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Externalities in ruminant farms in Sardinia: Landscape and Water Footprint

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ABSTRACT

This thesis focuses on the sustainability of livestock production in Sardinia, considering some externalities, *Landscape, Ecosystem services* and *Water Footprint.* The use of environmental resources as farm externalities, under the Common Agricultural Policies (CAP) framework, was reviewed. Two specific indexes were developed (Livestock Index and Grazing Impact Index), and georeferenced maps were made to determine the environmental impact of stocking rate and identify overgrazed areas. Livestock is important to utilize and valorize large areas in Sardinia, especially those at risk of abandonment, thus livestock agroforestry was studied as a mean to improve the ecosystem services of Sardinian farms, by quantifying the surface utilized and evaluating sustainability based on the livestock and grazing impact indexes. Results showed that livestock agroforestry is an important environmental resource for animal production in Mediterranean areas, but it would be fundamental to reduce stocking rates to avoid the potential harmful effects of overgrazing on landscape productivity and value. A new approach to calculate the water footprint of meat and milk, the Net Water Footprint (WFP_{net}), was developed and compared with the Water Footprint (WFP) in different production scenarios. For meat production, WFP_{net} values were equal to 5% and 54% of those obtained with the WFP calculation, whereas for milk production the WFP_{net} were equal to 4% and 63% of those calculated with the WFP method.

RESEARCH ISSUES

Sustainability is an issue of great importance that concerns the economies of developed and developing countries, strengthen consequently to increasing attention on well-being of human population, animal welfare and environmental preservation, conservation and improvement. About 40% of the global land surface is occupied by agriculture (Foley et al, 2011), which uses about 70% of the extracted water, pollutes river basins, and accounts for the degradation of a quarter of agricultural soils in the world (Grunwald et al., 2011), leading to the abandonment of land and the conversion of new soil to agriculture, as natural and semi-natural habitats (Tilman et al., 2011); producing a greater amount of greenhouse gases compared to other sectors, and constituting the greatest threat to biodiversity (Laurance et al., 2014).

The current world population of approximately 7.3 billion is expected to reach 8.5 billion, 9.7 billion and 11.2 billion by 2030, 2050 and 2100, respectively (UN DESA Population Division 2015). Understanding and supporting the demographic changes expected in the next years with adequate interventions, as well as dealing with the challenges and opportunities for sustainable development is the key to all development policies, according to Wu Hongbo, UN Under-Secretary-General for Economic and Social Affairs (UN DESA 2015). China and India, with more than 1 billion people each, represent 19% and 18% of the world's population, respectively. In 2022 the population of India is expected to overtake that of China, and by about 2050 the population of Nigeria is expected to surpass that of the United States. Therefore, by 2050 six countries (China, India, Indonesia, Nigeria, Pakistan, and the USA) are expected that reach more than 300 million of people (UN DESA Population Division, 2015). The considerable population growth in poor and developing countries makes it harder to fight hunger, poverty and inequality, which are crucial issues of the new sustainable development agenda, according to John Wilmoth, Director of the Population Division in the UN's Department of Economic and Social Affairs (UN DESA, 2015).

Consequently, the demand for food will probably raise by 60-110% by 2050 (Bruinsma 2009; Tilman et al., 2011) and would require an increase in agricultural production of 70% in developed countries, and nearly 100% in developing countries (FAO, 2011). Thus, it would be necessary to produce approximately 3 billion tones of cereals and 470 million tonnes of meat annually by 2050 (Bruinsma, 2009). This increase in agriculture production in the future must ensure food security, animal welfare and sustainability, posing problems of environmental impact.

Different variables may intervene and interfere with the sustainability of agricultural production. Scholars have advanced different key pathways to solve the issue of global food crisis: i) technological innovation such as plant breeding and genetically modified (GM) techniques, ii) strategies for more equitable food distribution, as reducing poverty, global meat consumption and amount of grain used for bio-energy production, iii) strategies to promote local and /autonomous food systems and, iv) strategies to correct market failures that include incentives to reduce food waste and a contribution to farmers that provide environmental benefits (Fraser et al., 2016).

The debate on Genetic Modified Organisms (GMOs) is very lively in the scientific world. Scholars in favor of GM techniques argue that biotechnologies are necessary to improve the productivity and to reduce pesticide use by new varieties that are more productive and by disease-resistant seeds (Fedoroff et al., 2010). These supporters claim that such reduction in insecticide use to control hangers-on and damaging insects would be useful to increase the sustainability of food production. In contrast, critical scholars argue that the use of biotechnology to produce high-tech crops, such as transgenic crops, would serve only to enrich a few corporations, creating sustainability issues, due to a reduction in food security (Tomlinson, 2013), water quality (Xie et al., 2007) and quantity (Pimentel and Pimentel, 2008), and animal welfare (Fraser, 2008, cited by Fraser et al. (2016), then increasing environmental impact (Weis, 2010). Therefore, technological innovation would lead to less sustainable and less equitable and more energy intensive food systems (Patel, 2007, cited by Fraser et al. 2016; Sage, 2013).

The debate on how to increase food production in a sustainable manner is developing also on organic agriculture. Badgley and Perfecto (2007) argue that small farmers who use crop rotation and organic agriculture, without the use of chemical products, can help meet the food needs of the world. In contrast, Connor (2008) assert that organic agriculture cannot feed the world, and Seufert et al. (2012) showed that yields in organic farms were lower than in conventional systems, and, were not sufficient to meet the demand for food.If we analyze the issue of global food crisis from a global equity and distribution point of view, it appears that the current production of food is enough for the world population but is unevenly distributed. In fact, about 800 million people are hungry and still lack sufficient food for conducting a healthy life (FAO, 2015), whereas 1.3 are overweight and obese (Pinstrup-Andersen, 2009; Popkin et al., 2012). Currently in the world, except for crops and food waste used for the production of bioenergy, about 2,850 dietary calories per person per day are available (FAO, 2015). Therefore, assuming that food production remains constant, also in case of a hypothetical increase in world population, there would still be 2,200 dietary calories available per person per day (Fraser et al., 2016). Furthermore, this availability is biggest if allocate to human consumption also 10% of global corn production, actually used for energy production

(Graham-Rowe, 2011), and for fuel (Zhang et al. 2010; Thompson, 2012). Also, one third of global food production is wasted (FAO, 2011). Therefore, it is clear that there is a problem of unequal distribution and use of food, rather than a problem of poor production. According Fraser et al. (2012) and Simelton et al. (2012), researcher that proponent a social approach to issue resolution, so food security can be reached mainly by reducing poverty, redistributing income, and achieving education programs of population, rather than improving the productivity and efficiency of farms.

Another way to ensure global food security is the development of local food sovereignty, often produced by organic farms (Blay-Palmer, 2011) or alternative farming systems that require low use of fossil energy and chemical products (Kloppenburg et al., 2007/). However, a criticism about an alternative method like the organic farming is that, it generally tends to lower yields compared to conventional farms (Benton et al., 2011; Seufert et al., 2012). This theory is supported by Seufert (2012), who showed that organic fields are, on average, approximately 25% less productive than conventional ones. A considerable opportunity for increasing yields in organic farms may exist only in some regions or localities (Ponisio et al., 2015) where the landscape or the environmental .characteristics do not permit to practice conventional or intensive agriculture, and some types of foods can be produced without environmental challenges (Benton et al., 2011). According to Abson et al. (2013) and KC et al. (2015),.mixed farms, which are in between these two viewpoints, are better for food security and offer more stable farm income

The debate on sustainable development and food security raise interest also in the political world that develops farm guidelines to produce in a more sustainable way, with low environmental impact, and defines strategies such as incentives and contributions to farmers that provide environmental benefits. The Europe 2020 Strategy sustainable development (European Commission, 2010), focuses on the concept of environmental sustainability, including ecosystem services and resources of the world (air, soil, water, food, biodiversity, plants, animals, people, and climate), as well as quality of life and amenities in rural areas, besides animal welfare.

Ecosystems and ecosystem services contribute differently and significantly to the welfare of humanity (Lal, 2012; Costanza et al, 2013), and the protection of environment and animal welfare, but their existence is endangered by the growing phenomena of environmental degradation. Therefore, there is the need to safeguard them, by considering them not as separate elements from agricultural activity, but as an integral part of it, in order to avoid further degradation phenomena and to take recovery actions of degraded lands (Acevedo, 2011).

Sustainable development of the territory cannot be measured solely by the market economic growth (Costanza et al., 2013), as it has been done until today, but by a whole series of other factors that interact with each other, such as human, social, and natural aspects, on which studies on environmental sustainability should concentrate. These factors are external to the production process in the strict sense, and are generally defined as *externalities.* Each farm uses external resources (*externalities*) for the production of goods and services, causing negative or positive impacts on human health, on welfare and livelihood of communities and on environmental quality (Buttel, 2003).

The topic of my thesis is the sustainability of livestock production in Sardinia, considering particularly two externalities, *Landscape* and *Water Footprint,* in order to provide new knowledge and new development perspectives on our productions. Sustainability could be an added value recognizable by consumers, through the payment of a higher purchase price, especially by the share of consumers more sensible towards these issues. The sustainability of a product would be represented by a label on the product itself, certifying its origin and characteristics. The payment of a higher price would support operators of the sector which produced them respecting the environmental through positive externalities, especially breeders and farmers, who are the main actors of the agricultural economy of our region.

The first chapter analyzed the available literature on externalities in general, with a special focus on agricultural products. The second chapter regarded the Livestock Landscape of Sardinia and its specificity as a contribution to the Regional Landscape Plan (RLP). An evolutionary analysis of the livestock landscape in the course of history was made, by analysis the literature and determining the zootechnical index (expressed as number of animals/ha, in relation to the main ruminant species reared in our region) and the grazing impact index. The third chapter analyzed the livestock agroforestry in Sardinia, in order to propose its adoption, as a model that could give great sustainable environmental resources for animal production in the Mediterranean area. Finally, the last chapter provided a new approach to calculate the water footprint of animal products. Although several studies have estimated that, globally, animal production has a high water consumption, we proposed a new approach to the calculation water consumption that demonstrates that livestock production is more sustainable than expected, especially extensive farming, whose feed source is largely represented by meadow or grassland. Regarding the three types of water that compose the water footprint (green, blue and grey), in this new approach the green water was not calculated as total evapotranspiration of culture, but as differential evapotranspiration (ΔET) between the crop considered, for which the green water was estimated, and a natural cover as woodland.

