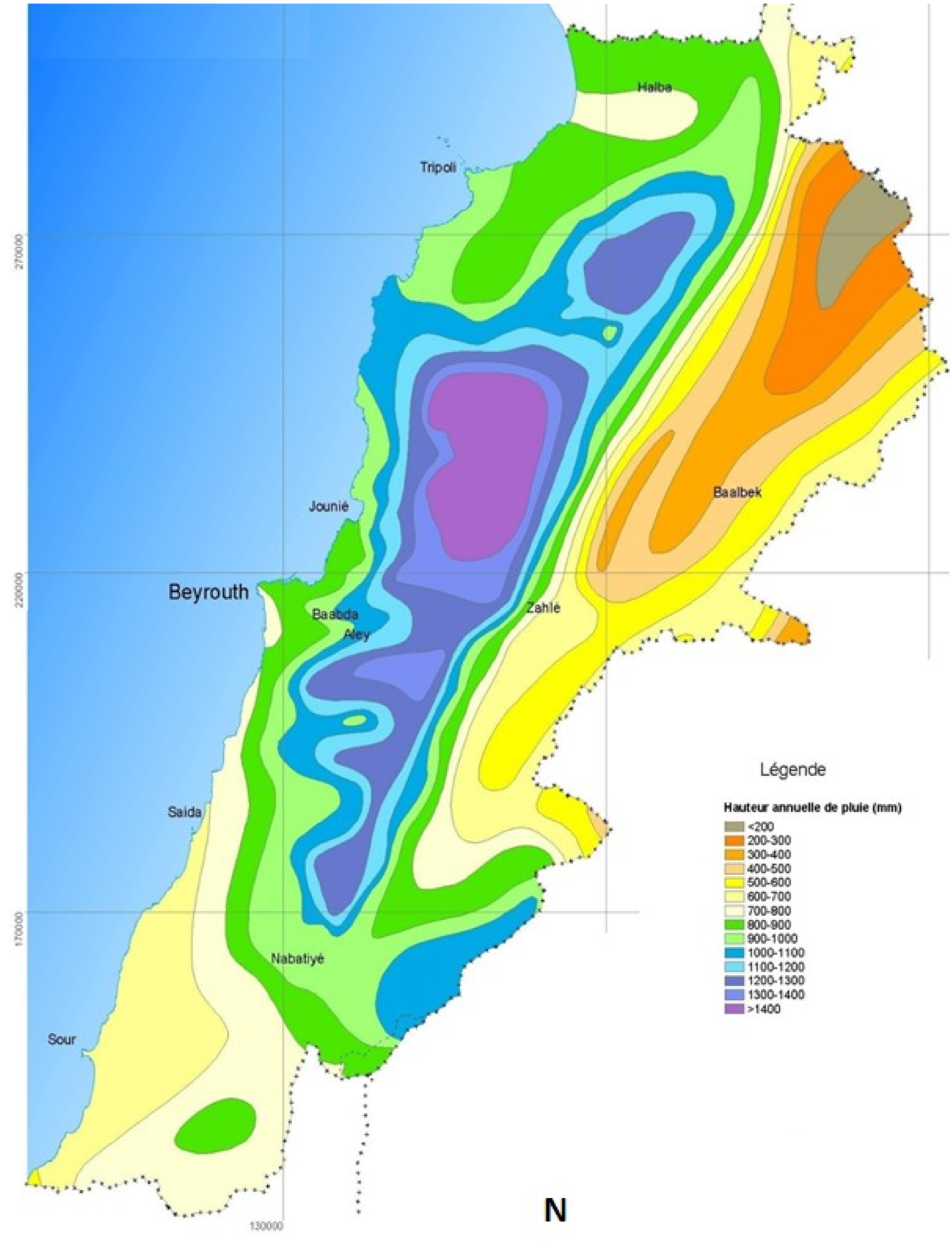

Figure 56: Rainfall average annual precipitation in mm (CDR-SDATL)

iii. Aspect

The *aspect* (*slope exposition)* function (3D Analyst) allows obtaining from the DEM. The degree of slope has been inserted to indicate both the possible greater or lesser recourse to the mechanization of the planting and government operations of a forest, and the seriousness of erosive processes caused by the same activities.With slopes of less than 30%, mechanization of almost all crop operations is possible. Beyond this value, up to 50%, it is still possible to use special machines during plant operations, and partially mechanize interventions for explanting. In the case of slopes greater than 50%, the use of machines is not recommended. In these sloping conditions, water erosion processes, both laminar and channeled, can be triggered or accelerated, in the event of incorrect or unnecessary soil preparation.Exposure plays a fundamental role in regulating temperatures and rainfall and consequently on plant cover. Normally the slopes with exposure from NW to NE allow a greater supply of rainfall as they intercept the masses of the wet area but, at the same time, decrease the values of both average and daily temperatures. Opposite conditions, occur on the slopes with exposure from SE to SW

iv. Geological characteristic: Substrate and relative slope deposits

In Lebanon, Cedars are observed mainly on Mesozoic crystalline limestone and on their slope deposits (Boydak, 2003). These formations are subject to karst processes that give rise to cracks of variable width from a few cm to several dm, with depths that can have orders of length from a few dm to several meters. In these cracks, the pedogenetic processes allow the progressive accumulation of the insoluble residues of the decarbonation process with the formation of highly fertile argillic horizons (USDA 2014).[6] Is the presence of cracks in the soil allow the root system to use both the water resources and the mineral elements accumulated inside them? The effusive rocks and the colluvial deposits of the crystalline, arenaceous and marl limestone, allow the development of medium depth soils capable of compensating the absence of the cracks, but are subject to processes of water erosion due to the less rocky outcrops and superficial stony compared to the soils on the karst formations. Alluvial deposits, both recent and oldest, as well as being little or nothing widespread in the hilly areas of Lebanon. They can have both sub-surface horizons with extremely variable textures, and lenses of coarse fragments strongly cemented by carbonates or silica. This process is frequent in the plio-pleistocene floods (Madrau, 2004). The geological characteristics of the area under study were obtained from the Geological Map of Lebanon at the scale of 1: 750,000

[6] For the definition of argillic horizon, see the USDA Keys to Soil Taxonomy (2014)

of the Conseil du Dèveloppment ET Del Reconstruction - Schéma Directeur d'Aménagement du Territoire (SDATL), ***Figure 57***.

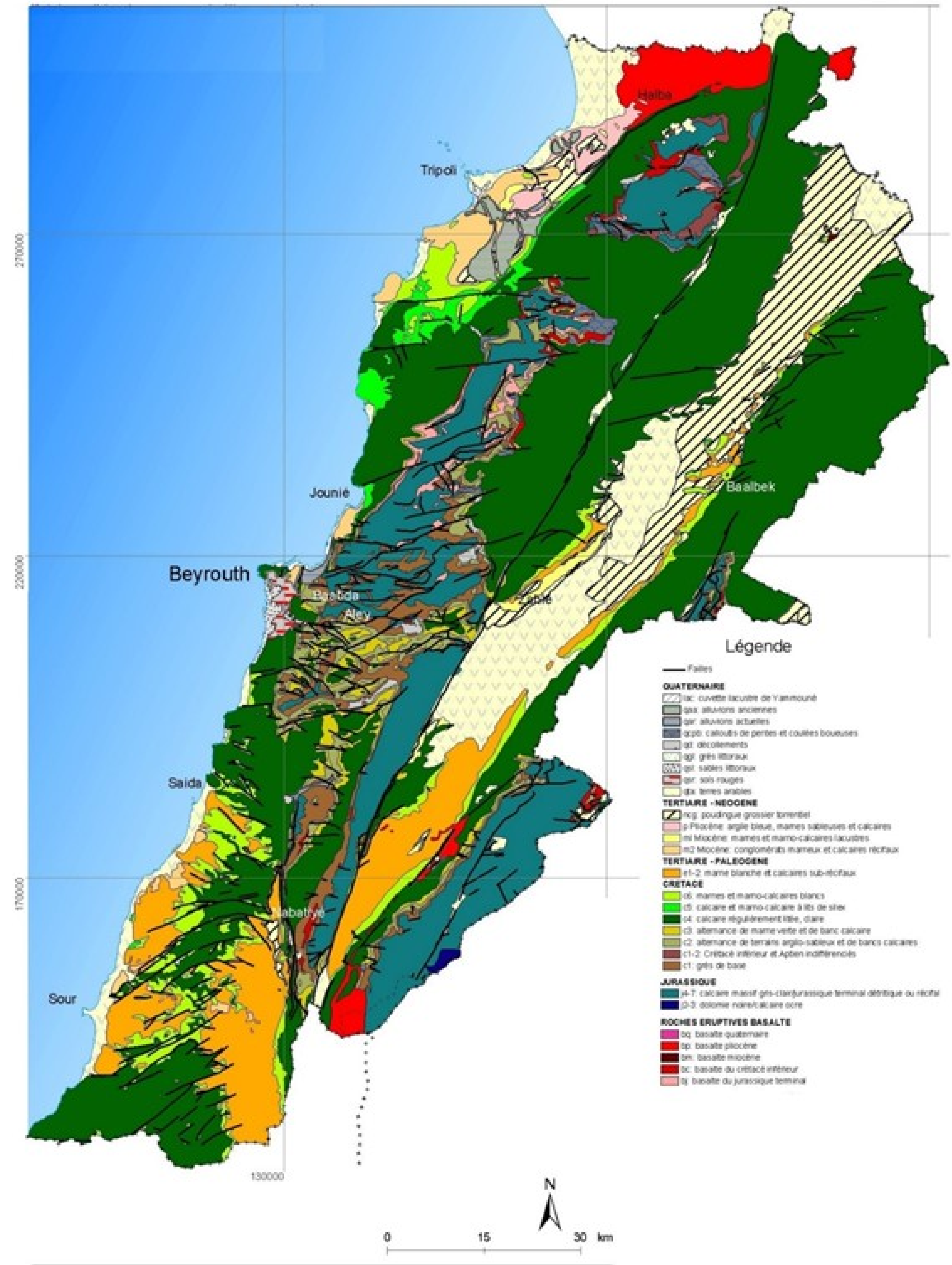

Figure 57: Geological map of Lebanon (CDR-SDATL)

v. Soil properties

The Lebanese CNRS has released, for this thesis work, a shape file for the Soil Map of Lebanon, derived from the assembly of sheets done for the Soil Map at a scale of 1: 50,000 (Darwish et al., 2006). From the original shape file, all surfaces with altimetry lower than 500 m a.s.l. have been excluded, including those of minimum extension with altitudes higher than 500 m emerging, as isolated reliefs, in the lower altitude range. The Physico-chemical characteristics of the map units were obtained based on their description in the monograph Soil Map of Lebanon 1: 50,000 (Darwish et al. 2006).

vi. CEC capacity, deficiencies in major macronutrients and soil pH

CEC capacity, deficiencies in major macronutrients, and soil pH are closely related to the soils, depending on the physic-chemical processes that occurred during their genesis and evolution, such as those of lateral leaching along the slopes, the substrata and clay mineralogical characteristics, presence of coarse fragments, etc. This information is available from the 1:50,000-scale map of Lebanon (Darwish et al., 2006). An excessively rapid or slow drain can give rise to water deficit or hydromorphic conditions, loamy sand texture involved reduced CEC capacity, and acid or high alkaline soil pH, represent, both individually and in co-presence, situations, where the cedar replant, will have important failures for the reduced development of young plants, and for the same lower resistance to phytosanitary problems. As highlighted above, medium-detailed pedagogical maps are available for this thesis work. This situation suggests that in this first phase of study the number of possible vocational classes should be limited. As operated for cork and olive crops, it is considered appropriate to propose the following classes:

- *Very suitable or high suitable*
- *Medium suitable or moderately suitable*
- *Poorly suitable low suitable*

Based on the characteristics listed, it is therefore possible to propose the following vocational evaluation scheme for the *Cedrus libani* plant in ***Table 17***.

Table 17: Soil and land characteristic proposed for the assessment of *Cedrus libani* reforestation

Land or soil characteristics	Codex	Positive	Indifferent	Negative
Elevation (m a.s.l.)	El	800 – 2100	500 – 800 2100 - 2500	>2500
Aspect	Ex	Flat, N, NE,E,NW	SE	S, SW, W
Rainfall (mm/year)	Rf	600 – 1200	500 – 600 1200 – 1500	< 500
Substrata and relative slope deposits	Sb	Limestones	Effusive rocks, Limestone deposits, marls, and calcareous sandstones	Intrusive and metamorphic rocks, recent and old alluvial deposits
Soil depth (cm)	Sd	>50	30 - 50[7]	< 30 cm
Soil Drainage	Sw	Well drained	Moderately well drained Somewhat excessively drained	Imperfect to very poorly drained Excessively drained
Soil pH	pH	6.5 – 7.5	6.0 – 6.5 7.5 – 8.1	< 6.0; > 8.1
CEC Capacity	Ce	High	Moderate	Low to very low
Nutrient deficiencies	Nd	Absent to low	Moderate	High

N.B. Soil depth and soil pH can be obtained from the legend of the soil maps. It must therefore be considered at this working scale the average of the map units.

The following points or weights have been attributed to the three classes of vocation:

- Positive 1
- Indifferent 0.5
- Negative 0.1

If we consider the elevation (EL) as the most limiting factor, the vocational (suitability) judgment can be expressed by:

$$G = El^* (Ex + Rf + Sb + Sd + pH + Sw + Ce + Nd)/8$$

Based on the combination of the remaining eight factors it was decided, assuming an initial hypothesis EL equal to one, to determine the limit of the three vocational classes as a function of the number of positive and indifferent factors, but with a maximum of two negative factors shown in ***Table 18***.

[7] Only in presence of carsic cracks

Table 18: Possible combinations of scores as a function of the number of characteristics considered

Influence class	**Positive**	**Indifferent**	**Negative**
Very vocated (high suitable)	7	1	
	5	1	2
Medium vocated(suitable)	3	5	
	2	4	2
Poorly vocated(suitable)	1	6	1
	1	2	5

Based on this consideration, the ranges of values of the three vocational (suitability) classes are:

positive 0.938 – 0.700

indifferent 0.700 – 0.525

negative < 0.525

Chapter III

Results

1. Soil properties

In this section from the result, a shape file is made up of 8,099 polygons, in turn constituting 107 map units, for a total surface area of 706,605 ha, corresponding to 67.6% of the Lebanese territory. In ***Table 19***, the values relating to the properties used for assessing land suitability are reported for each map unit.

1.1.The Map units

The soils present in the map units have been classified according to the indications of the WRB, acronym of the World Reference Base for Soil Resources (ISSS-ISRIC-FAO, 1998).

1. The WRB provides for two levels of soil classification:

- The first is the Soil Reference Group. The attribution of soil to a reference group is based on:
- The presence of chemical properties, such as the carbonate content,
- The presence of physical properties, such as the depth of the soil,
- The characteristics of the parental material, for example, alluvial or aeolian deposits or, less commonly, on climatic conditions

The names of the reference groups, which derive from Greek, Latin or terms commonly used in Soil Science have mnemonic properties as they recall the property of the main soil or of that, we want to highlight in this study.

2. In the second level, the qualifiers used, are divided into both principal and supplementary, which allow to specify or quantify other accessory properties of the soil, for example, the color of the horizons, their texture, the nature of the parental material.

Thus, for example, the most widespread soil in the area under study is classified as Eutric Leptosols, where:

- Leptosols[1] (Soil Reference Group), from the Greek leptos, (thin), where the thin soils with many coarse fragments fall.
- Eutric[2] (Principal Qualifiers), from the Greek eutros, (good), is used in presence of a base saturation calculated on the sum of exchangeable base…. plus, exchangeable Al.≥ 50%.