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RESEARCH OBJECTIVES

The aim of this thesis is to point out the externalities of agriculture with special focus on landscape and water footprint. After an initial review on externalities and Common Agricultural Policies (CAP), research has been carry out on the evaluation of some externalities of Sardinian farms, with particular focus on the landscape value and sustainability of livestock in Mediterranean areas. The second contribution deals with the Livestock Landscape in Sardinia and its specificity in the Regional Landscape Plan (RLP). An evolutionary historical analysis of the livestock landscape was made to evaluate the stocking rate role in determining the shape of the rural landscape. Two specifics indexes were developed: the Livestock Index (expressed as number of animals/ha, for the main ruminant species reared in our region) and the Grazing Impact Index. The third contribution regards the Agroforestry in Sardinia, in order to propose its adoption as a model that could give great sustainable environmental resources for animal production in the Mediterranean area. The last contribution provides a new approach to calculate the water footprint of animal products. Although several studies have estimated that, globally, animal production has a high water consumption, in our fourth contribution we proposed a new approach to the calculation of water consumption that demonstrates that livestock production is more sustainable than expected, especially in extensive farming systems, where feed sources are largely represented by meadow or grassland. Regarding the three types of water that compose the water footprint (green, blue and grey), in this new approach the green water was not calculated as total evapotranspiration of a culture, but as differential evapotranspiration (ΔET) between the crop considered, for which the green water was estimated, and a natural cover like woodland.

CHAPTER 1

1. Introduction

1.1. Externalities and ecosystem services

According to Hubbard and O'Brien (2012), an externality is a cost or benefit which is neither intentionally, nor directly intentionally concerned with the production process or consumption of that good or service. Therefore, an externality influences the production or consumption of goods or services, but its costs or benefits are allocated to other stakeholders, external to the production process or consumption, and its effects are not considered when determining the final price (Rhemani and Shapiro, OECD 1993; OECD, 2003a). Pollution is the classical example of negative externality linked to a production process. During the production process, a good part of economic activities use environmental natural resources to produce goods and services and the costs of using them are neither included in the final price paid by the consumer (Pretty et al., 2001) nor paid by the producer. All these benefits encourage the producers to consume freely natural resources, unconditionally, without considering they are indeed damaging environment and society because are not caring for resources renewability (Baumol and Oates, 1988; EEA, 1998; Brouwer, 1999; Pretty et al., 2000). On the other hand, many economic activities related to agriculture contribute to ensure ecosystem services provision so benefitting the community and the environment, while no compensation for farmers is coming through the market. However it is worth to clarify the conceptual difference between the two.

The humankind dependence on natural resources is obvious, but the concept of ecosystem services has been punctually elaborated only in the latest years thanks to the Millennium Ecosystem Assessment (2005), with the aim to underpin policy maker decision process to take into account the not renewability of natural resources as well as the positive contribute ecosystems offer to so many aspect of human life, as far as to attribute economic value to them.

Ecosystem services are grouped in four main categories, the most important of which is the set of supporting services, because they refer to basic natural process that condition the ability of the ecosystems to provide the other types of services. An example is the nutrient recycling or the primary soil formation. Another basic group is that regrouping the regulating services provided by ecosystems that naturally operate for ensuring purification of water and air, carbon sequestration and climate regulation, waste decomposition and detoxification, as well as for pest and disease control. A third group is the provisioning services which refers in general to the products provided by ecosystem, first of all food and water, beside to raw materials and genetic resources, including minerals, pharmaceuticals, chemicals, and energy. Finally a fourth group considers those services able to provide non-material benefit to people, such as recreation, spiritual enrichment, cognitive development, reflection, and aesthetic experiences. In this respect, natural capital is regarded for the ability to provide symbolic values to humans.

Without attempting to enter the complexity of the matter, it is to mention that several methods are been developed to attribute an economic meaning to all those complex functions provided by ecosystems. The difficulty was first of all in the variability of the scale to adopt, from the largest such as the role played by great forests, to the smaller such as the function carried out by microbiological process. Again the temporal scale is also ranging from the millions of year of the geological periods, to shorter time. In addition there is the inter-connection and interdependence of all ecosystems in the complex Earth's ecosystem balancing. Among others, some methods can be recalled (Farber et al., 2002) that grounds on the evaluation of the avoided cost, or the replacement cost, or again on the enhancement of the income. Again, for evaluate the benefit coming from human experience of the cultural services there are travel cost, or hedonic pricing (price people will pay for certain goods) or contingent evaluation (willing to pay for hypothetical scenarios that involve some alternatives). They are called into question, for example, about how shaping policy measures to incentive better land or landscape management.

Regarding the relationships between agriculture and ecosystem services, agroecosystems provide many basic services, even under evaluated, whose agriculture benefits. Otherwise, depending on management practices, agriculture too can provide both service and disservice, as figure 1 illustrates (Power, 2010). The land management mostly depends on the subjective farmers' evaluation of short and long term benefit (Power, 2010). In this regard, an important role is played by the fact that farmers, beside to other land owners, are potential producers of a range of agro-ecosystem services whose they are not first and direct beneficiaries. It is to consider also that the relationship between production and agroecosystem provision is subject to change over the time and the place.

Choices about management practice in agriculture are developed over the time, entailing different kind of relationship between agricultural production and environment. Traditional method used until 19th century (Gargano and Sardone, 2004), based on rotational method allowed a balanced equilibrium to held in the relationship between agriculture and environment. In the following, period and until the Eighties of the 20th century, modern practice of agriculture came in use that were based upon intensifying the use of natural resources and of chemical fertilizer to enhance quantitative level of production. A range of negative externalities are associated to that kind of production, to the extent that citizens called for chances in policies and in their consumption preferences.

Newly more traditional practice were re-introduced thanks to voluntary schemes adoption or as effect of compulsory policy measures with the aim to associate agriculture to the intentional production of positive externalities. Especially, in this case we can refer to public goods that are, by definition, benefitted by everyone, without diminishing the ability of other to equally benefit. The crucial policy choice is that aiming at lower levels of agricultural production that is possible only in the advanced economies. In fact, (Schomers and Matzdorf, 2013) in developing countries voluntary schemes such as Payment for ecosystem services are more social and economic instrument more than economic solely, in that they are associated to lower cost-efficiency.

Therefore, in the absence of some kind of intervention, trade-offs emerge between the supply of food, fibre, bioenergy and regulating services such as water purification or soil conservation, due to the intensive system of production. Similarly, the provision of cultural services and biodiversity conservation may be seen in the trade-off with high level of production (Millennium Ecosystem Assessment, 2005).

How to manage land and landscape is the key-choice to contribute ecosystem services by agriculture and it rests on the hands of farmers.

Since at global level the trend is estimated for disservice from agriculture will be increasing, there is room for voluntary schemes adoption, stemmed from the grown awareness of both consumers and farmers. For the latter, the Payments for ecosystem services (PES) are an example (European Commission DG ENV, 2012; FAO, 2012; Kissinger et al., 2013). There is also room for several kind of policy intervention through compulsory measures too, analysed in the following of this chapter.

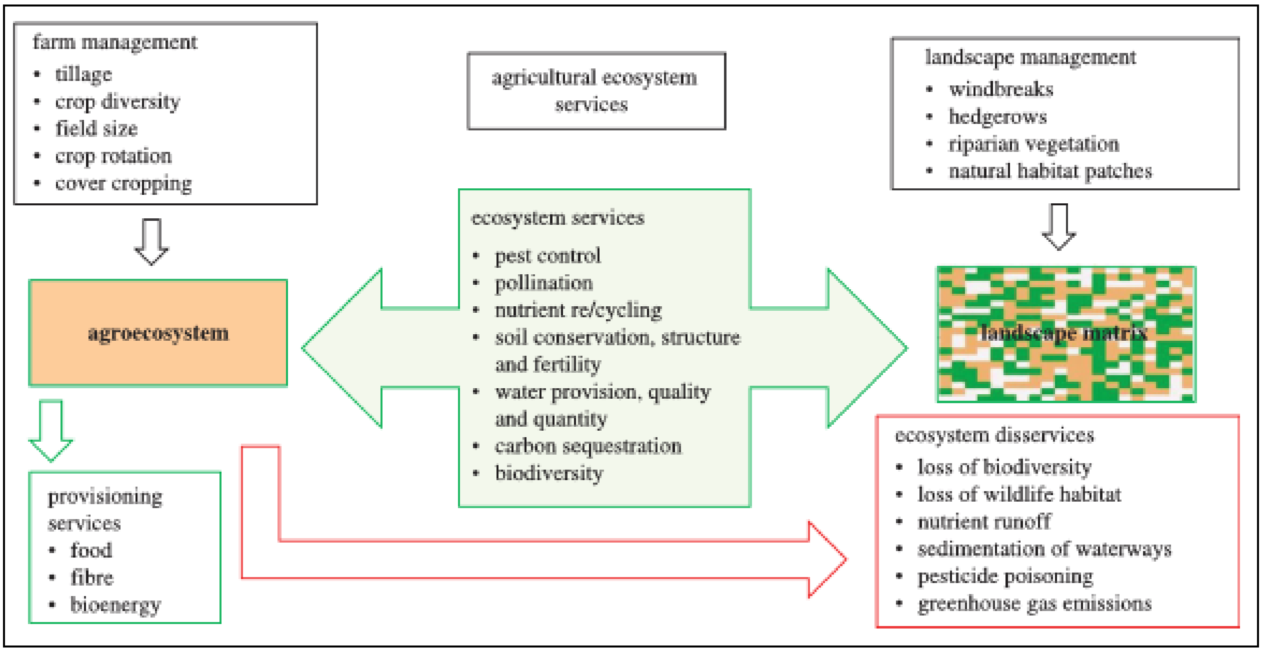

Figure 1.1. Impacts of farm management and landscape management on the flow of ecosystem services and disservices to and from agroecosystems. Source: Power (2010) p. 2960.

1.1.1. Positive and negative externalities

Commonly, externalities are classified as external cost or negative externalities, and external benefits or positive externalities (Holtermann, 1972; Krugman and Wells, 2012). Negative externalities occur when the private costs sustained by the producers or purchasers of a good or service differ from the total social costs. Differently, positive externalities refer to the benefits obtained from goods and services utilized by consumers, who have not paid for them, and occur when private benefits obtained by the producers or purchasers differ from the total social benefits (Qiuzhen, 2016). Particularly, when referring to production costs, negative externalities are when the production costs sustained by private individuals or entities are lower than the social costs supported by the collectivity. A typical example of negative externality is farming pollution (Pretty et al., 2001), caused by a producer of a good or service who thinks only about the direct costs of the production process and their profit and does not consider the indirect costs paid by the society. According to some researchers, social costs and negative externalities correlated with environmental impact can derive from the employment of new technologies in agriculture such as genetically modified crops, use of antibiotics in livestock farms (Qiuzhen, 2016), carbon footprint derived from the food production system (Garnett, 2011), food waste (FAO, 2011a; Kummu et al., 2012), obesity of population caused by overeating (Popkin et al., 2012), global warming of the Earth due to fossil fuel use (Connelly et al., 2011), and nutrient runoff.

Positive externalities occur when social economic benefits are higher than private returns. Research and development activities are an example, as they contribute to enhance the knowledge and lead to higher feedback for the community than for the scientists who carried out the research (Helbling, 2010). Agricultural production can generate positive externalities (e.g. greenhouse gas (GHG) mitigation) through the diffusion of farming practices like zero-tillage and fertilization, improved farm management and energy crop plantations (Schneider et al., 2007).

1.1.2. Externalities in agriculture

In agriculture it is very difficult to define and evaluate the externalities related to the production process of a farm, in order to assign them a value and to assess the sustainability in absolute terms, because it can be influenced by different elements such as the environmental context where the farm works (German et al., 2016). The first studies on agricultural externalities were related mainly to negative environmental externalities, such as the agricultural runoff externality, also defined as non-point externalities (Griffin and Bromley, 1982).

Furthermore, agricultural externalities have costs that are underestimated because it is very difficult to identify the makers of the externality (Pretty et al., 2001), particularly on positive externalities because it is hard to calculate their benefits compared to the negative externalities. In fact, how would you calculate the positive action of a landscape, a clean river clean, biodiversity, a good soil rich in organic matter or carbon sequestration? In the past, several researchers (Willis et al., 1993; Foster et al., 1997; Hanley et al., 1998) tried to give a value to the positive externalities, in reference to environment and landscape. Stewart et al. (1997) and Hanley et al. (1999) confirmed the value of benefits derived by agro-environmental policies to wildlife, landscape, water quality, etc., in the UK. Cobb et al. (1998) compared organic and non-organic farms in the UK and showed that organic agriculture produced € 75-125 per hectare of positive externalities each year (particularly for soil health and wildlife). Pretty et al. (2000) calculated the total cost of agriculture in the UK and showed that water contamination, soil erosion, and food poisoning had a cost of £2343 million to society in 1996. Other studies have sought to determine the cost of negative externalities (Pimentel et al.,1992, 1995; Steiner et al., 1995; Davison et al., 1996 (cited by Pretty, 2001); Fleischer and Waibel, 1998 (cited by Pretty, 2001); Bailey et al., 1999), but the data obtained are not comparable, because the frameworks and methods of assessment used are different. For example, Pretty et al. (2001) calculated a cost of €72-306 per hectare of arable and grassland for negative externalities in different countries e.g. Germany, UK and USA. Although there are no accurate assessments of positive externalities produced by agriculture, in the UK the estimated public benefits appear to be around €14-44 per household, or about €29-89 per hectare of arable land and pastures. Although these findings cannot be extended to all different agricultural situations found in the world, it is obvious that our production systems should be more sustainable and more efficient (Benton et al. 2011;Connor and Minguez, 2012) in order to limit the damage caused by the negative externalities.

Some economists recommended government’s intervention to take into account the effects of externalities. Long time ago, Pigou (1920) proposed that polluters paid a tax equivalent to the cost of the damage caused by pollution. However, using the same logic, government should recognize a subsidy to farmers that generate positive externalities (Pretty et al., 2001).

It is generally simple to quantify and remunerate externalities of private goods, whereas it is more difficult to give a value to externalities of public goods, such as water, air and biodiversity, produced in nature and available to everybody. In fact public goods do not have a defined owner, and the collectivity generally does not recognize their value, as in the case of reforestation and the interventions of hydrogeological recovery of some lands (Pretty et al., 2001), or ecosystems services.

GHG are an example of negative externalities, as they are identified as a major cause of global warming and climate change. It is difficult, also in this case, to identify the authors and calculate the costs and risks of these externalities in order to internalize them. Agriculture contributes to 10% of the total EU’s greenhouse gas emissions, which have declined by 24% since 1990, while maintaining total output of agricultural production, thanks to modern land management, which grounds on the use of modern technologies, improved knowledge and specific practices to combat climate change (EC, 2016).

Only the governmental level can contrast negative externalities in favour of positive externalities by making policy decisions, through environmental taxes, subside and incentives in agriculture for farmers (Pretty et al., 2001). In the past, the taxes applied in agriculture were pesticide taxes (Denmark, Finland, Sweden and several states of the USA), fertilizer taxes (Austria from 1986 to 1994, Finland from 1976 to 1994, Sweden and several states of the USA), and tax for manure produced (Belgium and the Netherlands) (Pretty et al., 2001). Among the different types of taxes, pesticide taxes have been more applied and have determined a growth of sale prices of agricultural products ranging from 0.7% (USA) to 36% (Denmark). The effects have been different in the various countries. For example, there has been a 65% reduction in pesticide use in Sweden since 1985 (Pretty, 1998).

The most recent approaches to study sustainability have considered the changes produced by externalities, from a socio-economic perspective (German et al., 2016) or in terms of impact on biodiversity, water use, and GHG (Gomez-Limon and Sanchez-Fernandez, 2010). Regardless of the type of approach used, the biggest difficulty when studying externalities in agriculture is the scarce availability of farm data. In the world, the large Monsanto agribusiness has big data in agriculture derived from a third or more of the US farmlands (Carbonell, 2016), which are controlled through wireless sensors mounted on tractors. This system permit to Monsanto to monitor farmers, dictating they turns of plant irrigation or amount and method of herbicide application. Big data are of significant importance not only to perform previous analysis but also to plan future farming operations. Recently, Monsanto acquired Climate Corp., thus increasing big data acquisition of the largest biotech agribusiness, in addition to producing and patenting new genetically engineered seeds. According to Carbonell (2016), the fact that a private company like Monsanto manages directly all this information poses an ethical problem, which make one wonder which could be the scenarios and consequences of big data use in agriculture and food production. Indeed, despite Monsanto has the large amount of agricultural data, it does not provide information on the agricultural sector and do not know the use that Monsanto make of they, then one believe that this agribusinesses can make commercial speculations (American Farm Bureau, 2015). Therefore, there is no information or critical analysis available on agriculture externalities, including loss of biodiversity due to different practices such as mono-cropping. As suggested by Raven (1965), big data should be available to everybody through open-access, in order to disseminate information throughout the population and have a more balanced relationship between farmers and large agribusinesses.

The analysis and development of big data is complex and requires expensive instruments and specialized technicians, so it would be more appropriate that big data were run by public organizations, which work for the good of the collectivity, rather by industrial corporations. The use of big data in agriculture could be of great importance for further research, which would be useful not only to farmers, but also to the calculation of externalities in agricultural and livestock production, sometimes leading to greater environmental sustainability (Carbonell, 2016).

As mentioned previously, if agriculture is practiced sustainably, it can potentially produce a range of ecosystem services, such as carbon dioxide absorption from the atmosphere, biodiversity conservation, improvement of the quality of life of the community, animal welfare, and the aesthetic and recreational value of the landscape (UK National Ecosystem Assessment, 2011). Farm management influences many of these ecosystem services, generating positive or negative externalities. Thus, the farm must be managed using ethical criteria and respecting the welfare of farmers and animals. According to German et al. (2016), it is important to keep the production in the same place where it is produced, avoiding to export environmental costs to other places. However, in our current globalized era it is very difficult to keep everything locally because this would lead to the closure of global markets and condemn billion people to hunger and migration from the poorest areas of the world (Van Dijk and Meijerink, 2014). Furthermore, it was demonstrated that Carbon Foot Print (amount of CO_2 emitted in the atmosphere per kg of food that arrives at our table) produced by transport is just 10% of the total cost of the production chain (Edwards-Jones et al., 2008).

In order to orient agricultural production towards sustainability, German et al. (2016) conducted a meta-analysis to determine possible correlations between different variables related to sustainability (e.g. soil, greenhouse gas, water and biodiversity), by comparing different management systems. The main goal was to interpret existing correlations and help the farmer to make better management decisions. The study focused on a common practice of sustainable management, “zero-tillage agriculture”, widespread in the past, because of the need to reduce soil erosion while maintaining soil fertility, biodiversity and carbon storage, and reducing costs derived from the use of agricultural machines (Lal et al., 2007). The results obtained by German et al. (2016) demonstrated that, on average, yield tended to be positively correlated with direct indicators of ecosystem services and was not negatively associated with other aspects of agricultural sustainability. The relationships between biodiversity and crop yield or farm profit were difficult to measure, because of the richness of species that encompassing. Negative correlations were observed between yield and plant, invertebrate and vertebrate biodiversity. A positive correlation was generally found between species that contribute positively to ecosystem services, such as pollinators and earthworms, and yield. According to Gabriel et al. (2010), it is difficult to assess biodiversity with a single measure, because the correlations between the different species and farm management systems differ, and results may also vary with the assessment scale.

The recent EU common agricultural policy (Pe'er et al., 2014) assessed other aspects of biodiversity conservation, using the proportion of uncropped land and the presence of vegetation features, but through of higher variability observed for many of the relationship between different aspects of biodiversity studied by German et al.(2016), they concluded that the use of only methodology to assess different aspects of biodiversity in different contest, is not suitable. Therefore, they argued that is more appropriate make limited groups of variables, where the relationship between different aspect of sustainability are similar, and so assessment individually analysis methodology. Gabriel et al., (2013) found that the conventional arable system generally had a higher crop yield but a reduced earthworm activity compared to the organic system. Whereas, it has been demonstrated that in a conventional system (Torabi et al., 2008; Endale et al., 2010), in case of use of manure or reduced tillage, you can have higher crop yields and earthworm activity. This confirms that good agricultural practices are important for the improvement of conventional farming system.