The Calcaric qualifier, frequent in the map units under study, is specific for soil which having calcaric material throughout between 20 and 100 cm from the soil surface or, between 20 cm and continuous rock, technic hard material or a cemented or indurated layer, whichever is shallower.

Of the 107 map units, the most widespread are those of Eutric Leptosols, which affect 143,302 ha, corresponding to 18.84% of the area under study, and of Calcaric Regosols with 42,311 ha (5.56%). With the exception of a limited number of map units that have areas between 42,000 and 20,000 ha, almost all of them involve significantly smaller areas. The extreme case is that of the association of Vertic Cambisols and Eutric Vertisols in which four ha fall.

Table 19: Map units, value properties, surfaces in ha and in percentage

SOIL MAP UNITS	SOIL CHARACTERISTICS						
	DRAINAGE	DEEP	NUTRIENT	CEC	pH	AREA ha	AREA %
Andic Cambisols	0.5	1.0	0.1	0.5	1.0	977	0.13
Andic Luvisols	1.0	1.0	0.1	0.1	1.0	1742	0.23
Anthropic Regosols	0.5	1.0	0.1	0.5	0.5	10,599	1.39
Areno-Eutric Leptosols	1.0	0.5	0.5	0.1	0.1	74,558	9.80
Aridic Leptosols	1.0	0.5	1.0	1.0	0.1	2227	0.29
Association of Haplic Luvisols and Leptic Luvisols	0.5	0.5	1.0	1.0	0.5	15,622	2.05
Association of Aridi-Calcaric Leptosols and Aridic Regosols	0.5	0.5	0.5	0.1	0.1	3918	0.52
Association of Aridi-Calcaric Leptosols, Aridic Regosols and Aridic Leptosols	0.5	0.5	0.5	0.1	0.1	1840	0.24
Association of Aridi-Calcaric Leptosols, Aridic Regosols, Petric Calcisols and Aridic Leptosols	0.5	0.5	0.5	0.1	0.1	3367	0.44
Association of Aridic Calcisols and Leptic Calcisols	1.0	0.5	0.5	0.5	0.1	2217	0.29
Association of Aridic Fluvisols and Haplic Calcisols	0.5	0.1	0.1	0.5	0.1	7122	0.94
Association of Aridic Regosols and Aridic Leptosols	0.5	0.5	0.5	0.5	0.5	633	0.08
Association of Calcaric Cambisols, Eutric Cambisols and Gleyic Cambisols	0.1	1.0	0.5	0.5	1.0	2223	0.29
Association of Calcaric Fluvisols and Calcaric Regosols	0.5	1.0	0.5	0.5	0.5	49	0.01
Association of Calcaric Fluvisols and Mollic Fluvisols	1.0	1.0	0.5	1.0	0.5	700	0.09

Association of Calcaric Fluvisols, Aridic Calcisols, Aridic Regosols and Haplic Calcisols	1.0	1.0	0.5	0.5	0.5	3168	0.42
Association of Calcaric Fluvisols, Calcaric Leptosols and Calcaric Regosols	1.0	1.0	0.5	1.0	0.5	43	0.01
Association of Calcaric Fluvisols, Calcaric Leptosols and Petric Calcisols	1.0	0.5	0.5	0.5	0.5	1419	0.19
Association of Calcaric Gleysols, Calcic Vertisols and Eutric Regosols	1.0	1.0	0.5	0.5	0.5	1114	0.15
Association of Calcaric Leptosols and Leptic Luvisols	0.5	0.5	1.0	0.5	0.5	26,293	3.46
Association of Calcaric Leptosols, Haplic Leptosols and Skeletic Regosols	1.0	1.0	0.5	0.5	0.5	13,088	1.72
Association of Calcaric Leptosols, Leptic Luvisols and Humic Leptosols	1.0	0.5	1.0	0.5	0.5	9405	1.24
Association of Calcic Luvisols and Lithic Leptosols	0.5	0.5	0.5	0.1	0.5	677	0.09
Association of Calcic Vertisols, Eutric Vertisols, Luvic Chernozems and Gleyic Chernozems	0.1	1.0	0.1	0.5	0.5	5630	0.74
Association of Chromic Luvisols and Ferric Luvisols	0.5	1.0	0.5	0.5	0.5	1140	0.15
Association of Endocalcaro-Hyperskeletic Leptosols, Calcic Vertisols and Vertic Cambisols	0.1	1.0	0.5	0.5	0.5	683	0.09
Association of Endogleyic Cambisols, Calci-Haplic Cambisols and Profondic Luvisols	0.5	1.0	0.5	0.5	0.5	807	0.11
Association of Eutric Cambisols and Eutric Leptosols	0.5	0.5	0.5	0.5	0.5	900	0.12
Association of Eutric Cambisols and Haplic Calcisols	0.5	0.5	0.5	0.5	0.5	652	0.09
Association of Eutric Fluvisols and Calcaric Fluvisols	0.5	1.0	0.5	0.5	0.5	2952	0.39
Association of Eutric Fluvisols and Eutric Vertisols	0.1	1.0	0.1	0.5	0.5	995	0.13
Association of Eutric Leptosols and Rendzic Leptosols	0.5	0.1	0.1	0.5	0.5	2782	0.37

Association of Eutric Luvisols, Leptic Luvisols and Lithic Leptosols	0.5	1.0	0.5	0.5	0.5	6622	0.87
Association of Eutric Regosols and Calcaric Regosols	0.5	1.0	0.5	0.5	0.5	2181	0.29
Association of Eutric Regosols, Eutric Luvisols, Eutric Fluvisols and Vertic Cambisols	0.5	1.0	0.5	0.5	0.5	369	0.05
Association of Gleyic Fluvisols and Eutric Fluvisols	0.1	1.0	0.5	0.5	0.5	79	0.01
Association of Haplic Cambisols and Mollic Gleysols	0.5	1.0	0.5	0.5	0.5	1393	0.18
Association of Haplic Cambisols and Endogleyic Anthrosols	0.5	1.0	0.5	0.5	0.5	413	0.05
Association of Haplic Cambisols and Rendzic Leptosols	0.1	1.0	0.5	0.5	0.5	783	0.10
Association of Haplic Cambisols, Calcaric Anthrosols and Eutric Anthrosols	0.5	1.0	0.5	0.5	0.5	15	0.00
Association of Hypercalcaric Fluvisols and Hypereutric Vertisols	0.1	1.0	1.0	0.5	1.0	193	0.03
Association of Leptic Andosols and Arenic Andosols	1.0	0.1	0.5	0.5	1.0	170	0.02
Association of Leptic Luvisols and Calcaric Leptosols	0.5	0.5	0.5	1.0	0.5	8189	1.08
Association of Leptic Luvisols and Haplic Leptosols	0.5	0.5	1.0	1.0	0.5	4125	0.54
Association of Lithic Leptosols and Bare rocks	0.5	0.1	0.1	0.1	0.5	16,815	2.21
Association of Lithic Leptosols, Leptic Luvisols and Eutric Luvisols	0.5	0.5	0.1	0.5	0.5	28,000	3.68
Association of Mollic Leptosols and Lithic Leptosols	0.1	0.1	0.1	0.5	0.5	56	0.01
Association of Petric Calcisols, Aridic Leptosols and Epileptic Calcisols	0.5	0.5	0.5	0.5	0.1	10,272	1.35
Association of Rendzic Leptosols and Calcaric Arenosols	0.5	0.5	0.1	0.1	0.5	41	0.01
Association of Rendzic Leptosols and Calcaric Leptosols	0.5	0.1	0.1	1.0	0.5	14,652	1.93

Association of Rendzic Leptosols and Haplic Cambisols	0.5	0.5	0.1	1.0	0.5	1534	0.20
Association of Rhodic Luvisols and Haplic Cambisols	0.5	1.0	0.5	1.0	1.0	673	0.09
Association of Skeletic Regosols and Hyperskeletic Leptosols	0.5	1.0	0.5	0.5	0.5	26	0.00
Association of Vertic Cambisols and Calcaric Cambisols	0.1	0.5	0.5	0.5	0.5	4	0.00
Association of Vertic Cambisols and Eutric Vertisols	0.1	1.0	0.5	0.5	0.5	184	0.02
Association of Vertic Cambisols, Calcaric Fluvisols and Eutric Cambisols	0.1	1.0	0.5	0.5	0.5	3580	0.47
Association of Vertic Luvisols and Eutric Cambisols	0.1	1.0	0.5	0.5	0.5	187	0.02
Association of Vertic Luvisols and Gleyic Leptosols	0.1	1.0	0.5	0.5	0.5	585	0.08
Calcaric Cambisols	0.5	1.0	0.1	0.5	0.5	7587	1.00
Calcaric Fluvisols	1.0	1.0	0.5	1.0	0.5	3212	0.42
Calcaric Gleysols	1.0	1.0	0.5	1.0	0.5	479	0.06
Calcaric Leptosols	1.0	0.5	0.5	0.5	0.5	7544	0.99
Calcaric Luvisols	0.1	1.0	0.1	0.5	0.5	131	0.02
Calcaric Regosols	0.5	1.0	0.5	0.5	0.5	42,311	5.56
Calcaro-Hortic Anthrosols	0.5	1.0	0.5	0.1	0.5	26,796	3.52
Calcaro-Mollic Leptosols	0.5	0.1	0.5	0.5	0.5	3596	0.47
Calcic Luvisols	1.0	1.0	0.1	0.5	0.5	3331	0.44
Calcic Vertisols with associated Luvic Chernozems, Chromic Cambisols and Luvic Phaeozems	0.1	1.0	0.1	0.5	0.5	350	0.05
Chromic Cambisols	0.5	1.0	0.1	0.5	0.5	3137	0.41
Chromic Luvisols	0.5	1.0	0.5	0.5	0.5	2423	0.32
Cliff	0.1	0.1	0.1	0.1	0.1	2155	0.28
Cumuli-Luvic Anthrosols	1.0	1.0	0.5	0.5	0.5	14	0.00
Endogleyic Anthrosols	0.1	0.1	0.1	0.1	0.5	645	0.08
Endoskeletic Regosols	1.0	0.1	0.1	0.1	0.5	3987	0.52
Endostagnic Vertic Cambisols	0.1	1.0	0.5	0.5	1.0	48	0.01
Eutric Arenosols	0.5	1.0	0.5	0.5	0.5	18,884	2.48
Eutric Cambisols	0.1	0.5	0.5	0.5	0.5	30,382	3.99
Eutric Fluvisols	0.5	1.0	0.5	0.5	0.5	2018	0.27

Eutric Gleysols	0.1	0.1	0.1	0.1	1.0	12,725	1.67
Eutric Leptosols	1.0	0.1	0.1	0.5	0.5	143,302	18.84
Eutric Luvisols	0.5	1.0	0.5	0.5	10	4876	0.64
Eutric Regosols	0.5	1.0	0.5	0.5	0.5	13,321	1.75
Fluvic Cambisols	0.5	0.5	0.5	0.5	0.5	39	0.01
Gleyic Leptosols	1.0	0.1	0.1	0.5	0.5	1823	0.24
Gleyic Luvisols	0.1	1.0	0.5	0.1	0.5	3	0.00
Haplic Arenosols	1.0	0.5	0.1	0.1	0.5	5837	0.77
Haplic Calcisols	0.5	1.0	0.5	0.5	0.5	7882	1.04
Haplic Cambisols	0.5	1.0	1.0	1.0	0.5	1752	0.23
Haplic Luvisols	0.5	1.0	0.5	1.0	0.5	10,881	1.43
Hypereutric Vertisols	0.1	1.0	0.1	1.0	1.0	162	0.02
Hyperskeletic Leptosols	1.0	1.0	0.1	1.0	0.5	2381	0.31
Hypoluvic Arenosols	1.0	1.0	0.1	0.1	0.5	1893	0.25
Lac	0.1	0.1	0.1	0.1	0.1	544	0.07
Leptic Andosols	1.0	0.1	0.5	0.5	1.0	9004	1.18
Leptic Calcisols	0.5	0.5	0.1	0.5	0.1	1238	0.16
Leptic Luvisols	0.5	0.5	1.0	0.5	0.5	42,033	5.53
Luvic Calcisols	0.5	1.0	0.5	0.5	1.0	239	0.03
Mollic Andosols	0.5	1.0	0.1	0.5	0.5	35	0.00
Mollic Gleysols	0.1	1.0	0.5	0.5	0.5	587	0.08
Petric Calcisols	0.5	0.5	0.1	0.5	0.5	9935	1.31
Rendzic Leptosols	0.1	0.1	0.1	0.5	0.5	14,956	1.97
Rhodic Luvisols	0.5	1.0	0.5	1.0	1.0	498	0.07
Rhodic Vertisols	0.5	1.0	0.5	1.0	1.0	54	0.01
Skeletic Regosols	0.5	1.0	0.5	0.5	1.0	4676	0.61
Vertic Cambisols	0.1	1.0	0.5	1.0	0.5	10,023	1.32
Vertic Lixisols	0.1	1.0	0.1	0.1	1.0	21	0.00
Vertic Luvisols	0.5	1.0	0.1	0.5	0.5	172	0.02
TOTAL						**760 605**	

1.2 Classes of influence of soil properties

i. Soil depth

The depth of the soil has the ability to significantly influence some soil properties of agronomic and forestry interest: workability is also defined as the ability to use mechanized processing and, crucial in the Mediterranean environment characterized by both seasonal and rainfall variability, which is its water reserve. The depth of a soil is correlated to various factors including the degree of alteration of the substrate, in turn related to rainfall and the water reserve of the soil, and the presence of erosive processes, both water and Aeolian capable of removing large volumes of soil even in a relatively short time.

In sedimentary rocks, where decarbonisation is the main altering process, the depth of the soil depends on the quantity and quality of their insoluble residue. In the Jurassic and Cretaceous crystalline limestone, common for the area under study, the insoluble residue is generally of the order of 3-10 gr, a situation that involves the formation of soils of reduced thickness and therefore often unsuitable for agricultural and forest crops. The reduced thickness of the surface horizons of the soil is compensated by the presence, in these formations, of karst pockets, which allow the accumulation of large volumes of soils, and, consequently, the presence of evolved stains and forest formations. The linked table indicates a relative uniformity, although with the prevalence of the indifferent class, with respect to the positive and negative ones shown in map ***Figure 58*** and ***Table 20***.

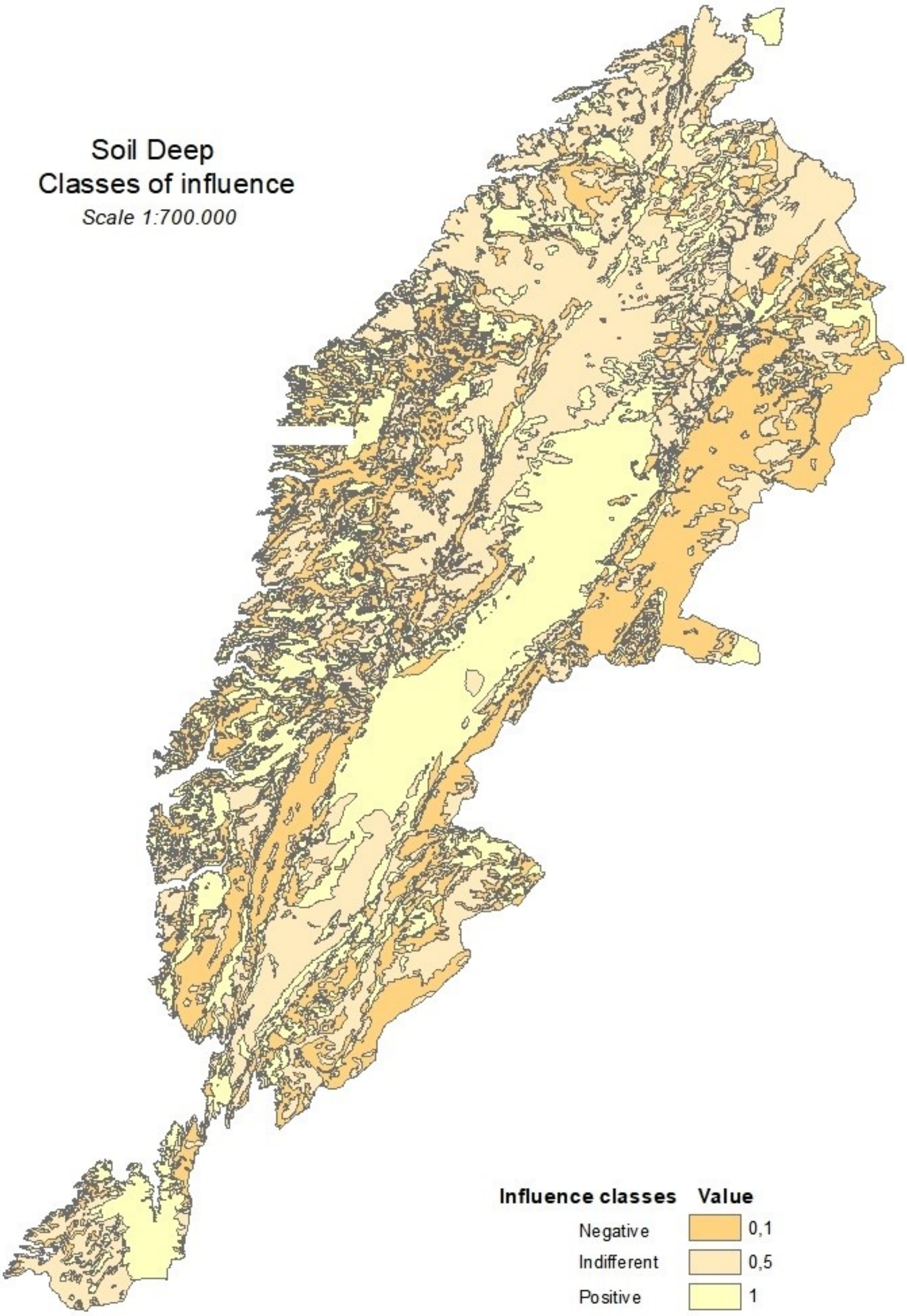

Figure 58: Map of soil deep, classes of influence

Table 20: Soil deep, influence classes.

Soil deep Influence classes	Value	Area ha	Area %
Negative	0.1	234,337	30.8
Indifferent	0.5	292,897	38.5
Positive	1.0	233,371	30.7
Total		**760,605**	

ii. Soil drainage

The drainage of soil has important repercussions both on natural vegetation and on its agricultural or forest use. Excessively rapid drainage is a function of the texture of the soil, both for the entire profile and for the individual horizons and of the morphology that influences both the infiltration of water and the subsequent intra-pedestrian movement or along the slope. In the presence of excessively rapid drainage, the time span in which the soil is able to constitute a sufficient water reserve for the vegetation (for agricultural interest and consequently for the natural and forest plants) is reduced. Poor drainage, which is also related to texture, such as the presence of an argillic horizon with a texture richer in clay than the overlying horizons, in the presence of depressed micro-morphologies or subsurface water tables, causes water stagnation on the surface and subsurface aquifers, resulting in redox potential variations in the horizons involved and radical asphyxia phenomena.. Situations that reduce the choice of possible agricultural and forest crops require the implementation of hydraulic reclamation works. It was obtained, from the Map Unit database using the function dissolve the layer of the soil drainage and classes of influence, ***Table 21*** and ***Figure 59***.

Figure 59: Map of soil drainage, classes of influence

Table 21: Drainage soil, influence classes

Drainage Influence class	Value	Area ha	Area %
Negative	0.1	87,914	11.6
Indifferent	0.5	380,033	50.0
Positive	1.0	292,658	38.5
Total		**760,605**	

The ***Table 21*** shows the prevalence in the study area, of the indifferent class, 380,033 ha which affects 50% of its surface and 292,658 ha (38.5%) of the positive class.

The surfaces falling in the negative class, which are 87,914 ha (11.6%) are those affected by the presence of very fine alluvial deposits or high content of 2:1 lattice clays (for example, the Association of Hypercalcaric Fluvisols and Hypereutric Vertisols and Calcaric Luvisols). Or the differences in textural classes derived from the map units with soil that shows significant variations in the clay content in the deep horizons compared to the superficial ones (for example, the Association of Vertic Luvisols and Eutric Cambisols). Finally, substrates with reduced permeability that allow the formation of a subsurface substrate, like the Eutric Gleysols in which the 12,275 ha fall, equivalent to 1.67 % of the area under study.

iii. Soil Nutrient deficiencies

In the Soil Map of Lebanon monograph, the content in major macronutrients was indicated for each map unit, specifying any deficiency in qualitative terms. In the context of this model, to attribute a value it was decided:

- 1 mean *Absent, or low* deficiency of a macronutrient
- 0.5 mean *Moderate deficiency* due to deficiency of two macronutrients or severe deficiency in one macronutrient
- 0.1 mean *High deficiency*, due to deficiencies in all macronutrients or severe deficiency in two

The result of processing the nutrient data with *dissolve* on ***Table 22*** and ***Figure 60***, indicates that the optimal situation, no deficiency or reduced deficiency in a macronutrient affects only 101,650 ha, equivalent to 13.4% of the total area. Of the remaining territory, 351,663 ha (46.2%) are affected by moderate deficiencies, while in the *negative class*, severe deficiencies in all macronutrients, fall 307,292 ha (40.4%).

Table 22: Soil nutrients, influence classes

Nutrient Influence class	Value	Area ha	Area %
Negative	0.1	307,292	40.4
Indifferent	0.5	351,663	46.2
Positive	1.0	101,650	13.4
Total		**760,605**	

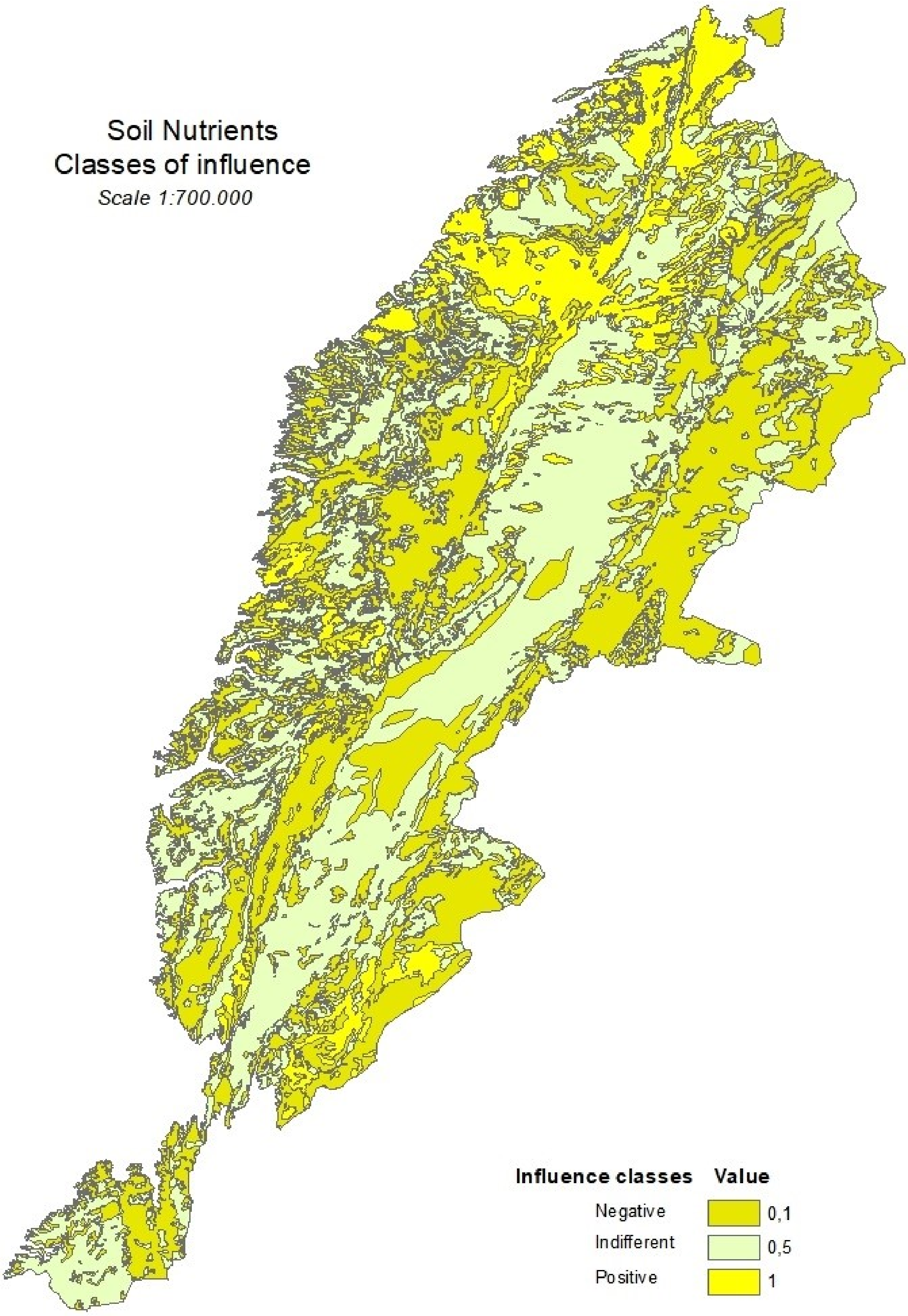

Figure 60: Map of Soil nutrient deficiencies, classes of influence

iv. Cations Exchangeable Capacity (CEC)

The CEC allows specifying the main property of the soil: to adsorb the cations present in the circulating solution and subsequently transfer them to the vegetation (Sequi, 1989). The CEC is a direct function of the content and mineralogical characteristics of the clays present, permanent CEC, and of the organic acid content, temporary CEC. The clays derive from the alteration processes of the parental material. In this case, their mineralogical characteristics are a function of the processes that during the paedogenesis may have directed the weathering of minerals towards different structural classes. The clays can be present in the parental material, for example, marly limestone and marl, where they are freed from the alteration processes, thus constituting a part of the insoluble residue. With regard to this property, the cited monograph indicates the cations present in the exchange complex for the typical profiles of the map units. The overall CEC is defined in three classes: high, medium, and low, which correspond respectively to the classes of positive, indifferent, and negative influence and the relative values. By applying the dissolve function to the relative field of the database, results are shown in ***Table 23*** and map ***Figure 61***, where 77,206 ha (10.2%) is present in the positive influence class, 525,836 ha (69.1%) in the indifferent and 157,563 (20.7%) in the negative class.

Table 23: Soil CEC, influence classes

CEC Influence class	**Value**	**Area ha**	**Area %**
Negative	0.1	157,563	20.7
Indifferent	0.5	525,836	69.1
Positive	1.0	77,206	10.2
Total		**760,605**	

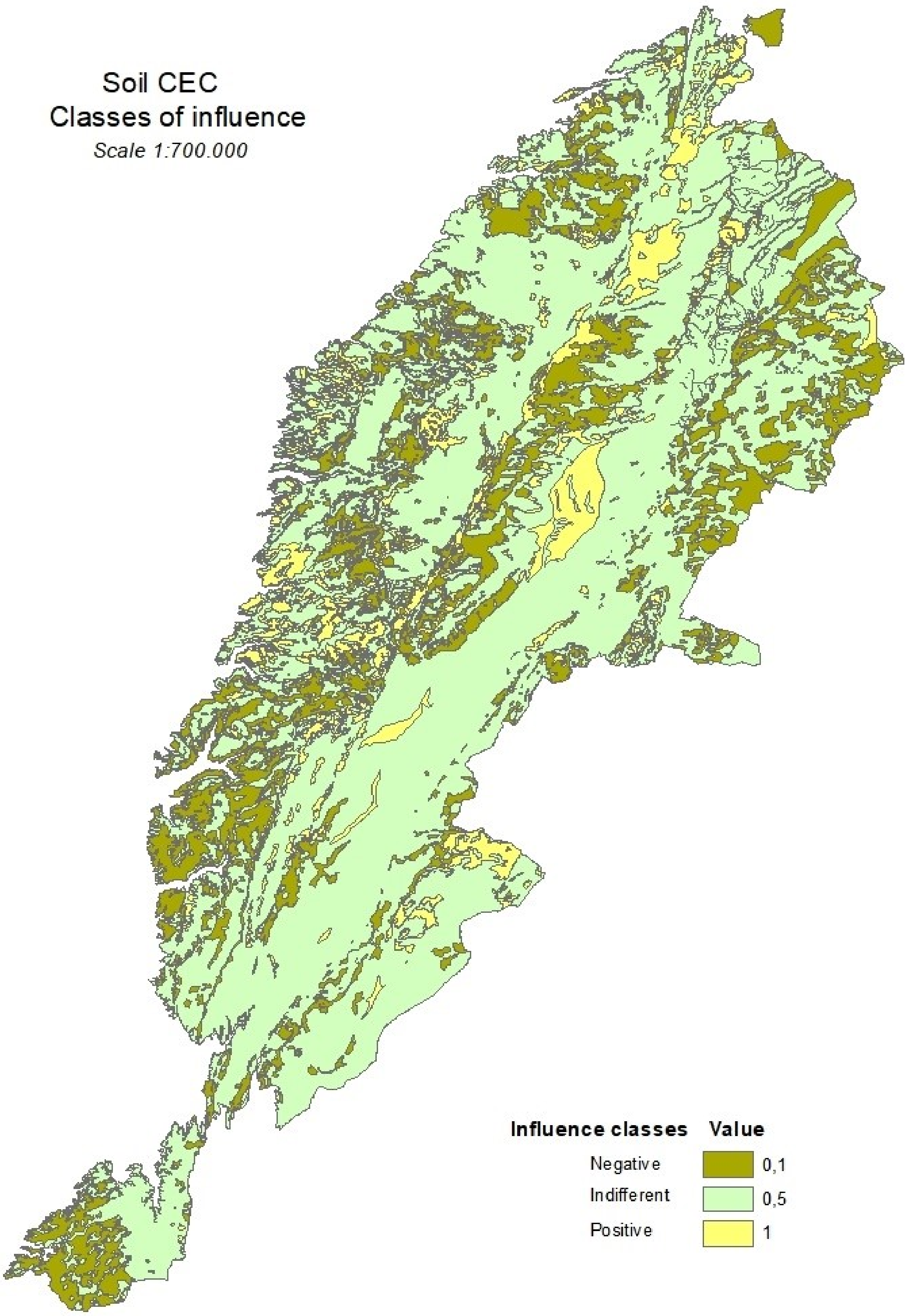

Figure 61: Map of soil CEC influence classes

As a first hypothesis, the indifferent class high value could be related to a greater presence of clays in soils, even inherited clays, with reduced exchange capacity due to the difficulty of replacing Al and Si cations in the octahedral and tetrahedral layers (Sequi, 1989).

v. Soil pH

The main factors that influence the soil's pH are closely related to the dynamics of the exchange complex that is to the degree of saturation of clays and humic acids. Occasionally, the minerals present in the source rock or resulting from the alteration processes of the same may also affect (Sequi, 1989).

In almost all the map units present in the area under study, the calcium cation plays a fundamental role by saturating the exchange complex. A situation involves soil pH varying from neutral to slightly sub-alkaline.

From the processing of the data relating to map soil pH in ***Figure 62*** and ***Table 24*** results in the prevalence of the indifferent influence class, which includes 612,867 ha (80.9%). This situation is due both to the prevalence of sub-alkaline reactions as in the case of *Aridic Leptosols* and *Areno-Eutric Leptosols*, and, probably, to partial desaturations of the exchange complex due to local climatic conditions as in the case of *Eutric Leptosols*, which favoured the leaching extrapedon processes.