German et al.(2016) found that "zero-tillage" favoured an increase in carbon and water in most of the cultivated lands present in the world, with the exception of wet tropical areas. Furthermore, in at least 50% of the cases studied, "zero-tillage" had a higher total yield in the long term (over 5 years) compared to "conventional tillage" and, at least in some studies, high yield was also associated with good water quality. Thus, the authors showed that planning on sustainable land management, considering different fields as ecosystem services -farm and landscape - can lead to high production and favour multifunctional agriculture. The authors argued that the simultaneous use of more statistical indicators, rather than the use of a single statistical indicator, provides better information for management decisions. They also showed that appropriate management decisions support the balance between the various aspects of sustainable farm management, so that a greater sustainability of food production can be achieved. Because aspects that influence sustainability vary from one place to another, actions that can be negative in one place, do not necessarily have the same effect on another place. Furthermore, in several cases the aspects that interfere with the production process and thus influence the sustainability of food production should be considered at a global scale, rather than at an individual level. Given the fragmentation of the available data, a continuous collection of data by food producers is recommended, in order to increase the available database to be used in sustainability studies (German et al., 2016). This type of information gathered could be processed and balanced in order to support, in a right way, the managerial choices (Dicks et al., 2014). It is important to point out that the adoption of other agricultural techniques, such as residual management and cover crop, in combination with zero-tillage could increase the benefits of this agricultural practice.

Agricultural activity and the changes in farming practices give rise also to social implication which affect rural environment, or better the rural environment ability to provide ecosystem services, though not being externalities according to the economic concept. For example, the structural changes of farms, which increased in size but decreased in number, and the abandonment of cultivated land have caused a dramatic decline in the number of people employed in agriculture. In the world, the number of workers in agriculture has declined considerably. For example, in 1900 about 41% of the workers of the United States worked on farms, whereas today this figure is less than 2%. A similar but less pronounced trend is found in the developing countries compared to the industrialised ones (The economist, 2016). In Sardinia region, in Italy, people employed in agriculture decreased from 1950 to 2010, mainly because there was an abandonment of the internal areas, with the population moving from the mountain to the coastal areas. That resulted also in important changes in land use, consequently in the externalities produced. The farmers moved into areas previously occupied by cereals, whose cultivation area reduced to 1/5. The areas with forests, which reoccupied the areas used previously for grazing, increased from 20% to 40% of the regional surface from 1950 to 2010 (Pulina et al., 2015). The growth of forests in areas previously sown or used by livestock grazing have modified the rural landscape and the connotation of the Sardinia region from agro-pastoral to sylvan-agro-pastoral (Pulina et al., 2015).

Among different agricultural activities, livestock production is accused of being the main producer of GHG, causing water deprivation, and treating biodiversity (Laurance et al., 2014), land degradation (e.g. from overgrazing) and pollution. However, there is a stronger debate about the possible negative externalities that drive towards social and environmental problems associated with the growth of this sector. In reality, livestock production can cause also positive social effects because is able to create good opportunities for economic growth and poverty reduction, particularly in rural areas and developing countries. Robinson et al. (2014) estimated that 766 million poor people keep livestock sector, without considering the potential improvements in food security and nutrition among the economies of developing countries, where meat and milk consumption will continue to grow. In fact, the average meat consumption in developing countries was approximately 16 kg per person in 2010, but it could easily double by 2050, whereas it was 90 kg per person in 2000, in developed countries (FAO, 2011).

More in general, it is largely accepted that that agriculture can have a positive impact and thus positive externalities, such as greenhouse gas mitigation, by adopting good practices, like reduced tillage and fertilization or more efficient use of manure (Schneider et al., 2007), which lead to sustainable production, thus respecting the environment, contributing to the conservation of biodiversity, and protecting human health.

According to Wiggering et al. (2016), good farm management practices are critical for ecosystem services and can reduce the inefficiencies of conventional agricultural practices (Power, 2010), such as intensive agriculture, which influence negatively the different ecosystem services (Gordon et al., 2010), including the cultural ecosystem services (Raudsepp-Hearne, et al., 2010), defined as non – material benefits that population obtain, for example, by landscape as recreation and aesthetic values, and cultural heritage (Ungaro et al., 2016).

1.2. Multifunctional agriculture: externalities and policy intervention

The fact that agriculture produce not only food and fibre but also many other results, whose people can enjoy more or less freely entered the public debate about which model of production could ensure the most sustainable use of the natural resources. Citizens are increasingly aware that agriculture - as an immediate and direct consequence of its production process - is able to produce non-commodity outputs that are positive externalities for environment. These non-commodity outputs concern ecosystem services such as rural landscape, preservation of biodiversity, food safety, food security and animal welfare together with cultural and historical heritage (Lankoski, 2003; Hediger and Lehmann, 2007). In the latest years, non-commodity outputs of agriculture are identified with the term of multifunctional agriculture.

Given its importance for the population and research groups, multifunctional agriculture has been studied by many disciplines such as Economics, Law, Ecology, Sociology, Political Economy, and Geography (e.g., Smith, 2000; Potter and Tilzey, 2007; Potter and Burney, 2002; Losch, 2004; Boody et al., 2005) and was recognized in the Rio Declaration on sustainable development in 1992 (Qiuzhen, 2016). It has been considered *as the way that aims sustainable development* (Caron et al., 2008; Hediger and Knickel, 2009), and promotes significantly and consistent sustainability (Caron et al., 2008; Hediger and Knickel, 2009).

The ability of agriculture to produce externalities *per se* is not a guarantee to obtain positive results in terms of benefit for the environment and public goods production. The pregnant meaning of multifunctional agriculture – as it has been currently used in the latest years – stem from the European Union policy choice for a new model of agricultural production, the European Agricultural Model at the time of Agenda 2000 reform (Commission of the European Communities, 1998a, 1998b).

In that policy design, multifunctional agriculture can meet the increased demand for food and, at once, safeguard the landscape by favouring the conservation of natural biodiversity, maintaining its aesthetic value and recreational function, favouring water accumulation and soil formation, protecting the land from landslides and preserving wildlife. By this way it aim to support the economic growth of the local population, supply jobs, thus contributing to the development of the country (OECD, 1997).

OECD (2001) has developed an analytical framework for setting up the bases to discuss whether and how a public government should intervene with specific policy measures as the most efficient intervention, and which would be the ones more suitable (OECD, 2003).

In the premises, it is considered that agriculture is more multifunctional than other productive sector, for its special land management action and some other special characteristics. EU considers that agriculture sector is multifunctional as whole, not the single product.

The multifunctionality working-definition that was adopted deserves much attention because attempt to highlight the core elements of multifunctionality. They are, as OECD put it: *"i) the existence of multiple commodity and non-commodity output that area jointly produced by agriculture; and ii) the fact that some of the non-commodity outputs exhibit the characteristic of externalities or public goods, with the result that markets for these goods does not exist or function poorly."(p.7).*

Therefore, the framework grounds only on economic considerations about three crucial hypothesis to verify about the presence or not of jointness production, market failure and public good.

Firstly, it is taken into account that externalities are a characteristic of the production process, especially they are recognizable only if non-commodity outputs come as a result of the same production process that generate the commodity.

A classic example is that of mutton and wool which results at the same time from the same productive process without possibility to choice something of different. Both are technically interdependent, coming from non-allocable inputs (that is both share the same inputs, e.g. pasture) and linked in the level of production (if sheep production reduce, wool resulting shrinks too). On this main character of externalities a fundamental distinction between sustainability and multifunctionality grounds in the OECD analysis. The former concerns the use of the stock of resource, has a long-term perspective as involves the future generations, and pertains to the global dimension. The latter *"refers to the fact that an economic activity may have multiple outputs and, by virtue of this, may contribute to several societal objectives at once. Multifunctionality is thus an activity-oriented concept that refers to specific properties of the production process and its multiple outputs" (p.6)*

The second component of the framework concerns the association between externalities and market failures. Under certain conditions, non-commodity outputs could meet demand. It is the case for some environment-friendly product that can meet the consumer desire to purchase the commodity and contribute to safeguard the natural environment at once. These consumers are usually willing to pay something more – a premium-price – for these products. In this case, the initial loss of effective allocation of resources, typical of the externality creation, is overcome through the market. If it is not possible to meet a demand for the externalities created, it is the case for market failure, then the ineffective allocation of resources holds and a social loss is born. Usually, this is the case for the public goods. These are goods whose consumption is not rival, nor excludable. Landscape produced by agricultural activity is an example of both cases: everybody can enjoy freely of it (not excludable good) and the consumption of one does not reduce the benefit of another one (not rival good). However, if the case were more particular, other considerations would follow. For example, if a particular landscape in a private property were being enjoyable by staying in a farm holidays, then there would be a market and a price to valorise that enjoyment, that is reserved only to who are paying for it (excludable). Different policy implications follow in both cases.

The third component to take into account is the possibility to have non-governmental alternatives that give rise to an effective allocation of resources, such as market creation or voluntary provision. They are method that ground on incentives to incorporate (intentionally and being motivated by the incentives) social benefit into production decision.

Only if the three hypothesis are positively verified public policy intervention is to be considered the most efficient intervention. If the jointness production of the non-commodity output could be released any intervention to support the commodity output production should not be justified.

Even without deepening all the complex discussion of the matter, however, it is relevant for the thesis herein discussed right the example OECD (2003, p.18) take to discuss the jointness issue. Aiming at balancing the most efficient policy measure, it considers that the linkage between the input and the non-commodity output is what really matters, more than that between commodity and non-commodity output. In fact, it takes the example of a hypothetical incentive to produce milk pursuing the preservation of pastoral landscape. The OECD example refers to grazing cows, but we can actually think about sheep. It considers, hence, that *per se* such a measure might not be efficient because it does not affect the management practice involved. Therefore, an intensification of the farming practice (practice farming B in the figure 1.2) implies a change of the non-allocable inputs (from cows on feeders to cows on pasture) that should easily results in landscape deterioration, which is the converse of what policy pursued.