Table 24: Soil pH, influence classes

pH Influence class	**Value**	**Area ha**	**Area %**
Negative	0.1	109,458	14.4
Indifferent	0.5	612,867	80.6
Positive	1.0	38,280	5.0
Total		**760,605**	

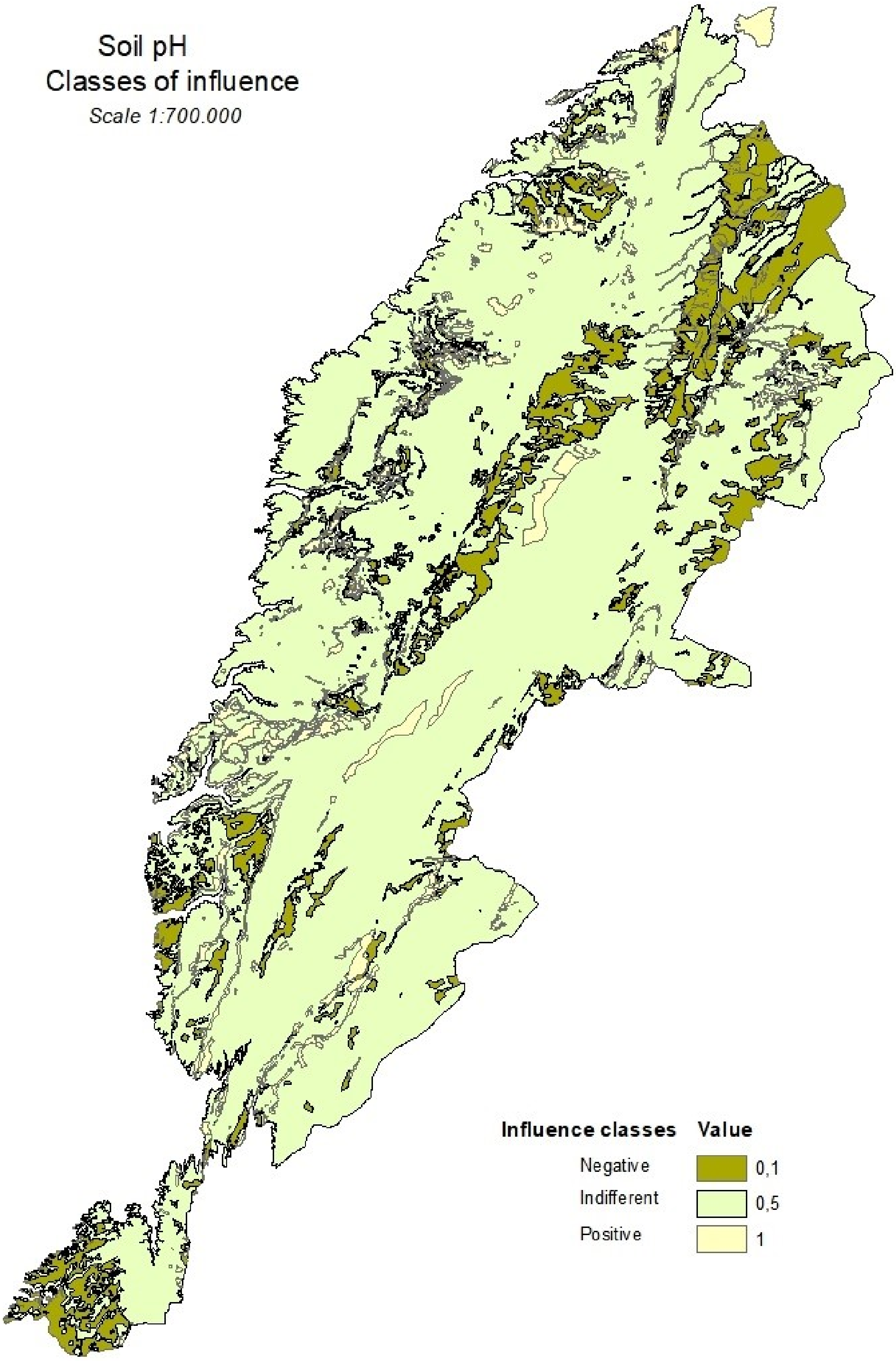

Figure 62: Soil map of pH influence classes

2. Rainfall

Precipitation is influenced by exposure and altitude. Average annual precipitations of less than 500 mm are to be considered situations at the limit of the semi-arid condition: Values that in the Lebanese territory are observed in the central inland areas, (Darwish et al., 2006)[8].

The map in ***Figure 63*** and ***Table 25***, summarizes the ones relating to the pluviometric ranges. The 900 - 1000 mm/year is the most widespread, affecting 79,513 ha (10.5%), a value that does not present significant differences with those of between 500 - 600 mm / year and 1100 - 1200 mm/year, considered to have a positive influence on the cedar planting.

[8] For the inland areas of Lebanon Darwish and collaborators indicate average annual rainfall ranging from less than 200 mm, which affects 27% of the area falling on the Joussie sheet of the pedological map to 50,000, to 1300 -> 1400 mm of 30% of the sheet Zahle of the same cartography.
Precipitation and altitude affect the frequency of snowfall and the subsequent duration of the snowy chin. An early thaw can, for example, favor the early birth of Cephalcia tannourienensis or Syndemic cedricola insect whose larval forms are particularly active on younger cedrus.

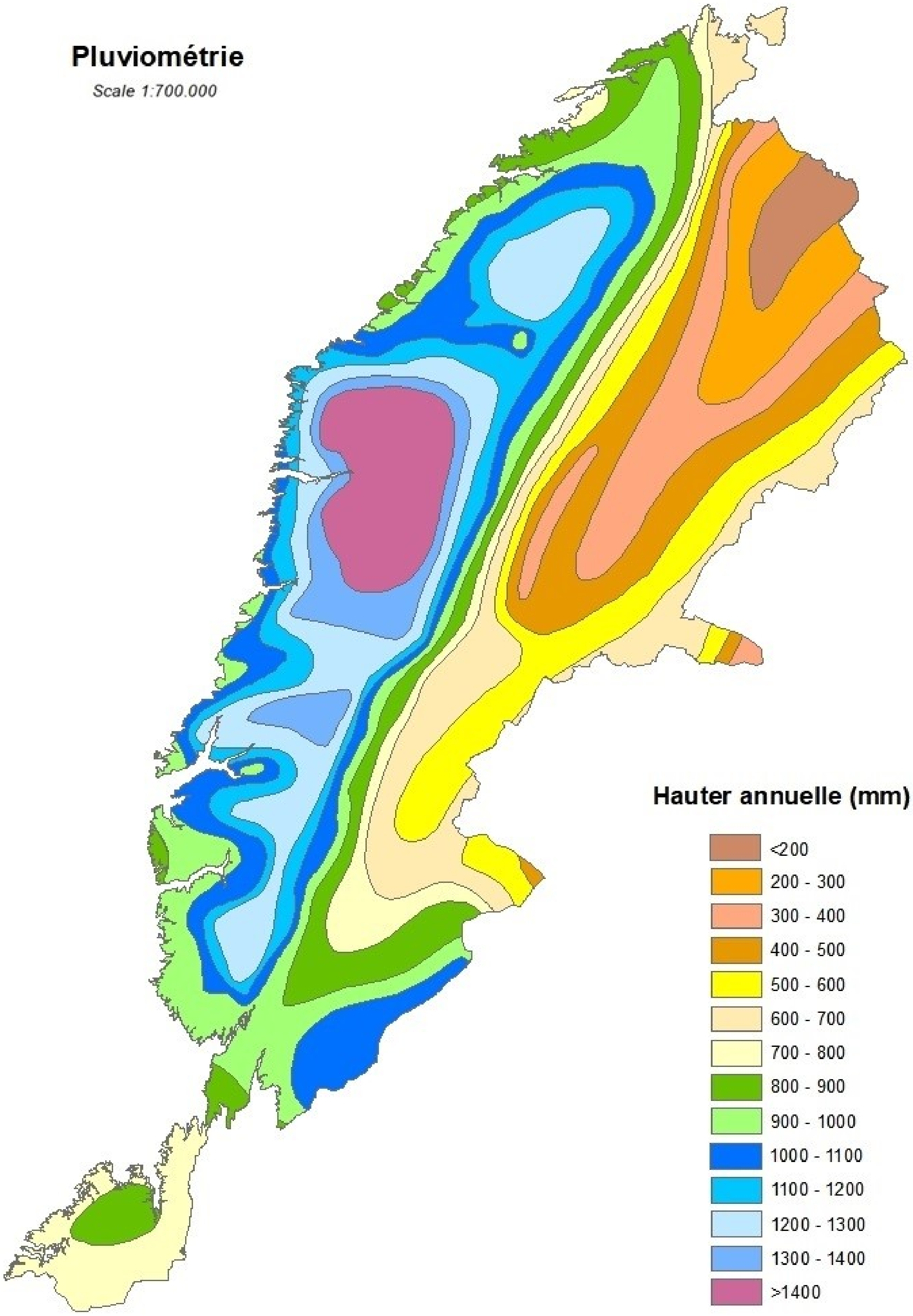

Figure 63: Rainfall, classes of average annual precipitation in mm (from CDR-SDATL)

Table 25: Average annual heights of precipitation in the area under study areas (in ha and in percentage)

Rainfall mm/year	Area ha	Area %
< 200	15,365	2.0
200 - 300	31,681	4.2
300 - 400	50,044	6.6
400 - 500	57,138	7.5
500 - 600	65,367	8.6
600 - 700	66,654	8.8
700 - 800	55,846	7.3
800 - 900	64,038	8.4
900 - 1000	79,513	10.5
1000 - 1100	75,411	9.9
1100 - 1200	59,377	7.8
1200 - 1300	71,263	9.4
1300 - 1400	28,858	3.8
> 1400	40,050	5.3
Total	**760,605**	

Table 26, as the previous ones obtained with the dissolve function, shows the data relating to the surfaces affected by the influence classes.

Table 26: Rainfall annual average, influence classes

Rainfall Influence class	Value	Area ha	Area %
Negative	0.1	154,228	20.3
Indifferent	0.5	205,538	27.0
Positive	1.0	400,839	52.7
Total		**760,605**	

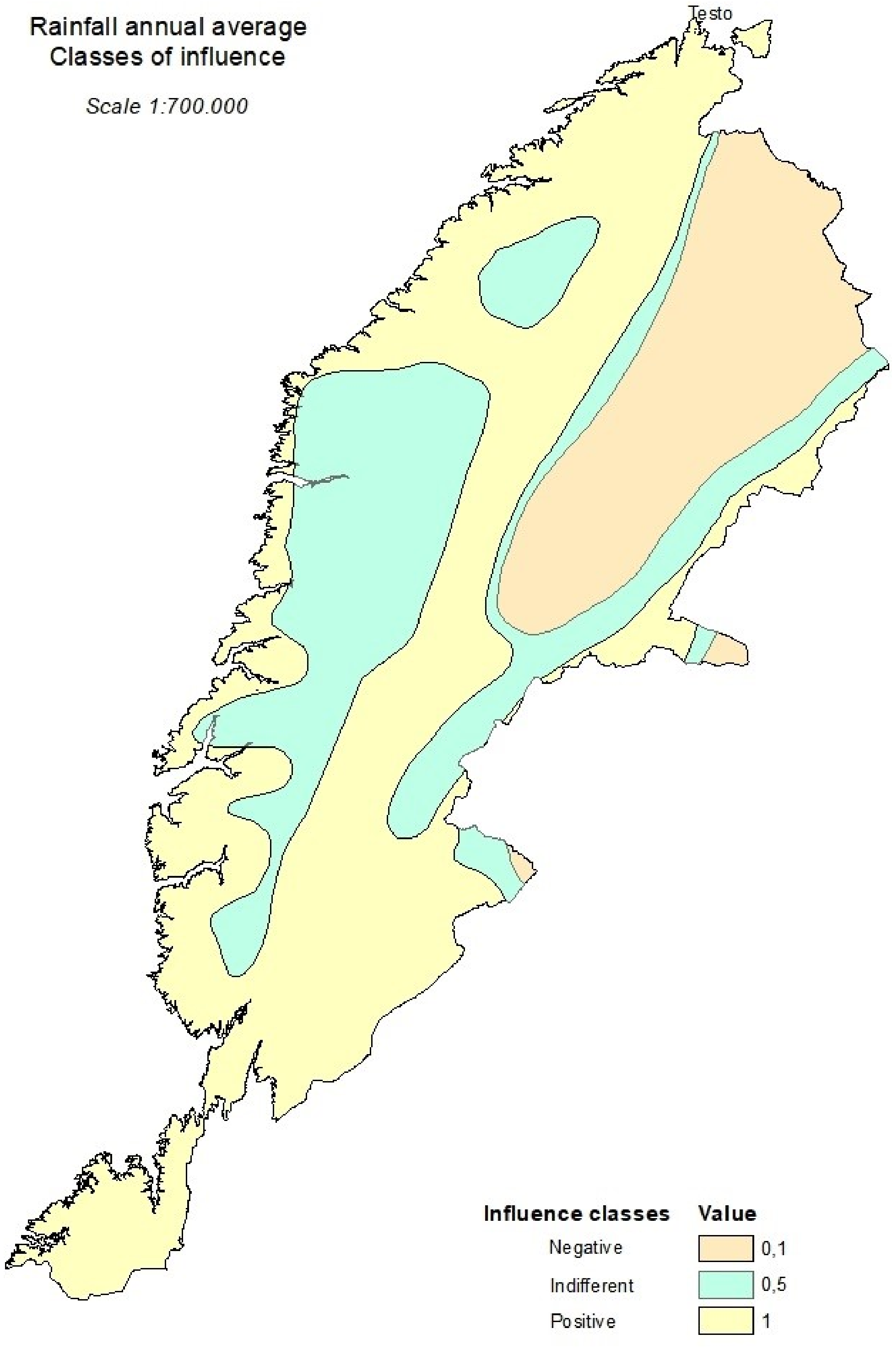

Figure 64: Rainfall annual average, influence classe

Based on the map rainfall annual average in ***Figure 64***, the positive influence class includes 400,839 ha (52.7%) affecting both sides of Mount Lebanon and the lower altitudes of the western slopes of the Anti-Lebanon. The model attributes 15,4228 ha (20.3%) to the negative influence class, almost all falling within the Bekaa valley. Lastly, the model assigns 205,538 ha (27.0%) to the indifferent influence class, which affects both the areas with a lower altitude on the eastern side of Mount Lebanon, and its higher-altitude areas.

3. Geological characteristics: Substrate and relative slope deposits

From the Jurassique to the Quaternaire, the map is segmented into 28 map units organized according to the System in **Table 27**.
Similar to the rainfall map, the area below 500m was cut out as shown in figure 63 and table 28. Compared to the original cartography, the map units are 16 having been eliminated both almost all the Quaternary units and the effusive eruptive formations of the basalts, all widespread in the areas excluded by altitude.

The prevailing formation per area concerned 347,629 ha, which is equivalent to 45.7% of the territory under study and the c4 - Calcaire reguliérement litéee, Claire (Cretace). This unit characterizes almost all of the reliefs of Mount Lebanon and the reliefs of the Anti-Lebanon falling within the governorate of Baalbek-Hermal. The second unit for diffusion is the j4-7 Calcaire massif gris claire / jurassique terminal détritique ou récif, with 116,903 ha (15.4%) that the intermediate altitude range, 800 - 1100 m, on the western side of the Mountains of Lebanon and the Anti-Lebanon Mountains falling within the Bekaa and Nabatiye governorates.