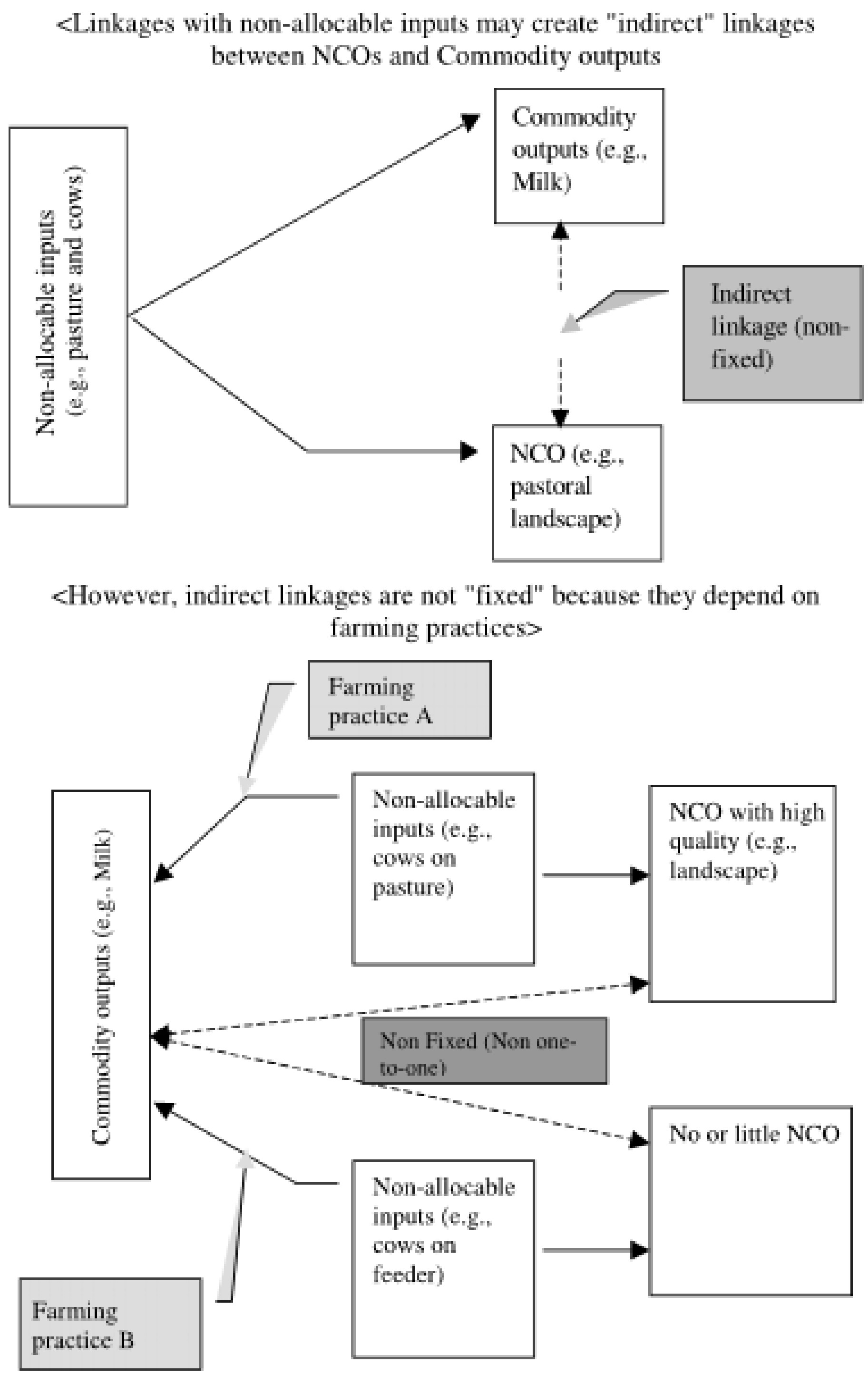

Figure 1.2. Illustration of indirect linkages between NCOs and commodity production
Source: OECD 2003, p.19.

1.3. The greening of the Common Agricultural Policy

From its foundation after the Second World War, the European Common Agricultural Policy (CAP, in the following) pursued first of all the food security in the frame of a balanced development of the agricultural sector aiming at advantaging from enhanced productivity thanks to technical progress, stabilising markets, ensuring fair standard living to agricultural community, as well as guaranteeing reasonable prices to consumers. Those are the objectives of the CAP stated in the article 39 of the Treaty on the functioning of the European Union (European Union, 2016).

From the Treaty of Rome to that currently in force, the objectives of the CAP rest unchanged. Within that overarching framework many reforms applied in order to pursue purposes closer to consumers and citizens and with the aim to counterbalance inequities in the distribution of public support among small and big, northern and southern farms, as well as among types of production differently supported. In few years the food security objective was met. Anyway a thirty-year period had to pass before CAP aimed new direction having regard to the environment.

For the purpose of the thesis it is to point out that the modernisation of agriculture was at the core of the policy design. In the name of the modernisation productivity was enhanced, so producing a range of negative externalities for the environment, including loss of biodiversity, pesticide poisoning, nutrient runoff, loss of wildlife habitat and greenhouse gas emission, among others.

The legal basis to introduce environmental objective among those other the CAP had to achieve was firstly in the Single European Act (European Communities, 1986), come into force on 1987, as the Title VII, art. 130r, 130s, 130t introduced the possibility for the European policies to act for:

- preserving, protecting and improving the quality of the environment
- contributing towards protecting human health
- ensuring a prudent and rational utilization of natural resources.

More in particular, paragraph 2 states that "Action by the Community relating to the environment shall be based on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source, and that the polluter should pay. Environmental protection requirements shall be a component of the Community's other policies".

Therefore environmental policy was setup as a horizontal policy to pursue within many others able to affect positively or negatively the ecosystems.

The subsequent CAP review, the Mac Sharry reform which come into force in 1992, firstly introduced agro-environmental measures to move forward the first pace for greening the CAP and answer to social concern.

That was possible through the regulation on agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside (European Communities, 1992). Policy intervention take the form of Community aid scheme, partially co-financed by the Community, able to give a premium per hectare or livestock unit to farmers willing to undertake at least two actions, and held it for five years, among the following (art.1):

> (a) to reduce substantially their use of fertilizers and/ or plant protection products, or to keep to the reductions already made, or to introduce or continue with organic farming methods;
> (b) to change, by means other than those referred to in (a), to more extensive forms of crop, including forage, production, or to maintain extensive production methods introduced in the past, or to convert arable land into extensive grassland;
> (c) to reduce the proportion of sheep and cattle per forage area;
> (d) to use other farming practices compatible with the requirements of protection of the environment and natural resources, as well as maintenance of the countryside and the landscape, or to rear animals of local breeds in danger of extinction;
> (e) to ensure the upkeep of abandoned farmland or woodlands;
> (f) to set aside farmland for at least 20 years with a view to its use for purposes connected with the environment, in particular for the establishment of biotope reserves or natural parks or for the protection of hydrological systems;
> (g) to manage land for public access and leisure activities.

In the "whereas" of the same regulation it was pointed out that the reduction of the production could ensure *per se* an advantage for the environment.

That very tentative to overcome the trade-off between production and sustainable use of natural resources was attempted firstly in the proposition of Agenda 2000, synthesised in the vision of the European agricultural model (Commission of the European Communities, 1998a, 1998b; European Commission, 1997) that grounds on the multifunctionality of agricultural, and better deepened and ruled in the subsequent Mid-term review – the Fishler Reform in 2003 (Commission of the European Communities, 2002; Commission of the European Union, 2002).

Since this period, CAP address environmental issue in a ramose form that stem from the basic changes occurred.

To make it suitable for the thesis purpose, it suffice to consider four fundamental new orientations.

First of all the European Agricultural model grounds on the multifunctional farm, able to purse at once productive goals and environmental ones, while contributing to viability of rural areas. The most important change is the decoupling, that is the CAP recognize the farmer a premium decoupled from the level of production. That was the most significant choice of policy to disincentive the increasing of agricultural and food production that aimed at multiple purposes, one of which is the setting up of a sustainable model of production for the environment protection.

> Secondly, the CAP was reorganized into two pillars: the first (European Communities, 1999b) for the market measures finalized to regulate the functioning of the market through the common market organizations that were established for groups of products; the second one to support the rural development (European Communities, 1999a) on the push of the Cork declaration (European Commission DGAgri, 1996), to ensure endogenous and integrated growth of the rural areas, keep population there. Both pillars, in an integrated way, provided a range of voluntary and compulsory measures to achieve environmental goals.
> Thirdly, the quality of productions, more than quantity, was pursued as a mean for better competing in the open global market as well as for valorizing rural areas through territorial values embedded in the emerging PODs and typical products.

Therefore, while budget funds for agriculture became increasingly shrinking, support to farmers was mostly oriented towards investments and income support in the form of a single farm payment with the Fishler reform (European Union, 2003).

Multiple measure intended to protect environment were introduced since Agenda 2000. With some modification they constitute nowadays the basic framework of measure in force, so a short description deserves.

Under the first pillar (European Communities, 1999b) was firstly introduced environmental protection requirements (article 3) with the aim to reach better integration of environment onto the Common Market Organization. That assumed the stronger form of the cross-compliance mechanism under the Fishler reform (European Union, 2003, articles 3-9) in a conditional and compulsory way. In concurrence with Members States, a list of requirements to ensure a good agricultural and environmental condition were established in order to allow a farmer to receive direct (decoupled) payments. The statutory management requirements could concern with public, animal and plant health, environment and animal welfare. Whether the statutory management requirements or good agricultural and environmental condition were not complied with, the total amount of direct payments were reduced or cancelled.

Under the second pillar (rural development) several measures were provided.

First of all, chapter VI of the regulation 1257/1999 (European Communities, 1999a) ensured the continuity of the agro-environment scheme - already provided by the regulation 2078/1992 – designed to support agricultural production methods to protect environment and to maintain the countryside. Again, farmers were required to meet agro-environmental commitments for at least five years. Agro-environmental commitments goes beyond the usual “good farming practice” and farmers’ support is calculated on the basis of the income foregone, the additional costs resulting from the commitment given, and finally the need to provide an incentive to cover the cost-opportunity. Unlike the precious, it is a voluntary scheme to adopt.

The following too are voluntary measures to implement. Farmers who operate in less favoured areas were provided by a payment ruled in the Chapter V of the same regulation. Payment is again calculated on the base of the costs incurred and income foregone.

Chapter VIII provided measure to contribute to the maintenance and development of the economic, ecological and social functions of forest in rural areas. Over and above the cost of implantation the support may cover also an annual payment per hectare planted for a maximum of five years or an annual payment to compensate income losses.

Among the objectives of adaptation and development of rural areas, Chapter IX provided payments for farmers that engaged in agricultural water resources management, protection of the environment in connection with agriculture, forestry and landscape conservation, as well as with the improvement of animal welfare, notwithstanding action to restore agricultural production potential damaged by natural disaster and introducing appropriate prevention instruments.

It is to be mentioned also organic farming regulation, also starting in 1991 and revised with the Council regulation 1804/1999. This measure incentivized the creation of a new market for a new kind of products by ruling method of agricultural production for crops and livestock, the labelling, processing, inspection and marketing of organic products within the Community.

Over the time two further reforms occurred, both in the direction of intensifying the greening of the CAP, definitively reducing any coupled support and reducing direct payments too.

The current programming period 2014-2020 is framed by the Europe 2020 strategy for a smart sustainable and inclusive growth (European Commission, 2010a) and the strategy for a bio-based economy (European Commission, 2012) able to ensure smart green growth to Europe.

Environmental issues are much more integrated in the CAP policy too that is designed to meet food, environmental and territorial challenges (European Commission, 2010b).

Especially in the first pillar, the level of statutory requirements arose (European Union, 2013b). The Regulation 1307/2013 rules direct payment and states that (whereas 37) *One of the objectives of the new CAP is the enhancement of environmental performance through a mandatory "greening" component of direct payments which will support agricultural practices beneficial for the climate and the environment applicable throughout the Union.* As a condition, *failure to respect the greening should result in penalties* (whereas 39). Direct payments result from a composition of several components compulsory or voluntary chosen by each Member State. For the Italian case (INEA, 2014), the overall scheme is the following:

Compulsory components are:

- the basic payment for farmers, max 68%
- the greening: a payment for farmers observing agricultural practices beneficial for the climate and the environment 30% (fixed)
- payment for young farmers commencing their agricultural activity, max 2%

The voluntary components and their respective maximum are:

- the voluntary redistributive payment , max 30%
- the voluntary payment for farmers in areas with natural constraints, max 5%
- the voluntary coupled support scheme, max 15%
- the voluntary simplified scheme for small farmers, max 10%.

Both greening and payment for farmers in areas with natural constraints are to produce public goods and meet social demand for environment protection in a stronger way than before. More in particular, the agricultural practices beneficial for the climate and the environment shall be (a) crop diversification; (b) maintaining existing permanent grassland; and (c) having ecological focus area on the agricultural area. The latest are for example land lying fallow, terraces, landscape features or areas with nitrogen-fixing crops.

The second pillar, (European Parliament and the Council, 2013; European Union, 2013a) in no longer organised per axes. It pursues three objectives: (a) fostering the competitiveness of agriculture, which is linked to smart growth; (b) ensuring the sustainable management of natural resources, and climate action, which is linked to sustainable growth; (c) achieving a balanced territorial development of rural economies and communities including the creation and maintenance of employment which is linked to inclusive growth. It is leaded by six priorities. The first, *Fostering knowledge transfer and innovation in agriculture, forestry and rural areas* is an horizontal one. Two address environmental issues: restoring, preserving and enhancing ecosystem related to agriculture and forestry; promoting resource efficiency and supporting the shift towards a low carbon and climate resilient economy in agriculture, food and forestry sectors. Two are to support competitiveness: enhancing farm viability and competitiveness of all types of agriculture in all regions and promoting innovative farm technologies and the sustainable management; and promoting food chain organization, including processing and marketing of agricultural products, animal welfare and risk management agriculture. Finally, promoting social inclusion, poverty reduction and economic development in rural areas is to support inclusive growth in rural areas.

Implementing Regulation (EU) 808/2014 (European Union, 2013), defines the twenty measures of intervention of the RDPs.

The major part are referring to environment.

As general measures, there are the M01 Knowledge transfer and information actions and M02 - Advisory services, farm management and farm relief services. As indirect measure we can consider also the M19 -Support for Leader local development (CLLD) since it can operate in favour of the environment at local scale through specific projects.

Specific measures are in continuity with those undertaken since Agenda 2000 (M05, M08, M13, M14 AND M15) or Mac Sharry reform (M10 and M11), or previously ruled to specific Council Directives (M12):

- M05 Restoring agricultural production potential damaged by natural disasters and introduction of appropriate prevention;
- M08 Investments in forest area development and improvement of the viability of forests;
- M10 Agri-environment-climate (AEC)
- M11 Organic farming
- M12 Natura 2000 and Water Framework Directive payments
- M13 Payments to areas facing natural or other specific constraints
- M14 Animal welfare
- M15 Forest-environmental and climate services and forest conservation

At Union level, approximately €987 billion of the financial resources provided by the European Agricultural Fund for Rural Development (EAFRD) are going to be allocated for Rural Development (RD) in the period 2014-2020, There are 118 different rural development programs (RDPs) for the 28 Members States, twenty of which have single national programs and eight of which have two or more regional programs. The distribution plan of contributions will privilege the EU Priority "*Ecosystems*" (preserving and enhancing related agriculture and forestry), which is going to receive in total 43.1% of the global amount available. This significant percentage demonstrates how much the environmental challenge is felt. This allocation Ecosystems priority can be found in all countries in Europe, ranging from 73.1% in the UK to 26.7% in Lithuania, being 32.9% in Italy Priority receives the second largest funding allocation (20.4%), followed by the "*Promoting social inclusion, poverty reduction and economic development in rural areas*" Priority (16.0%), and the "*Promoting food chain organization*" Priority (9,9%), Italy receives 19.3% (the highest allocation among EU countries) of total expenditure, along with Spain (13.2%) and France

(9.1%). The "*Promoting resource efficiency*" Priority receives 8.0% and the "*Fostering knowledge transfer and innovation in agriculture*" Priority gets 2.6% of the EAFRD RDP funds in total.

1.4. Sardinia Rural Development

1.4.1 Agricultural and rural characteristics of the area

Sardinia is an island, whose total surface is about of 24 100 km², 81% of which is rural surface: agricultural land covers 44%, forest land (*stricto sensu*) 29% and about 27% has represented by natural grassland and natural areas. Sardinia has nearly 1.7 million inhabitants, of which 83% live in rural areas, whereby the territory high list prevalent rural character.

Livestock and agricultures are the main productive activities of the island, in fact of 1.6 billion euro regional agricultural production value, approximately 43% is livestock, 41% are agricultural crops (26% herbaceous, 7% forage, woodsy8%), and the remaining 16% are secondary and support activities (ISTAT, 2010),

The UAA(Utilized Agricultural Area) is 1,153,690 ha and from an analysis of the use of territory, emerges the predominantly extensive use of cultivated areas and /or livestock farming, along 77.2% of the UAA used to low intensity (Italy 51.1%), 17.4 % medium intensity (Italy 24.9%) and 5.5% high intensity (Italy 27.9%).

Therefore, the mayor of the UAA in Sardinia, is affected by extensive farming system, < 1LU (Livestock Unit) / ha of grassland. Permanent grassland covers a total of 692 990 ha (20% of Italian pastures), used for the breeding of 585 860 LUs (6% of the LUs national), which corresponds to 0.85 LUs/ha, compared to 2.89 LUs /ha nation.

The average farm size is 19 ha, against the Italian average of 7.9 ha, but that size is not corresponding to an improved competitiveness of the system because of the diffuse presence of extensive sheep farming that implies wide use of land and low productivity at once.

Furthermore, the presence of higher percentages of areas with natural restrictions (mountainous and disadvantaged areas), than the rest of Italy, carried farmers to have more availability of farm surfaces, in order to compensate these limitation. That major dimension, does not mean better ability to organize production, nor higher productivity than smaller farms in the same branch.

Therefore, agricultural, livestock and food productions play an important role in the economy of Sardinia and in particular in that of rural areas which have to face important structural changes (ENRD, RDP 2014-2020) that call for RDP support.

It is to point out that there is a close linkage between the vitality of the rural production system and farms' ability to provide also public goods to preserve and maintain the environment. Therefore, even if the focus of the reasoning in the follow is on the environment measures, let be clear that in order to ensure the equilibrium of such a fragile rural system, the best use of the measure to support the competitiveness of the productive system are equally necessary, though indirectly.

1.4.2. Sardinia RDP 2014 - 2020: main lines

In Italy, Regions have the power to manage directly their RDP, so at national level rural policy is implemented through 22 RDPs, one of which at national level and 21 at regional level.

The RDP of Sardinia was adopted by the European Commission on 19 August 2015, and expect nearly € 1.3 billion of public money, which are available for the 7-years period from 2014 to 2020, and that include the EU budget (over € 628 million) and a national co-funding (nearly 700 million). It is expected that 17% of management contracts, among those that interest farmers, will support biodiversity, that the 15% rate will improve water management and 19% soil management. Over 1870 farmers will receive founds to restructure and modernize their farms and 1120 young farmers will receive monetary and technical support to their agri-business (ENRD, RDP 2014-2020).

Sardinia RDP is developed along six intervention priorities (EC, 2016) which are referring to environment, climate-friendly, farm investments and actions related to restoring, preserving and enhancing the regional ecosystem. On this basis, the RDP measures are concerning:

- *Knowledge transfer and innovation in agriculture, forestry and rural areas,* which occurs through specific training addressed to farmers (in particulars young farmers). It affects particularly climate change, sustainable agriculture and food quality. Sardinian Region, in order to realize this programmer, will provide to plan more than 77 co-operation projects of which 6 will be Operational Groups under the European Innovation Partnership for Agricultural Productivity and Sustainability.

- *Support to competitiveness of agro sector and sustainable forestry*, promote farm investments and modernization, with particular undertakings to innovative projects of young farmers, organic farming and integrated projects. It incentivizes also rational use of water resources and an efficient use of renewable energy resources to favour the sustainability of agricultural production.