From the database with the dissolve function, the layer relating to the classes of influence of geology in ***Figure 65*** and ***Table 28*** has been obtained.In the positive influence class where the value is one, the processing attributed 498,235 ha which is equivalent to 65.5% of the area being assessed. This class includes all Jurassic formations and those of crystalline limestone, c1 - Grés de base, c1-2 - Crétacé inférieur ET Aptien indifférenciés and c4- Calcaire réguliérement litée, Claire. In the indifferent influence class, 204,697 ha (26.9%) are ascribed to the Cretaceous, Paleogene, and Neogene formations affected by the presence of marly limestone, marls, clays, and the qcpb - Calloutis de pente et coulées boueuses of the Quaternary.
Finally, in the negative influence class, 57,673 ha (7.6%) are of the Terres arables quaternaires.

Table 27*:* Geological map units in study area, surfaces in ha e in percentage

MAP UNIT	VALUE	AREA ha	AREA %
QUATERNAIRE			
qcpb - Calloutis de pente et coulées boueuses	05	8063	1.1
qta - Terres arables	0.1	57,673	7.6
TERTIAIRE - NEOGENE			
ncq - Poudinge grossier torrentiel	0.5	70,815	9.3
p Pliocéne – Argile bleue, marnes sableuses et calcaires	0.5	10,117	1.3
ml - Miocéne: marnes et marnes calcaires lacustres	0.5	1,489	0.2
TERTIAIRE - PALEOGENE			
e1-2 - Marne blanche et calcaires sub-récifaux	0.5	44,825	5.9
CRETACE			
c6 - Marnes et marmo-calcaires blancs	0.5	15,202	2.0
c4- Calcaire réguliérement litée, claire	1.0	347,629	45.7
c3 - Alternance de marne verte et de banc calcaire	0.5	41,227	5.4
c2- Alternance de terrains argilo-sableux et de bancs calcaires	0.5	186	0.0
c1-2 - Crétacé inférieur et Aptien indifférenciés	1.0	6326	0.8
c1 - Grés de base	1.0	26,824	3.5
JURASSIQUE			
j2-3 -Dolomie noire/calcaire ocre	1.0	553	0.1
j4-7 - Calcaire massif gris-clair/jurassique terminal détritique ou récif	1.0	116,903	15.4
ROCHES ERUPTIVES: BASALTE			
bq - Basalte quaternaire	0.5	12,682	1.7
bj – Basalte du jurassique terminal	0.5	91	0.0
TOTAL		**760,605**	

Table 28: Geological map units table, influence classes

Influence class	Value	Area ha	Area %
Negative	0.1	57,673	7.6
Indifferent	0.5	204,697	26.9
Positive	1.0	498,235	65.5
Total		**760,605**	

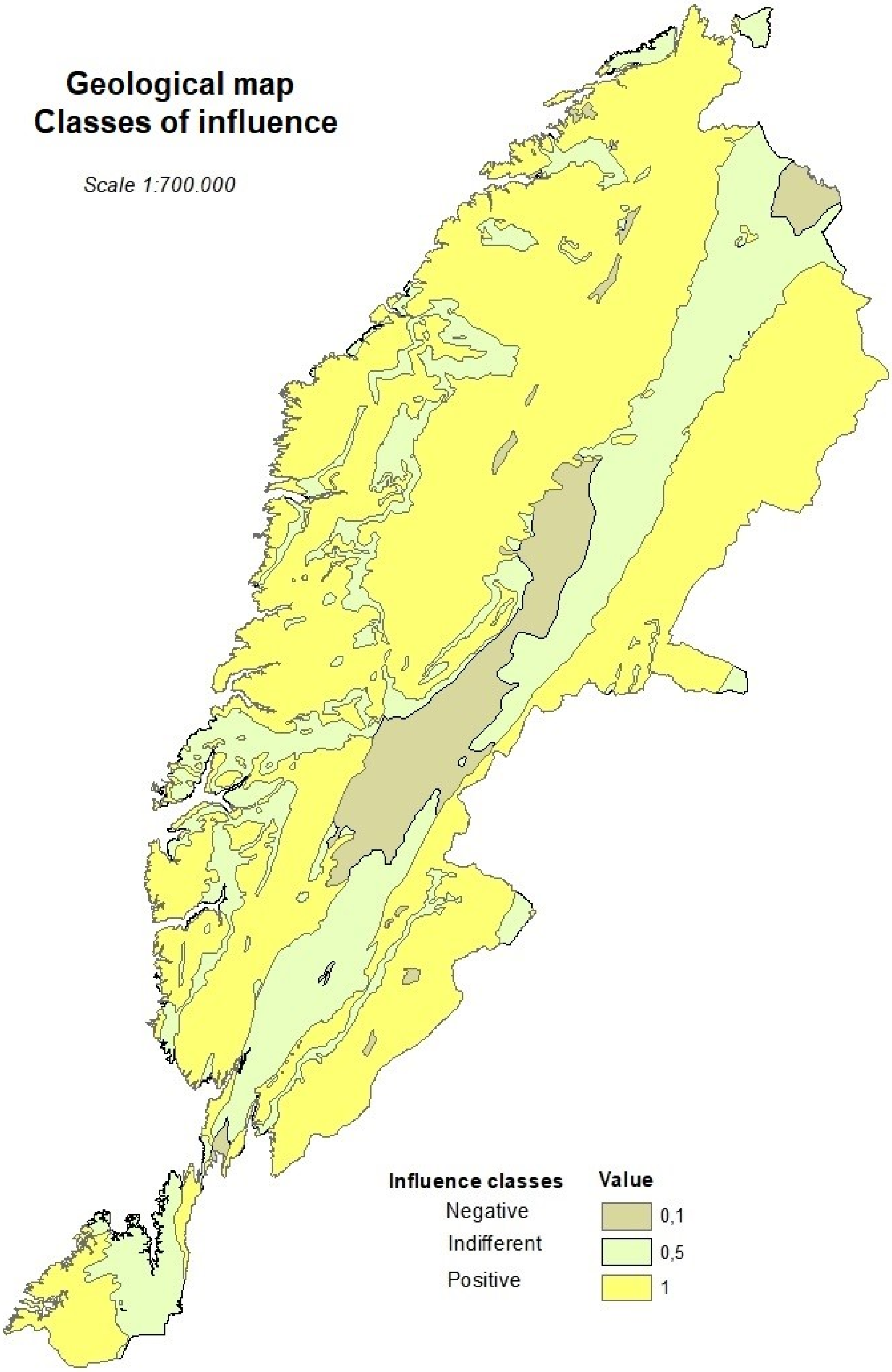

Figure 65: Map of Geological units, influence classes.

4. Elevation

For the latter, it is necessary to specify that there is an area of 1552.63 ha (0.2% of that under study). This situation is due to the different format between the DEM (*Raster*) and that of the ***Figure 55*** used (*Vector*).

From the ***Table 29*** and ***Figure 66***, it appears that the most common elevation classes are those between 800 - 900 m, with 69,340 ha (9.1%) and 1000 - 1100 m with 69,795 ha (9.2%) among the most favorable to cedrus.

Table 29: Elevation class of the study area

Elevation m a.s.l.	Area ha	Area %
< 500	1553	0.2
500 - 600	45,074	5.9
600 - 700	56,043	7.4
700 - 800	44,682	5.9
800 - 900	69,340	9.1
900 - 1000	66,862	8.8
1000 - 1100	69,795	9.2
1100 - 1200	51,352	6.8
1200 - 1300	48,293	6.3
1300 - 1400	45,295	6.0
1400 - 1500	41,822	5.5
1500 - 1600	36,991	4.9
1600 - 1700	30,656	4.0
1700 - 1800	26,932	3.5
1800 - 1900	28,533	3.8
1900 - 2000	24,521	3.2
2000 - 2100	19,953	2.6
2100 - 2500	42,060	5.5
2500 - 3088	10,788	1.4
Total	**760,543**	

The following (***Table 30***) summarizes the data relating to the elevation classes according to the influence on the assessment of Cedrus. The *positive class* affects 661,068 ha, equivalent to 73.0 % of the area under study.

Table 30: Elevation influence classes

Influence class	Value	Area ha	Area %
Negative	0.1	12,341	1.6
Indifferent	0.5	187,859	24.7
Positive	1.0	560,343	73.7
Total		**760,543**	

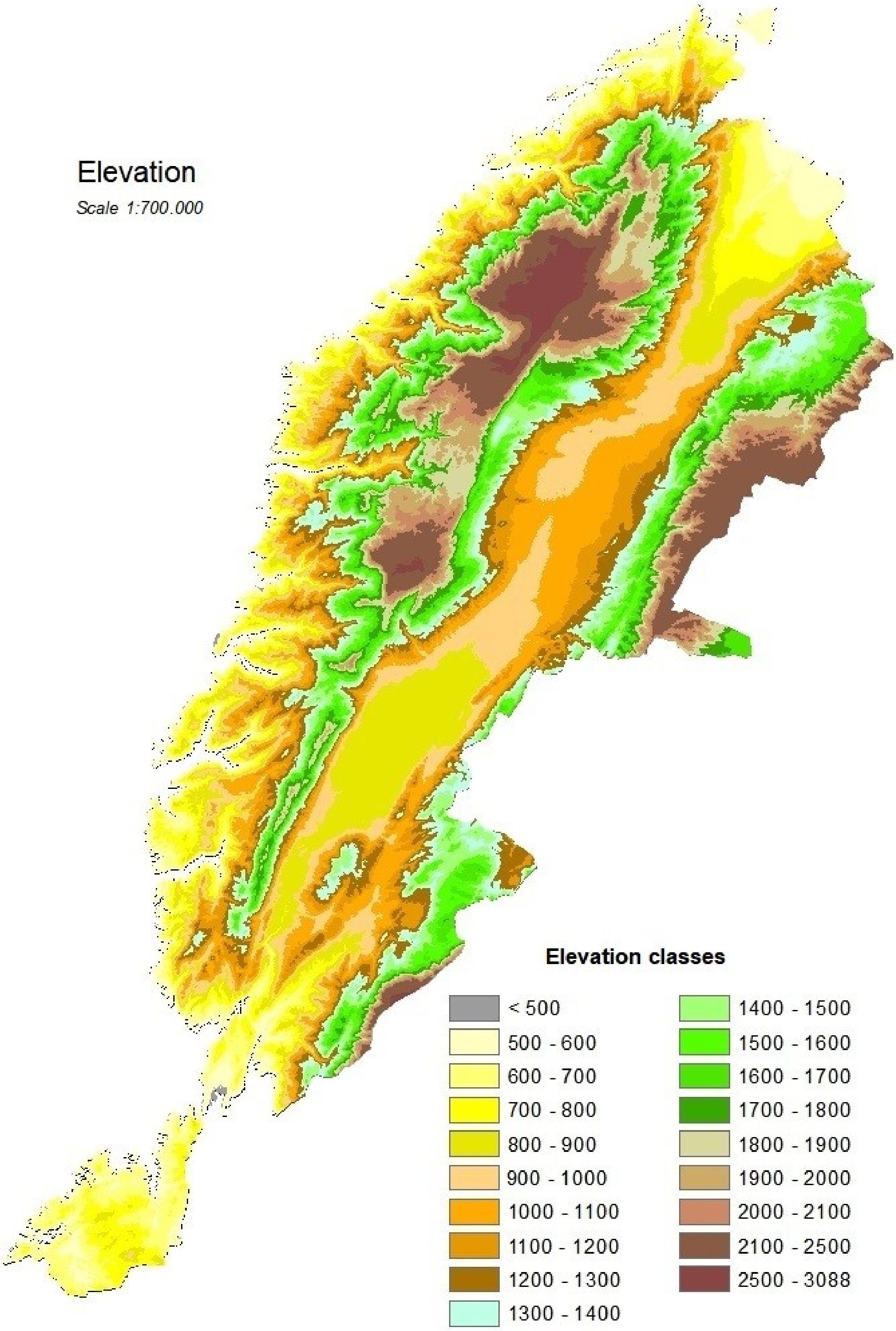

Figure 66: Map of Elevation classes

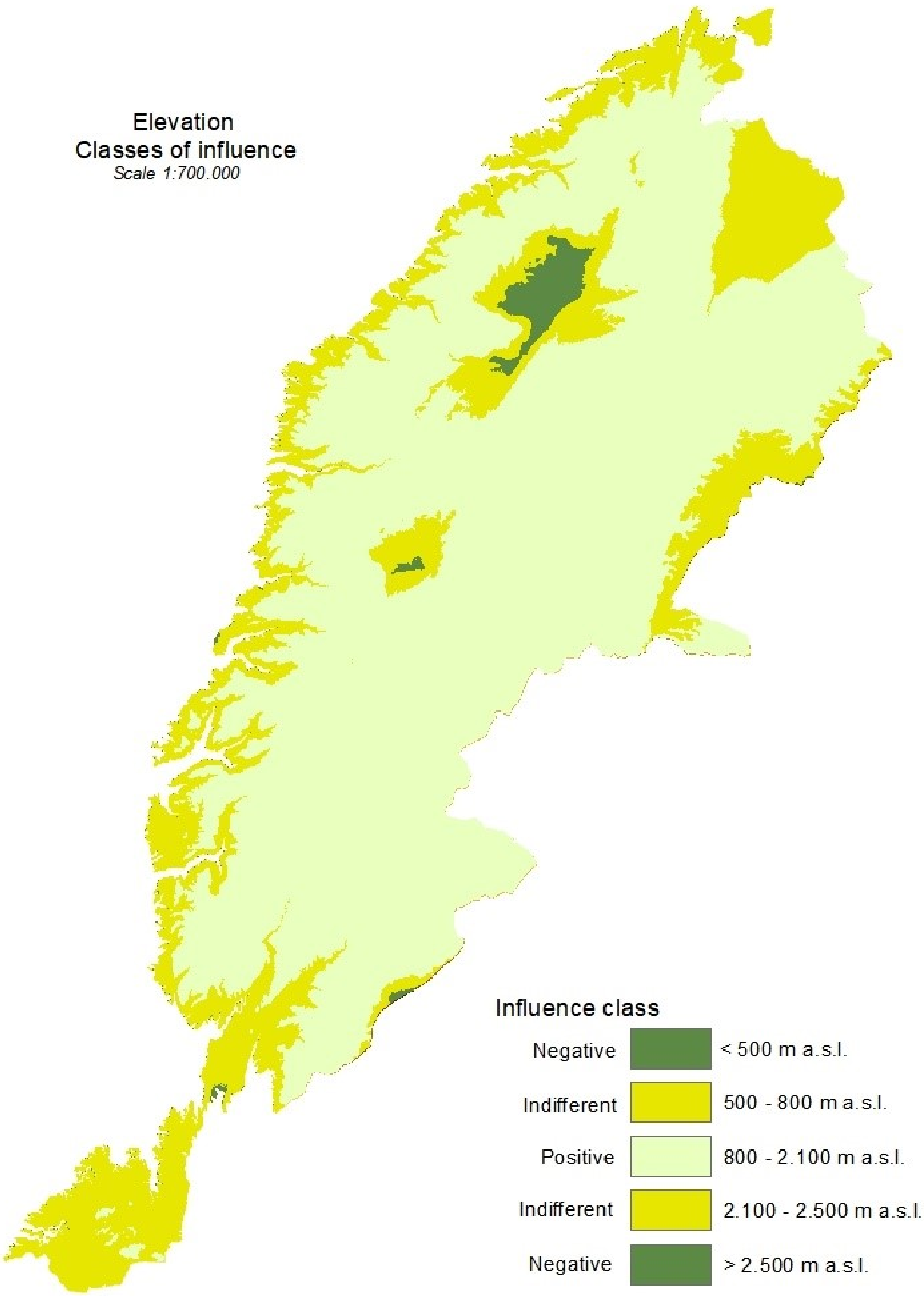

Figure 67: Map of Elevation influence classes

The *indifferent* influence class affects 187,859 ha (24, 7%) falling largely in the 500 - 800 m altitude range. In the *negative* class, elevations lower than 500 m or higher than 2,500 m have been attributed 12,341 ha (1.6%) shown in ***Figure 67***.