- *Sardinia quality products* is promoted through food chain organization, and includes different interventions as processing and marketing of agricultural products, animal welfare and risk management in agriculture. Its application will concern 400 farms that will participate to quality schemes and it is expected that 500 farms will be help to development of supply chains, including short supply chains and local markets. Furthermore, nearly 11 000 farms will be supported to maintain animal welfare.

- *Restoring, preserving and enhancing ecosystems related to agriculture and forestry,* will pay particular attention to quality of water, biodiversity and soil protection. To this end, contracts will be agree upon with farms that will support the biodiversity, affecting about 17% of the agricultural land, 15% to improve water management and 19% for contracts finalized to improve soil management. Overall 43 000 hectares will receive support to convert to organic farming and another 117 000 ha to maintain it.

- *Maintenance of resource efficiency and climate*, will happen mainly supporting forestation, agro forestry systems, safeguard of forests, and forest ecosystems as well as their conservation. Furthermore, the co-operation measure will support enhanced sustainability through the European Innovation Partnership and through co-operation for climate change adaptation and mitigation.

- *Social inclusion and economic development in rural areas*, will occur through projects drawn up, by 13 Local Action Groups (LAGs), which represent municipalities, provinces and economic operators of the territory. Local Development Strategies will affect the 40% of the rural population and will create around 500 additional jobs. LAG's projects too can involve environmental issues tackled at local scale.

1.4.3. Agro-environmental measures: objectives and expected results

Resources available in nature are not inexhaustible and renewable, so a continuous and mistake use, will lead to exhaustion and depletion of them and to environment pollution, at the expense of the well-being of populations and animal welfare. Farmers in order to safeguard these resources would adopt suitable agricultural practices to environmental protections. Sardinia Region, has designed four measures of intervention concerning the 1) Agro-environment-climate, 2) Public health, Animal and Plant, 3) Animal Welfare, 4) Maintenance of permanent pasture.

1) Agro-environment-climate (AEC)

€ 163 million were allocated to this measure to favour environmental preservation by changes in agricultural practices with positive effect on the environment and the climate. Conversion or maintenance of organic farming practices and methods are encouraged, providing compensation to beneficiaries for additional costs and income foregone resulting from disadvantages in the areas concerned. Farmers are considered as “environmental guardians" and are supported and encouraged to contribute to environmental preservation, creating a pact between farmers and environment, in harmony and not competing with each other.

Key issues of this measure include water, soil and carbon storage, biodiversity, and maintenance of landscape features.

1.a) Water

Global water availability is limited due to climate change, with short rainy seasons that cause a depletion of water resources stored in the soil. Consequently, water availability is limited not only for human consumption but also for the agricultural and agro-food production sectors. In addition, degradation and pollution have posed considerable risks to the conservation and survival of water bodies.

Sardinia water needs (civil, irrigation, industrial and environmental), are mainly satisfied by surface water, gathered into 34 artificial catchment, with a total delivery of 1,799,330,000 cubic meters, supplied by public entity (ENAS: *Ente Acque Sardegna*).

The water management plan, has highlighted the low resilience of catchment, because water reserves re-form slowly, due to the climate characters of island. Therefore, Sardinian Region in the 2008 has issued guidelines to careful manage water resources. In the 2010, water withdrawals of agriculture were 318.6 million cubic meters at net of adduction loss.

As farms use the available water for different necessity and culture, not only for livestock, the specific rate of water consumption due to livestock is generally difficult to quantify. Furthermore, it should be considered that most of our livestock farms use well water or rainwater, gathered in private catchment. That make it hard to determine their exact water consumption.

The Regional Law of 5 January 1994, n. 36 contains several provisions related to water resources. In particular, the Art. 1 provides the following: i) all surface and ground waters are public and are a resource that is protected and used in accordance with criteria of solidarity; ii) any use of water is carried out safeguarding the expectations and the rights of future generations to benefit from an intact environmental heritage; and iii) uses of water are directed to saving and renewal of resources not to affect water resources, the liability of the environment, agriculture, wildlife etc.

Water use involves a serious of rules and obligations for farmers concerning the management of livestock farms and food processing sewage as follows:

- protection of groundwater from pollution caused by nitrates from agricultural sources, regulated by the Directive 91/676/EEC, which applies to all farms that produce and/or use livestock manure and nitrogen fertilizers. In particular, it regards farms that fall into the so-called "Zone Vulnerable to Nitrates" from agricultural sources, located mainly in the municipality of Arborea (province of Oristano), to which a specific disciplinary proper use of the effluents (Regional Resolution No. 14/17 of 4 April 2006) applies, whereas the "Ordinary Zones" are regulated by the Legislative Decree 152 of 3 April 2006;

- prohibited fertilization in areas adjacent to water courses (buffer zones). Usually, these zones are grass-covered areas and/or woodlands, whose function is to avoid the transfer of pollutants, reduce the runoff of pesticides and nitrates, increase biodiversity and enhance the rural landscape. Observance of this rule involves an integration (greening portion) of the base quota within the CAP.

- respect of authorization procedures for the use of water for irrigation. Good public water should be safeguarded not only from a qualitative but also from a quantitative point of view, because its availability is progressively decreasing in the world. Therefore it should not be wasted and should always be rationalized;

- correct management and disposal of dangerous substances used in the farm production, which become dangerous if dispersed in the soil or placed directly into drains without prior treatment. The risks of bad management of disposal of water, resulting from the production process can be pollution of groundwater with consequent problems of toxicity that make it unsuitable for both human and animal consumption. The farmer is obliged to respect the rules concerning the storage and disposal of waste water containing substances harmful to health.

The Directive 2000/60/CE provides incentives to farmers to better use of water resources with the aim to contribute to environmental objectives and to retrieve costs of water services and environmental, dividing them among different sectors (industry, civic and agriculture), on the basis of economic analysis and according to the principle " polluter pays".

1.b) Soil and carbon storage

The soil is a fundamental good for humanity because has important functions such as being a reservoir of harvested rainwater and holding a carbon stock because, reduces the concentration of carbon dioxide in the atmosphere, thus mitigating climate change. Therefore, soil must be protected from degradation and erosion, and soil fertility and organic level must be preserved, by adopting good agricultural practices.

1.c) Biodiversity

Biodiversity is the result of the evolutionary process of all animals and plants over millennia. . Sardinia together with Sicily, Corsica and Malta are the home of 25,000 plant species, approximately 75% of the European insects, and a high number of endemic species, as animal that plant. Agriculture has a strategic role in achieving the Natura 2000 objectives, with the aim of maintaining and/or restoring natural and semi-natural habitats, pastures, etc.

1.d) Maintenance of landscape features

Rural and pastoral landscape of Sardinian represent a very important aspect of multifunctional agriculture. Agroforestry system, the more representative livestock landscape, which covers a surface of 1,319,378 ha (about 54% of regional territory) and is constituted by 560,984 ha of woodlands (sensu stricto) and by 645,726 ha of bushlands and 112,668 ha of Meriagos, results mainly affected by grazing and represents an important feed animal resource for sheep, goat and cattle reared extensively (Pulina et al., 2016). Therefore, pastoral landscape is the resource of this productive system.

In the period 2009-2010 the agriculture productivity, determined by the ratio between the volume of output (products) and factors of production (inputs), has showed the grown of the sector, confirming that agriculture production system has great development potentiality (ISTAT 2010). Clearly, that will be possible only if the abandonment of land and of extensive livestock will be avoided. Landscape contribute to well-being and development of local populations also through others activities related to agriculture and livestock, as tourism, agro-tourism, transformation of animal and plant products, didactics farms and so on. Hence, it can increase the productivity of the agricultural work and contribute to contrast the present unemployment in many areas. Furthermore landscape contributes to maintenance of habitats and biodiversity and thus would be protected and preserved.

In order to ensure the maintenance of these multifunctional activities linked to the and characteristic landscape of the region, the Sardinia Region approved the Regional Landscape Plan (RLP) (Resolution no. 36/7 of 5 September 2006). The objective was to give the "guidelines" for planning the territory, so that sustainable development and economic growth are favoured. The typical elements of the landscape are stone walls, hedges, ponds, endemic plant and animal species, terracing, Meriagos (Pulina, 2014), agroforestry, forests, pastures and grassland, etc. Recently, the Sardinia Region gave some research groups a commission to draft the new Regional Landscape Plan, and the second chapter of my thesis represent one part of first contribute, data from Department of agriculture section animal science, to which I belong.

2) Public health, Animal and Plant

€ 259 million were allocated to these RDP measure, in order to ensure a high level of food safety. The key issues include:

2.a) Food safety

This measure is applied to farmers that conduct agricultural activities in the food sector. Consumers give a lot of importance to food safety issues, and to food contamination by toxic residues derived from the use of illicit substances or the abuse of medication or pesticides.. Farmers must ensure traceability along the food chain, from production to processing and distribution.

2.b) Identification and registration of farm animals

The registration must ensure *traceability* of products in relation to: i) farm location, ii) general information about the farmer, and iii) identity and history of the animals bred in the farm. Only in this way it is possible to protect and ensure public health and reduce sanitary emergencies

2.c) Animal diseases

The Regulation EC 999/2001 concerns the prevention, control and eradication of certain transmissible spongiform encephalopathies (TSE) affecting mammals, including man. The most common diseases are the transmissible bovine spongiform encephalopathy (BSE), or "mad cow disease" and the scrapie or "mad sheep disease", which can cause the death of the animal.

2.d) Phytosanitary products

These products are used to protect plants or crop products before harvest and/or during storage from harmful organisms. The farms are obliged to keep the register of phytosanitary treatments, the invoices and authorization to buy and a storage depot and where they reported for treatment dates, quantities used, diseases etc ... It is thus possible to make an accurate control of the use of pesticides by the farmer and essential is the fact that the competent authorities monitor the farms.

3) Animal Welfare

€ 225 million were allocated by Sardinia RDP to this measure. Extensive and semi-extensive farming contribute to animal welfare, while intensive farming increases the risk of stress and diseases development. The EU Regulation No. 1305/2013- Measure 14, guarantees the welfare of animals with the aim to improve farm management according to extensive system, where woodland (Meriagos) and polyphite pastures, represent the principal use of soil. Animal welfare is a very important measure in the Region because guarantees also the highest quality of food products for the consumers.