5. **Aspect**

The identification of the slope exposures according to their position with respect to the North expressed in degrees and hundredths of a degree. (***Table 31*** and ***Figure 68***).
In the case study, the breakdown of default was adopted, which in addition to dividing the horizon into octants also provides for the identification of flat situations. Given the working scale adopted and the pixel dimensions of the DEM[9], there are no flat surfaces in the area.

Table 31: Aspect classes of the study area

Slope Class	Value	Area ha	Area %
N	337.5 – 22.5	111,061	14.6
NE	22.5 – 67.5	69,784	9.2
E	67.5 – 112.5	78,008	10.3
SE	112.5 – 157.5	94,043	12.4
S	157.5 – 202.5	88,141	11.6
SW	202.5 – 247.5	80,303	10.6
W	247.5 – 292.5	107,365	14.1
NW	292.5 – 337.5	131,837	17.3
Total		**760,542**	

The ***Table 31***, highlights the prevalence of the slopes with exposure from NW to N, respectively 131,837 ha (17.3%) and 111,061 (14.6%), both of positive influence.

[9] 29,03239 m, equivalent to 842,88 mq

Table 32: Aspect of influence classes

Influence class	Value	Area ha	Area %
Negative	0.1	275,809	36.3
Indifferent	0.5	94,043	12.4
Positive	1.0	390,690	51.4
Total		**760,542**	

In ***Table 32*** and ***Figure 69***, the data relating to the *aspect* of the slopes are summarized according to the class of influence. The *positive class* includes 390,690 ha, equivalent to 51.4% of the territory being assessed. In the *negative class*, value 0.1, there are 275,809 ha (36.3%). Finally, the *indifferent class* affects 94,050.58 ha (12.4%).

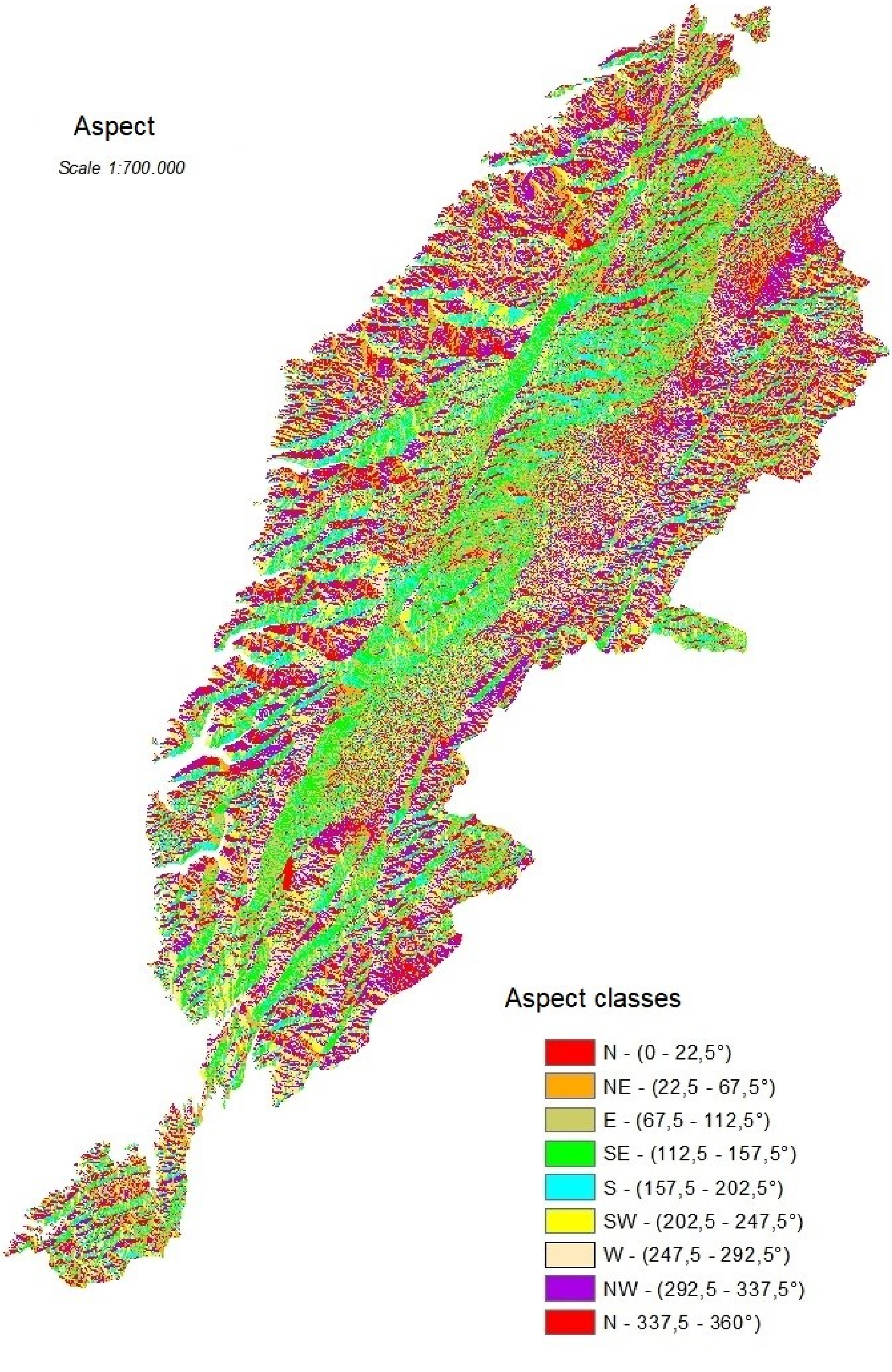

Figure 68: Map of Aspect classes

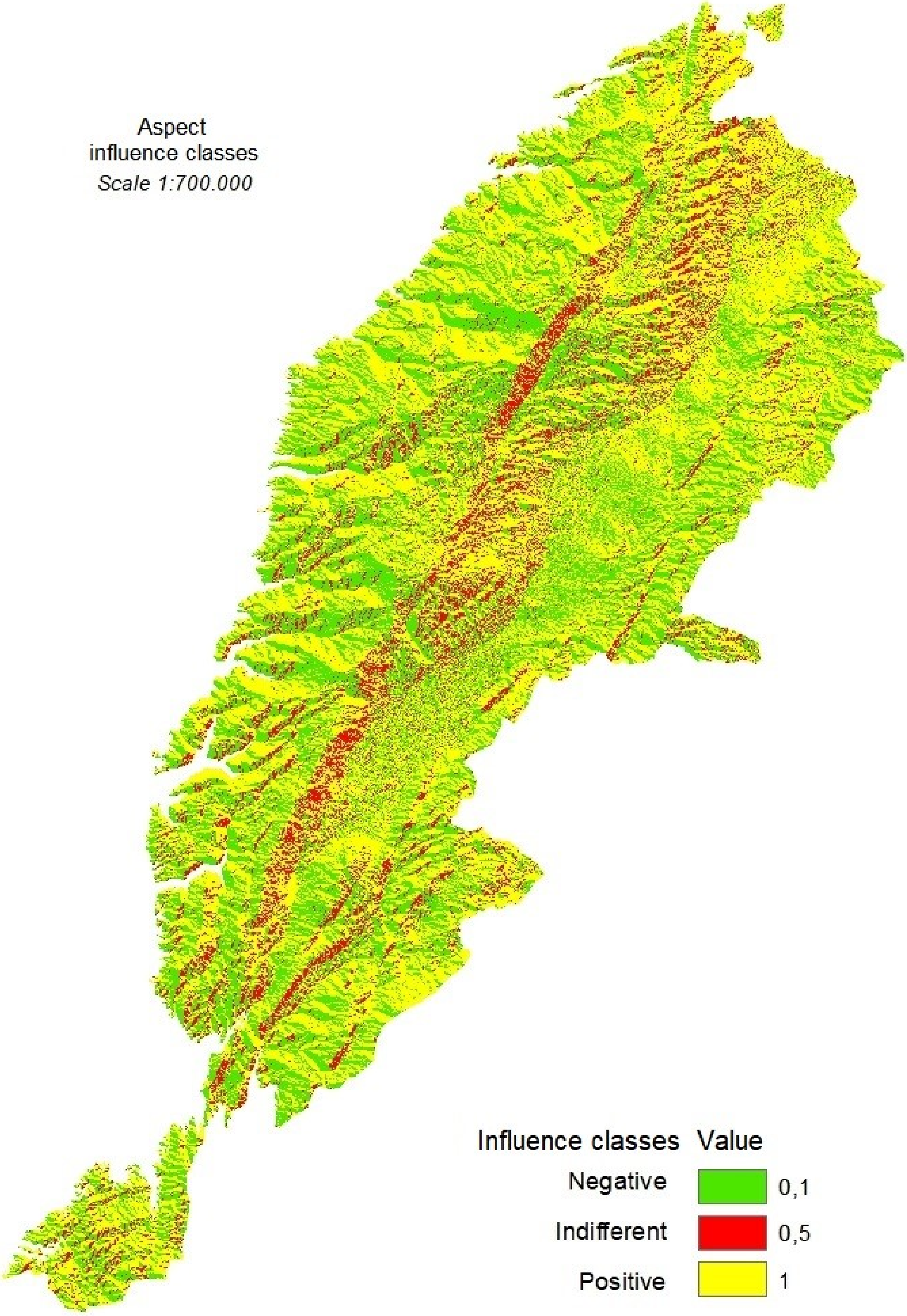

Figure 69: Map of Aspect influence classes

6. Vocational classes (suitability classes)

From the raster of the nine characteristics of the soil and the territory proposed for the identification of vocational classes to the *Cedrus libani* that it was possible, using the Map Calculator and Reclassify functions, to determine their distribution in the territory under study.
The results of the calculation equation used:

$$G = El^* (Ex+Rf+Sb+Sd+pH+Sw+Ce+Nd)/8$$

The results of equation are shown in ***Table 33*** and ***Figure 70***.

Table 33: *Cedrus libani* vocational classes (suitability classes)

Vocational classes	Value	Area ha	Area %
Poorly vocated (unsuitable)	0.1	386,460	50.8
Medium vocated (Moderetly suitable)	0.5	306,323	40.3
Very vocated (high suitable)	1.0	67,751	8.9
Total		**760,534**	

The most widespread vocational class is poorly vocated (value 0.1) with 386,460 corresponding to 50.8% of the study area. This vocational class affects the highest elevations of the Lebanese Mountains, Qurnat al Sawda and mountains of Mazraat mcheik, Kfarzebian, Hrajel, Harf sannine, its easten slopes, almost all of the Bekaa valley and the reliefs of the Anti-Lebanon mountains along the border of Syria.

In the medium vocated class, (value 0.5), fall 306,323 ha (40.3%). Its distribution in the Lebanese territory is probably influenced by the concomitance of various factors such as pedological characteristics, such as depth of the soil, and geological ones.

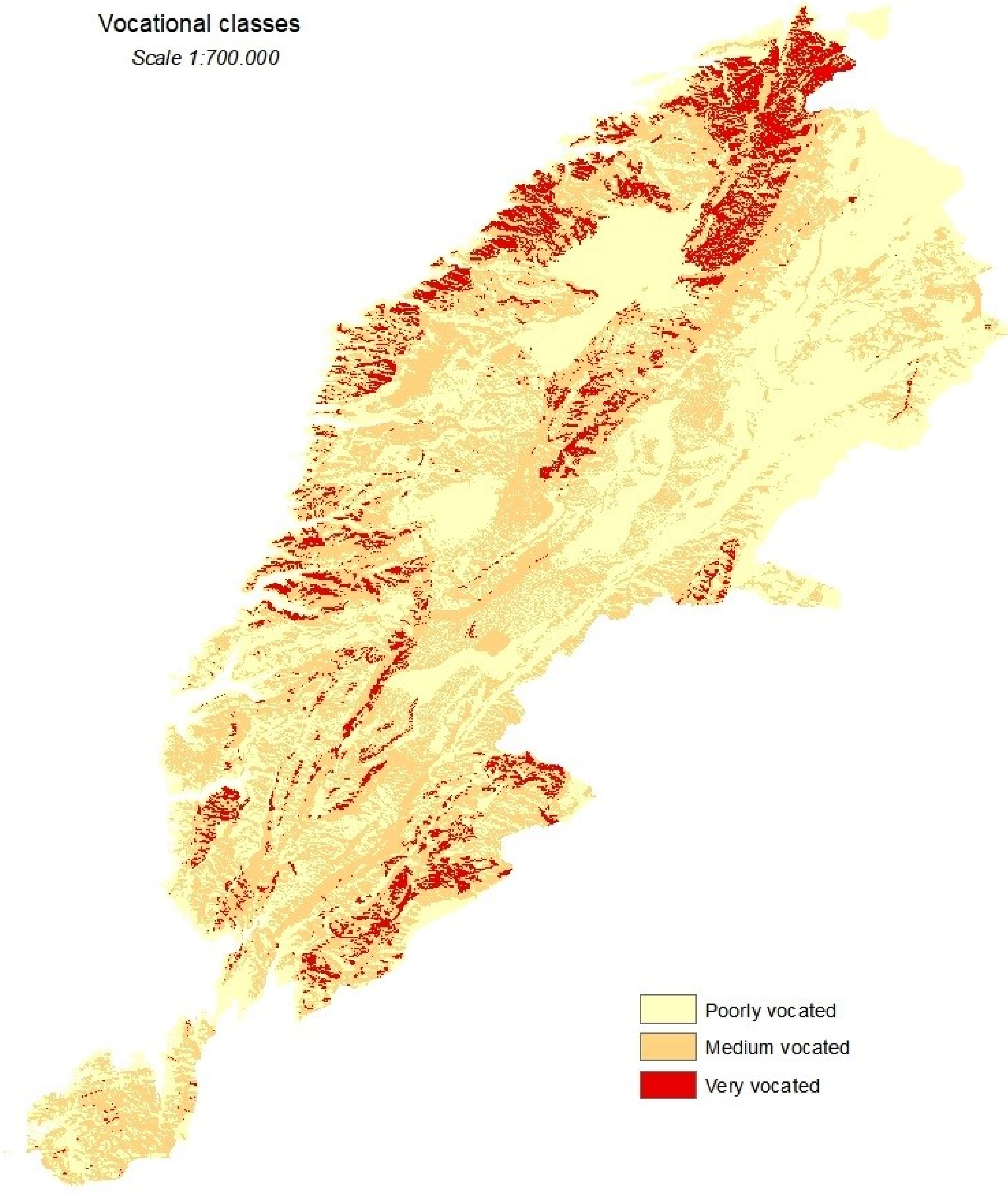

Figure 70: Map of land suitability for *Cedrus libani* (vocational classes)

Finally, to the very vocated class, the model attributed 67,751 ha (8.9%). In the north, this class affects vast areas of :The governorates of Akkar, Minieh - Dannieh, Bcharri, Koura, Hermel, and Zgharta. In the center of the country are the areas of the governorates of Rachaya (Mazraat Deir el-Ashayer region) and Hasbaya (Yanta, Mountain Hermon, Beit Lahya, Chwayya, Mimes and Libbaya). On average, there is a lot of appropriate high suitable land on the Syrian border and in Baalbek on the western slopes of the Anti-Lebanon reliefs. between Nabi Sbat, Maaraboun, in the north and Maarboun, Ain Dara, in the south. Finally, we have a tiny high-suitable region in the Jurd of Arsel.

Discussion

In recent decades, there has been a shift from an empirical evaluation of this potential, often based on local habits and customs, to methodologies capable of objectively considering the characteristics and qualities of the territory capable of positively or negatively influencing the onset and aggravation of these degradation processes. Some of these methodologies, such as the USDA's Agricultural Land Capability Classification (Klingebiel and Montgomery, 1961) and the FAO Framework for Land Evaluation, (1976) have wide use globally. Often, their correct application in evaluation procedures presents different degrees of difficulty due to the lack of information, especially of an economic nature in the case of the FAO Framework (FAO,2019). Locally, various models have been proposed that make it possible to overcome these information gaps by making it possible to formulate assessments of the territory according to the different degrees of information available. The FAO Framework for Land Evaluation was designed mainly for developing countries but has many applications in advanced countries. It is a complex model that requires a multidisciplinary approach for its correct application as it requires the comparison of the benefits - not only economic - but that can also be obtained. The model can be used both for agricultural and forest crops and for specific uses, allowing for comparison. The evaluation always refers to a specific crop or relatively homogeneous crop groups or specific uses (FAO, 1976). Compared to the FAO Framework for Land Evaluation, the model work through it in the research (VCs) have the advantage of excluding any economic considerations and requiring less information on biological and climatic factors capable of influencing, positively or negatively, the plant and the subsequent evolution of an arboreal crop (COSSU et al., 2019). Advantage particularly significant where, as in the case of this doctoral thesis, the available layers of information, such as soils and geology maps, are available only medium scale.

Among the problems related to the use of the FAO Framework, in addition to the economic evaluations necessary to define the limit between the suitable (S) and not-suitable (N) orders, there is the definition of the requests and specific crop requirements for the individual crops, groups of crops for which evaluation is sought.

However, the VCs model was facing several limitations as follow:

- They refer to environments for climatic and pedological conditions different from those of the territory being evaluated.
- Cultivation varieties different from those adopted or adaptable;

- Lack of information on the territory in which the experimental tests reported in the bibliography were carried out.
- High number of data necessary for a correct evaluation;
- Furthermore, the necessary data can be difficult to acquire, for example, climatic ones. This situation is normal in Countries without a dense network of weather stations.
- Under some circumstances it is now common practice, perform evaluations not for crops, but for intended uses, as in the case of the VCs model.
- The VCs were proposed as a tool for defining a territory to host groups of homogeneous crops.

The VCs is initially used in northern Italy, in areas with flat morphology, where forms of intensive agriculture are widespread, the model can be easily adapted to different climatic conditions by modifying both the characteristics considered and the values that these can assume in the possible vocation classes (Madrau et al., 2006). As well, Madrau and Cossu in 2019 develop an assessment for the habitat distribution of Oak trees in Sardinia, south part of Italy. In the assessments of Madrau and Cossu, the morphology and exposure were included as factors, not considered in the original model and the useful water reserve at 120 cm was replaced with the AWC.

Parameters comparison between Land evaluation models

The reference model for assessing susceptibility to reforestation is the Land Evaluation for Forestry (FAO, 1989). It represents the application of the Framework to the reforestation interventions. The model makes a profound examination of the possible uses of the territory in the forestry sector in terms of production of wood for work, protection of the territory, or, lastly, as a venue for tourist and recreational activities. In the case of productive forestation, the following factors are indicated:

a. *Growth requirements*:

   - Soil and climatic conditions: radiation, temperature, soil moisture, aeration (soil drainage), nutrients.

   - rooting conditions: salinity and sodicity, toxicity.

   -climatic hazards: fire, frost, wind.

   -physiographic hazards: floods and landslides.

   -pest and diseases.

b. *Requirements based on estimates of forest volume growth and yield:*

   -present forest stands.

   -estimated growth rates.

-estimated survival rates.

- Estimated yield of non- timber products.

c- Management requirements:

-mechanized operations.

-harvest operations.

-road construction and maintenance.

-internal access.

-nursery sites.

-vegetation clearance.

-size of potential management unit*:* location, existing accessibility, potential accessibility.

d- Conservation requirements:

-tolerance to soil erosion.

- (morphological) conditions affecting stream flow response.

-tolerance to vegetation degradation.

-requirement for preservation of plant and animal.

The analysis of the indicated environmental data is particularly complex and articulated, and therefore it is not always possible. It is evident that in the specific case of reforestation interventions aimed at the reintroduction of *Cedrus libani*. The production of wood for work or wood to be used as fuel represents a secondary production, which is a function of the normal displacement interventions (felling of plants malformed, underdeveloped, which show signs of intolerance for plant diseases) which are made in woodland plants to reach the optimal expected densities. The requirements connected to forest volume growth and yield are also difficult to determine a priori, both because they are normally available for the species of productive interest for timber and cellulose. For example, poplar, fir, and because they are difficult to estimate in this case from the cycle decades of production where the variability of climatic, phytosanitary and anthropogenic factors is predictable only in the short term.

In the case of reforestation aimed at conservation, greater importance is given to criteria relating to the conservation and enhancement of natural resources- Criteria that include:

-catchment protection for water conservation and yield.

-protection against soil erosion and associated off-site sedimentation.

-reclamation and conservation of eroded areas.

-conservation of flora and fauna, including of genetic resources and endangered species.

Danusso (2001) was developed final consideration must be made on the Framework. As will be highlighted in the following brief description, the limit between the suitable or susceptible order and the unsuitable or non-susceptible one depends on both the economic response of the market and the progress of technical knowledge. Two situations, which I repeat, are not possible in the case of long-cycle forest plants aimed mainly at soil conservation and tourist and recreational activities. The factors originally proposed by the authors of the model are shown in table 16. Each of them and the corresponding classes have been assigned a code.

Table 34: Factors considered in the VCs evaluation and their codes according to Danuso et al., 2001

FACTOR	CODEX	CODEX CLASS
Useful soil depth	PTU	Pp
Soil texture	TES	Pt
Soil coarse fragments	SCH	Ps
Water reserve helpful to 120 cm	RU	Pr
Potential productivity	PP	Pf
Vocation (suitable) to irrigation uses	VIR	Pi

Boydak, 2003, following the analysis of the bibliography on *Cedrus libani* present on the Taurus Mountains, indicates the following main ecological requirements in the Mediterranean area for this species which is compatible to our results indicators:

- *Parent materials*. Although it is possible to observe the *Cedrus libani* on different geological formations, the preferential one is represented by limestone formations.
- *Soils*: From shallow to medium deep. Since the crystalline limestone are normal, karst pockets are possible, within these, physiologically deep soil.
- *Drainage*: Good. Often associated with a high AWC in soils present in karst pockets. This property is also related to the content in coarse fragments, which influence the speed of water infiltration.
- *Climate*: The possible climatic conditions, according to Boydak (2003), vary from humid to semi-arid.
- *Precipitation:* mean yearly precipitation 600 to 1200 mm. Rains very few to absent during summer season and duration of snow cover 1 to 5 months / year.
- *Temperature*. Mean annual from 6 to 12 ° C. Mean July 18 to 25 ° C and mean January 0 to -5 ° C.
- *Relative humidity*: during the growing season 40 to 60%.

Conclusions

Distribution habitat of forest species has been affected by changes in environmental parameters. The contribution of each parameter can limit the regeneration of forest tree species. Basic climatic and biophysical parameters can be involved such as temperature, precipitation, soils properties, and elevation. The most sensitive species, such as endemics and rare species, respond to changes in their geographic distribution. Remote sensing and geographic information systems (GIS) have recently played an essential role in analysing forest structure and mechanisms for natural regeneration, providing a suitable approach for determining the fundamental elements affecting species distribution. The use of dynamic spatial modelling and land suitability categorization to species can help us better understand the distribution of sensitive species.

In this research, the suitability classes for *cedrus libani* in Lebanon were monitored and analysed using GIS. Suitability analysis leads to the determination of land use development needs that are appropriate for the situation. Accurate and informative modelling programs are deemed necessary to assist and guide Lebanon's reforestation initiatives. In this study, the VCs model was used and adjusted using GIS. The model's elevation limiting and eight variables were prepared (temperature, rainfall, soil pH, CEC capacity, nutrient deficiency, depth, drainage, and geological characteristics). The most widespread vocational class is poorly vocated (value 0.1) with 386,460 ha corresponding to 50.8% of the study area. This vocational class affects the highest elevations of the Lebanese Mountains, Qurnat al Sawda and mountains of Mazraat mcheik, Kfarzebian, Hrajel, Harf sannine, its easten slopes, almost all of the Bekaa valley and the reliefs of the Anti-Lebanon mountains along the border of Syria. In the medium vocated class, (value 0.5), fall 306,323 ha (40.3%). Its distribution in the Lebanese territory is probably influenced by the concomitance of various factors such as pedological characteristics, such as depth of the soil, and geological ones. Finally, to the very vocated class, the model attributed 67,751 ha (8.9%).

As a result, just 8.9 % of the Lebanese territory at an altitude over 500 m a.s.l.m. possesses soil and territory features appropriate for reforestation with Lebanon's cedar. It is important to note that the data utilized in this study has a considerable effect on the results produced. With the exception of the medium-scale CNRS pedological cartography, the data relating to the geology and average annual rainfall were available only on a small scale, a situation that did not allow having an informative detail comparable to that of the pedological cartography and aspects morphological *elevation* and *aspect* derived from DEM. To plan land use, we need a large amount of data to support a land model, to represent this model in an understandable way, and to introduce variables that are dependent on the effects of land policy, technical intervention, or natural resource management alternatives. The result of this initial application of the vocational evaluation model to Lebanese area over 500 m may thus be taken solely as a preliminary or general indicator for the sake of planning any future reforestation efforts.

Its subsequent application in the phase of a real executive design of new cedar plants, will require a more detailed analysis of the physico-chemical characteristics of the soils, of the geological aspects, the latter above all in relation to their effects on the paedogenesis of the areas possibly affected and climatic conditions such as precipitation and windiness, the latter also in function of forest fire prevention.

The Lebanon cedar forests are one of the most important natural monuments and cultural treasures to be preserved for future generations. As this study sets up a potential methodology for mapping purposes, some recommendations and lessons learned can generate improvements and precisions to the results for further studies:

- Refinement of the vegetation map of Lebanon, according to different species that can be for instance used as indicators level of suitability.
- Update Lebanon's laws and regulations, particularly the forest law of cedrus and many species.
- Increase the research studies of trees of *Cedrus libani*.
- Develop public health forest strategies to reduce the pests and diseases in the forest.
- Discuss the influence of snow and fog on the distribution of vegetation on *Cedrus libani* is raised, as it could provide new insights into the tree’s ecology.

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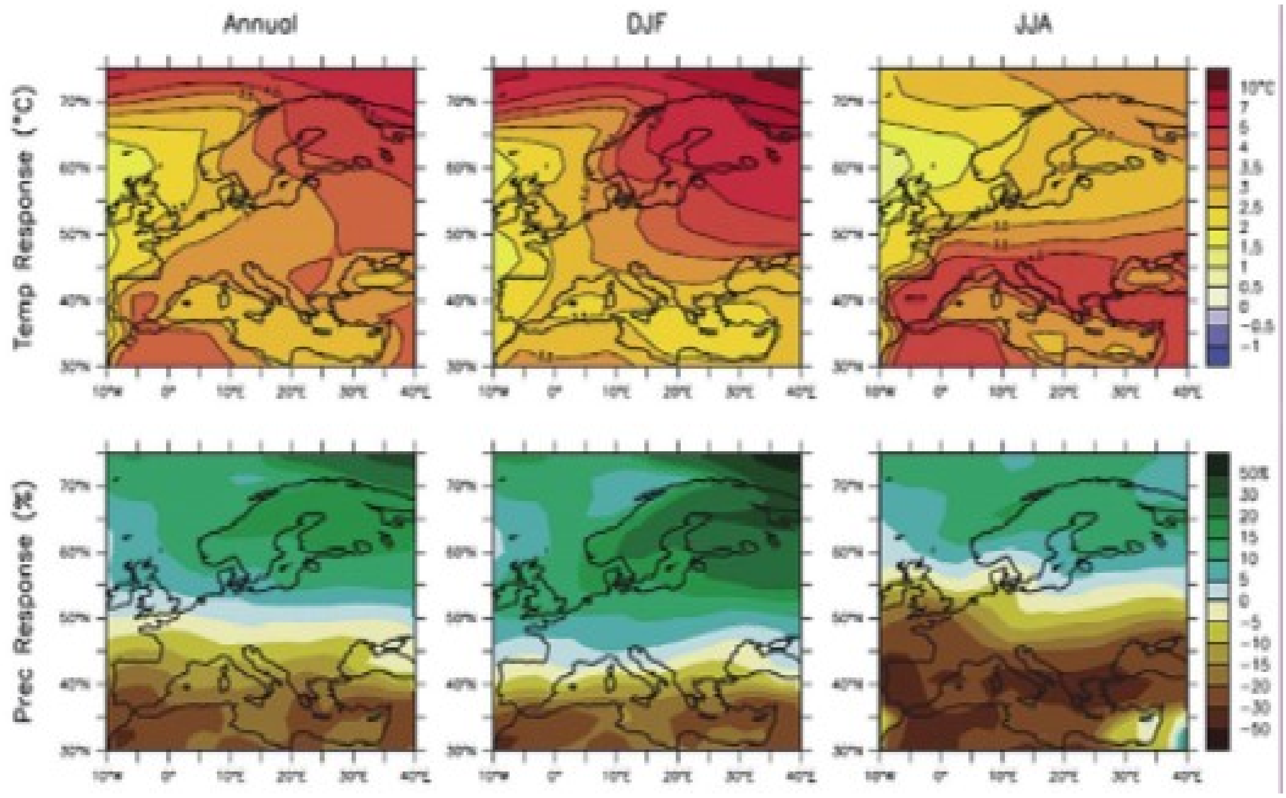
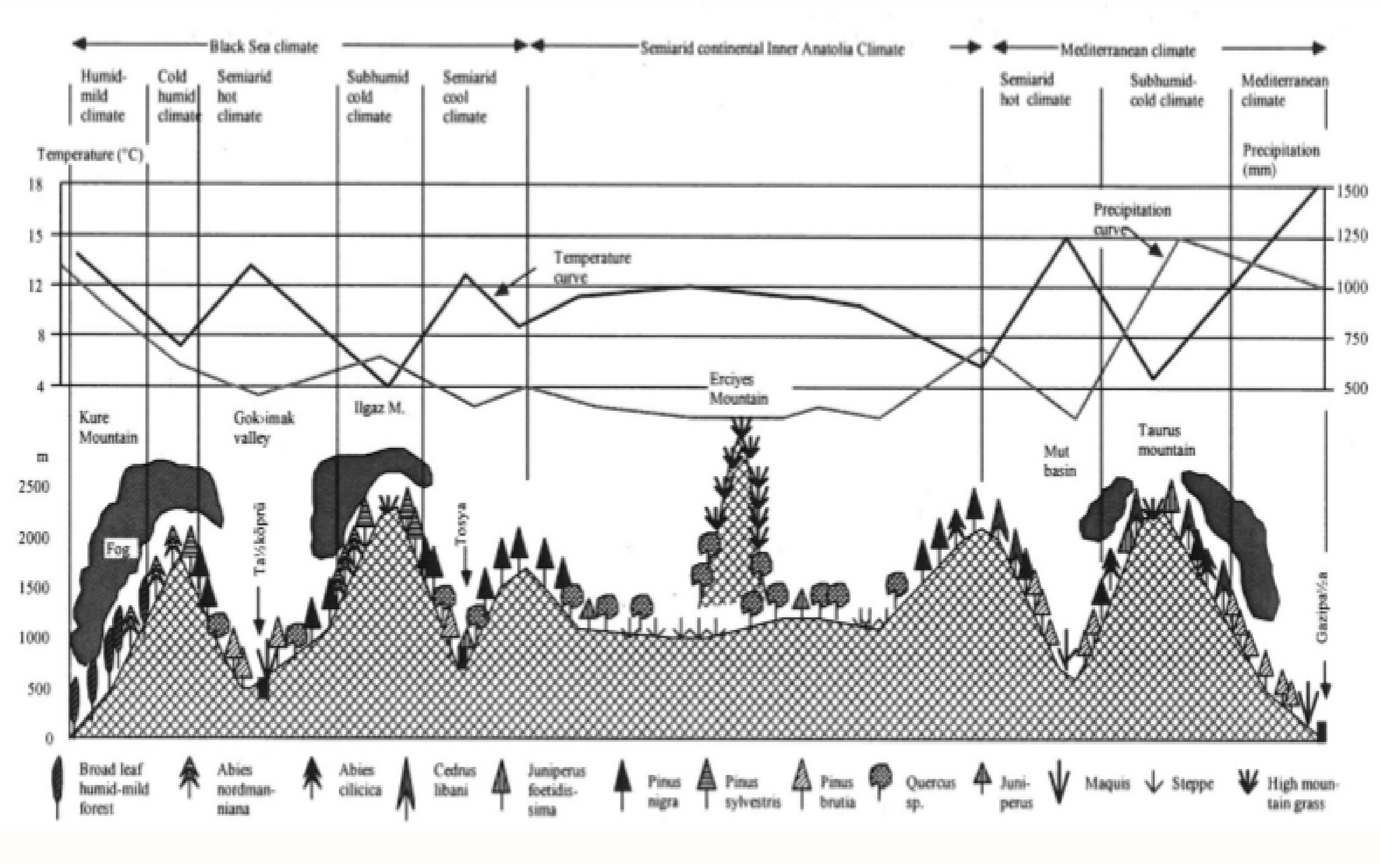
Annex

Annex 1: Simulated temperature and precipitation over Europe scenario between 1980 and 1999, 2080 to 2099 (IPCC report 2007)



Annex 2: Climate and vegetative profiles in N-S direction from black Sea to Mediterranean Sea



Black Sea climate
Semiarid continental Inner Anatolia Climate
Mediterranean climate
Humid-mild climate
Cold humid climate
Semiarid hot climate
Subhumid cold climate
Semiarid cool climate
Semiarid hot climate
Subhumid-cold climate
Mediterranean climate
Temperature (°C)
Precipitation (mm)
Temperature curve
Precipitation curve
Kure Mountain
Ilgaz M.
Erciyes Mountain
Mut basin
Taurus mountain
Fog
Tosya
Broad leaf humid-mild forest
Abies nordman-niana
Abies cilicica
Cedrus libani
Juniperus foetidis-sima
Pinus nigra
Pinus sylvestris
Pinus brutia
Quercus sp.
Juni-perus
Maquis
Steppe
High moun-tain grass

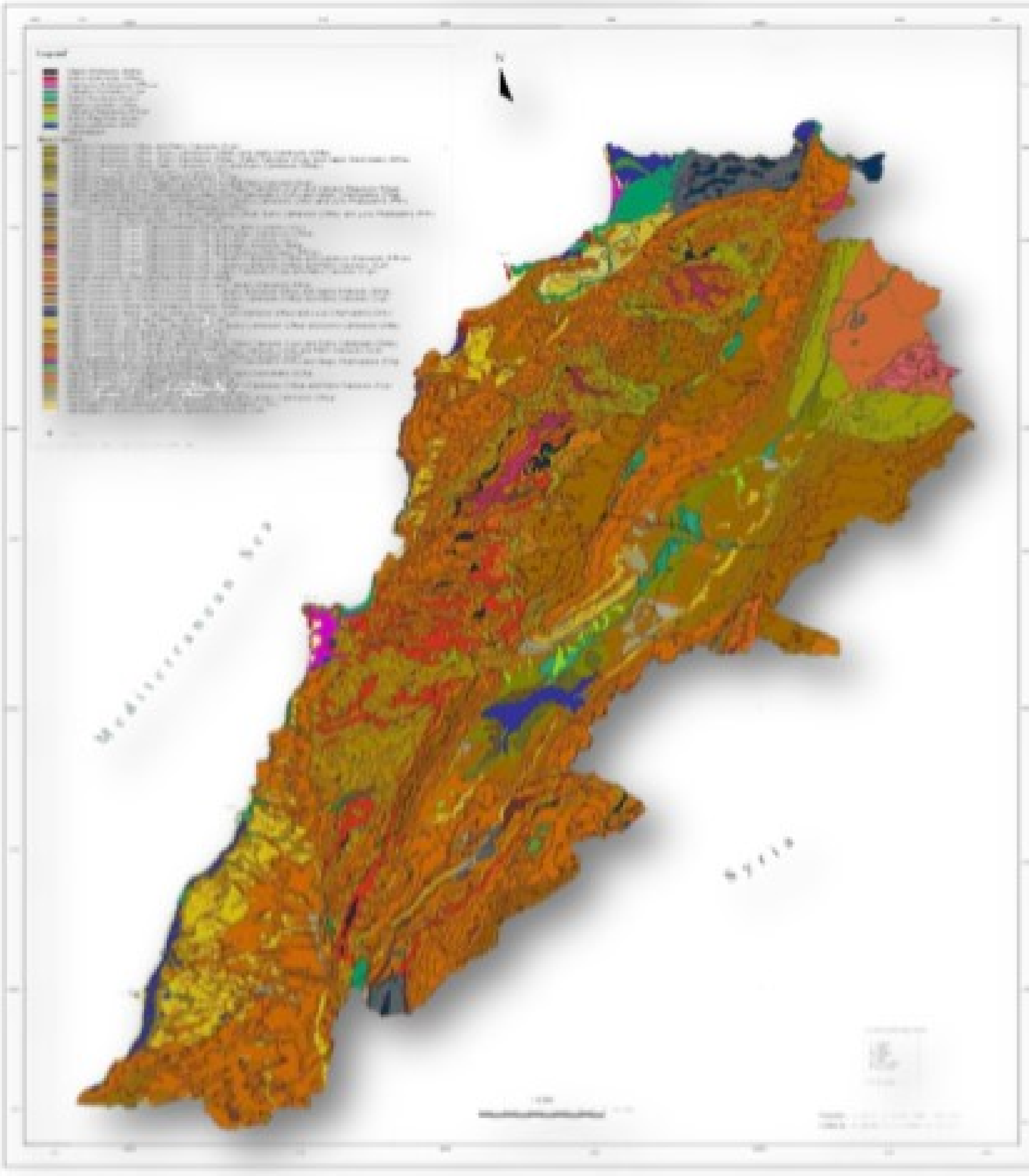
Annex 3: IUCN, 2020. Improving Climate Resilience of Vulnerable Communities and Ecosystems.

VULNERABLE ECOSYSTEMS	MAJOR THREATS/CHALLENGES	RECOMMENDED ACTIONS TO INCREASE RESILIENCE
Juniperus excelsa	▪ Unregulated grazing, hunting, junipers regeneration capabilities, poor forest management	▪ Improve forest conservation economics and social involvement ▪ Adopt and implement forest management plans accounting for regeneration capability, stress reduction, and shifting to sustainable integrated practices (grazing & hunting)
Cedrus libani	▪ Outbreak of Cephalcia tannourinensis and other pests ▪ Sensitivity of Cedars and the specific conditions affecting their regeneration capability. ▪ Urban expansion over mountainous areas	▪ Adopt and implement an integrated action plan for forest health control targeting pest management
Abies cilicica	▪ Illegal logging ▪ Unregulated grazing in forest understory ▪ Urban expansion over mountainous areas ▪ Poor forest management	▪ Improve forest conservation, economics and social involvement ▪ Adopt and implement forest management plans accounting for regeneration capability, stress reduction, and shifting to sustainable integrated practices (grazing & hunting)
Quercus cerris	▪ Forest fragmentation ▪ Land use changes (urban encroachment) ▪ Unregulated grazing in forests understory ▪ Risk of Pest outbreaks	▪ Improve forest conservation, economics and social involvement ▪ Adopt and implement forest management plans accounting for regeneration capability, stress reduction, and shifting to sustainable integrated practices (grazing & hunting)

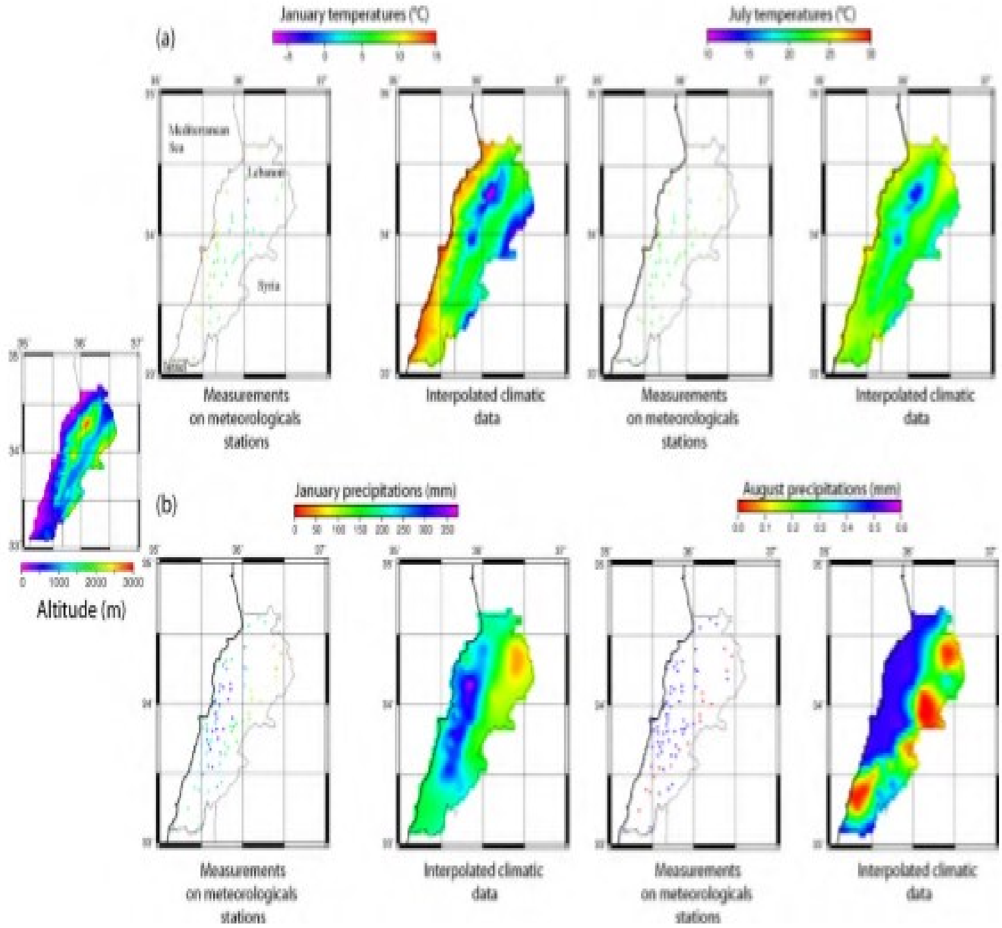
Annex 4: laws of forest Cedrus in Lebanon

Location nature reserves	Law
Palm, Sanany and Ramkeen Islands	Law no. 121 of 1992
Horsh Ehden Nature Reserve	Law no. 121 of 1992
Al Shouf Cedars Nature Reserve	Law no. 532 of 1996
Tyre Coast Nature Reserve	Law no. 708 of 1998
Tannourine Cedar Forest Nature Reserve	Law no. 9 of 1999
Yammouneh Nature Reserve	Law no. 10 of 1999
Bentael Nature Reserve	Law no. 11 of 1999
Karm Chbat Forest Nature Reserve	Ministerial decision no. 14 of 1995

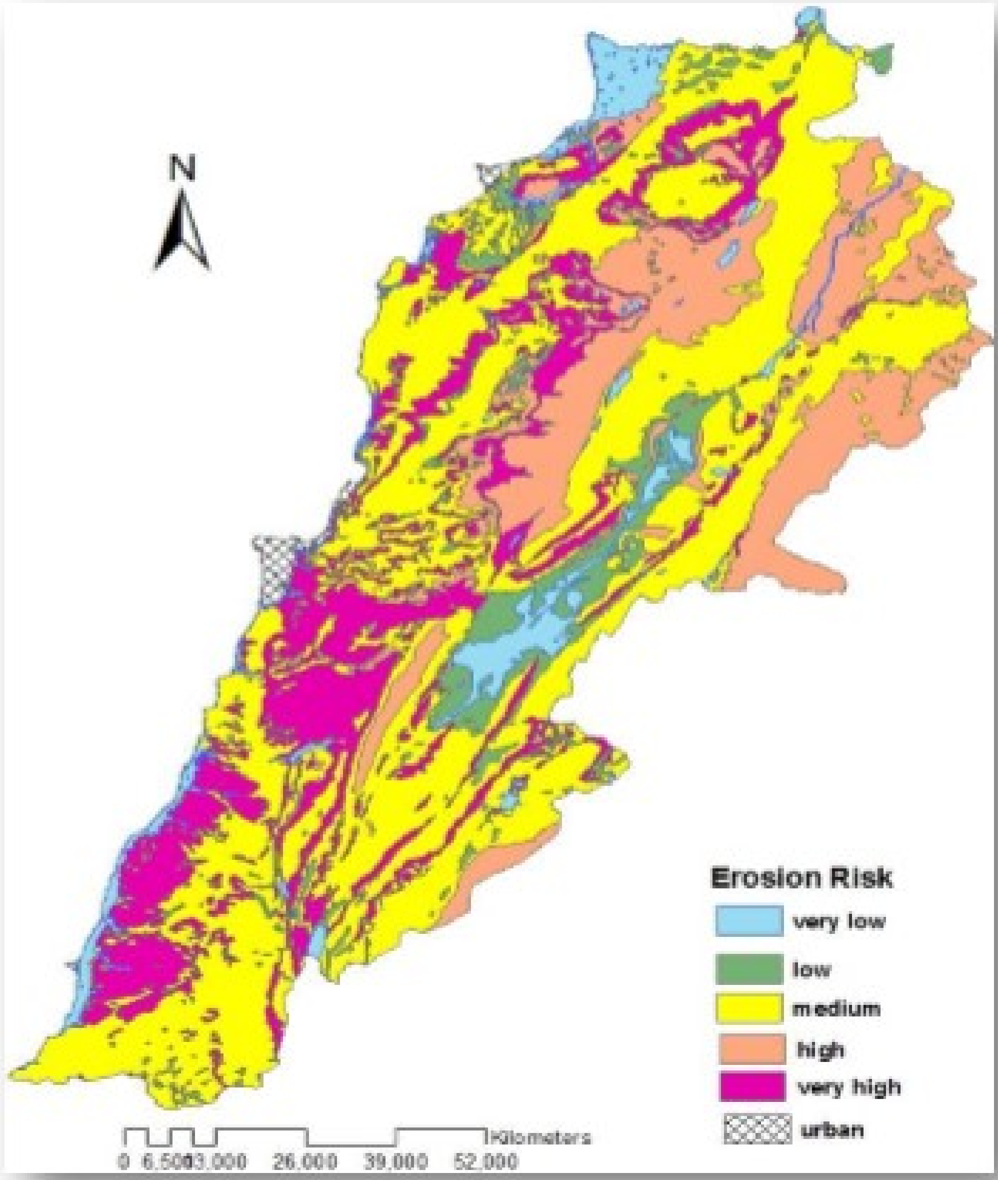
Annex 5: Soil map of Lebanon updated (Darwish et al., 2002a).



Annex 6: Temperatures and precipitation in Lebanon between January and August(L. Hajar et al., 2010)



Annex 7: Map of Lebanon,potential soil erosion at 1:200000 scale (Darwish et al., 2002 b)



Annex 8: Potential distribution of *Cedrus libani* (Stephan et al., 2017)