4) Maintenance of permanent pasture

€ 230 million were allocated by Sardinia RDP to this measure. The maintenance of permanent pasture was regulated, for the years 2015 and 2016, by BCAA Norma 8, with the objective of maintaining, on a national level, the ratio of the permanent pasture area (not grassland alternated at least 5 years) and the total agricultural surface. Possible conversion of permanent pasture to other uses, have to be authorized by competent authorities.

Community law provides penalties for single sectors of RDP measures, summed if infringements committed by farmers belong to more fields of conditionality. In the assessment of the violations, it is evaluated if has been committed by negligence, so is attributed an evaluation index, or to intentionality. In case of violations of limited relevance, be notified to the farmer so-called "early warning", that calls it to take corrective actions agronomic, environmental or public health, structural and administrative and that if performed promptly, eliminate the effects of reductions in payments of conditionality. Whereas, for the most serious violations that constitute a risk to public health, animal health or the environment or cause pollution of aquifers, or contamination of food or feed, you always have a reduction or exclusion from financial support expected.

In summary, it can say that new CAP, provides a range of legal protections in respect of the environment in within the farm is situated, pushing the farmer to be able for safeguarding this public good.

The objective is, over time, to sensitize the farmer “sentinel” to environmental issues. One must understand that implementing a production process, you can do without damaging, polluting and depleting natural resources: common goods of the whole community. But these objectives can only be realized if the control bodies will carry out their surveillance role continuously, with the knowledge that it is taking a re-educational path of man, as inhabitant, farmer and entrepreneur of our planet, respecting sustainability.

Therefore, it appears of relevant importance to adopt good agricultural practices, which generate positive externalities, to assure environmental safeguard, agriculture and livestock systems. Abandonment of these activities actually could represent a risk for, the interlinked production system, landscape and biodiversity, the regional economy as whole. It is to strongly remark that the abandonment of extensive pasture or excessive intensification of farming system, could lead to loss important habitats, environmental resources and cause further depopulation.

Finally, even the focus in the following part of these thesis will be on the specific aspect of water and landscape management, I am to point out that, when designing policy and planning their implementation, it is to bear in mind the deep interconnection between environmental and socio-economic effects for the peculiar systems of the Island.

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CHAPTER 2

2. Livestock Landscape in Sardinia: A Contribution to the Regional Landscape Plan (RLP) of the Sardinia Region

2.1. Livestock Landscape

2.1.1. Introduction

The livestock landscape contributes substantially to the rural landscape in Sardinia. Among the southern regions of Italy, Sardinia has the highest livestock density, with a predominance of the dairy sheep farming that characterizes the pastoral landscape. In Sardinia, the predominant ruminant species are cattle, sheep and goats, which amount to 749,095 Livestock Units (LU) in a total of 25,171 farms (Table 2.1; Laore Sardegna, 2013). The Sardinian landscape is considerably influenced by different management and farming systems. The natural pastures are utilized by ruminant species for the production of milk and meat, which are fundamental products for the economy of the rural areas of the island. The rational management of livestock presume adequate animal grazing, because of its implications on plant biodiversity and other environmental components, whose equilibrium varies with seasonal and climatic conditions.

Table 2.1. Number of livestock heads and farms in Sardinia (Laore Sardegna, 2013).

Species	Livestock heads (n.)	Livestock farms (n.)
Cattle	264,957	8,792
Sheep	3,190,830	12,718
Goats	198,133	3,661
Total (n.)	**3,653,920**	**25,171**
Total (LU)[1]	**749,095**	

[1] 1 Livestock Unit (LU) = 1 adult cattle = 6.67 adult sheep or goats.

2.1.2. The definition of Livestock Landscape

Livestock landscape can be defined as *the perception of identity of that part of the rural landscape whose processes characterize a society economically and culturally based on animal breeding*. The predominant factor in the definition of livestock landscape is the “perceptive” component, which distinguishes it from the general definition of landscape. Perception is a complex elaboration of the psyche that gives a specific meaning to the sensorial information perceived by the observer and that identifies characters of the observed area (Hillmann, 2004). Another component of the livestock landscape definition is “identity”, which derives from the relationship between morphological characteristics of the rural area and the anthropological, ethnological and cultural heritage of the populations that live there. Identity is an essential concept that expresses a sense of belonging of a population to the territory and that identifies its inhabitants as sons of the same land, and thus of the same homeland. In fact, it is not a coincidence that the idea of “identity” expressed by Croce (1920), Bottai (1939) and Galasso (1985) was included into the Article 131 of the Codice Urbani (2004), which defines the landscape as an “*expressive identity of the territory”*. The rural landscape is the part of the anthropic landscape that is complementary to the natural landscape and different from the urban landscape. The rural landscape can be separated into cultivated, livestock, forest and natural landscape. The livestock landscape links the cultivated and forest landscapes and does not have well-defined boundaries, because its typical elements and processes are also mixed with those of the urban landscape and, above all, the natural landscape. In the latter case, some elements that appear natural could be the result of secular and extensive grazing.

Similar to the approach used to define "ecology", the term "livestock landscape" includes economic, cultural, social, anthropological and historical processes. The concept of "a society economically and culturally based on animal breeding" recalls the definitions of Sereni (1997) and Croce (1920). The first author was from the Marxist school and interpreted the rural landscape as an economic superstructure of the production relationships between different social classes of the country. In contrast, the definition of landscape given by the second author included the concept of cultural roots of the population (homeland, which literally means fatherland). Therefore, the cultural characteristics of animal breeding are strictly related to a common sense of identity and identification of the populations with crops, cults and culture of the livestock practices adopted. Consequently, the livestock landscape definition given above, i.e. *the perception of identity of that part of the rural landscape whose processes characterize a society economically and culturally* *based on animal breeding*, is a synthesis of perception, identity, society, processes, economy and cultural concepts concerning the technological evolution of livestock breeding.

The livestock landscape can be classified as intensive, semi-intensive, semi-extensive and extensive. It is intensive if characterized by fertile land, high stocking rate, considerable investments in land and agriculture, and high technical, financial and entrepreneurial capabilities of the breeder. It is considered extensive if characterized by low land fertility, low stocking rate, modest investments in land and agriculture, and scarce financial, technical, and entrepreneurial skills of the breeder. Finally, the livestock landscape is semi-intensive or semi-extensive if characterized by intermediate land fertility, stocking rate, land investments and entrepreneurship of the breeder. The intensive livestock landscapes are similar to the agricultural landscape, which differs only for the cultivated crops, which are mainly fodder and require high investments in mechanization, fertilization, herbicides and knowledge. The semi-intensive livestock landscape is mainly represented by artificial grassland and artificial grassland-pasture, with the adoption of some intensive practices such as tillage. The semi-extensive livestock landscape includes natural grasslands and pastures that can ensure an adequate stocking rate, if rationally managed by adopting practices such as grazing of crop residues and crop rotation systems like land fallowing. The extensive livestock landscape can have permanent pastures, bushland and woodland pastures.

2.1.3. Feeding behavior of herbivores and their impact on the livestock landscape

The evolution of the landscape over time depends on the different feeding behavior of ruminants. Sheep are *grazers,* with 90% of dry matter intake coming from herbaceous species, goats are *browsers*, with approximately 50% of the dry matter consumed being derived from woody species, and rustic cattle show an *intermediate* behavior, grazing both herbaceous and woody species (Van Soest, 1994).

The adaptation of different animal species to their morphological evolution processes are the basis of the relevant differences in feeding behavior among cattle, sheep and goats. The size of the animals is one of the main factors that can influence feeding behavior because it determines their nutritional requirements. Generally, if we consider the feed intake, ruminants of small size have higher energy requirements than large ones. This implies that small ruminants should be more selective to ingest feed of high quality compared to cattle, which belong to the category of large grazing herbivores (Hofmann, 1989). Differences in the aptitude of animal species for selecting the edible flora in the pasture is the basis of ruminant classification. Cattle and sheep are considered grazers of herbaceous species, whereas goats have an intermediate feeding behavior, showing a preference for shrub species (Hofmann, 1989). Goats are able to consume larger quantities of sprouts or fruits from shrubs compared to cattle and sheep, at varying quantities and composition, depending on the season. Under mixed pasture conditions with heterogeneous vegetation (i.e. presence of grass and shrubs), cattle and sheep tend to feed more on shrub species as the availability of herbaceous species decreases, whereas goats maintain a high shrub intake even when the availability of herbaceous species is high.

The feeding behavior of ruminants is influenced not only by plant species, but also by season. In fact, the phenological stage of the different plant species influences their composition and palatability, and consequently animal preference. The time dedicated to grazing is conditioned by the amount of herbaceous species available, which is higher in winter and spring under Mediterranean conditions. In winter and spring, goats employ 50-60% of the grazing time on grassy pastures, whereas in summer and autumn 75-80% of the grazing time is spent on shrubs and trees of the Mediterranean scrub (Decandia et al., 2008).

In the presence of mixed pasture, the distinct grazing behavior of different ruminant species influences the productivity and sustainability of pastoral systems. In fact, grazing animals show a high degree of overlap in feeding behavior, with a low level of complementarities corresponding to an increased competition for the same plant resources. Differently, when feeding behaviors are highly complementary, feed competition is reduced. Generically, the level of complementarities is low between cattle and horses, intermediate between cattle and sheep, and high between cattle and goats. Celaya et al. (2008) studied the preferences of grazing goats, sheep and cattle during several months and found a high level of feed overlap between sheep and cattle, and a high level of complementarities between these two species and goats. It is important to highlight that the complementarities of the feed behavior between different ruminant species is highly influenced by animal stocking rate and availability of pasture species. Beyond cattle, sheep and goats, Sardinian pastures also host a considerable number of horses. This monogastric species can utilize pasture essences with a considerable efficiency. Generally, the feeding behavior of horses is considered similar to some extent to that of cattle and goats, because they also show a preference for herbaceous fodder. However, horses are more selective than cattle, being able to have a diet with up to 85% of herbaceous plants, also when this type of vegetation represents a low percentage (5-6%) of the pasture.

2.2. Sardinia Livestock Landscape

2.2.1. Introduction

The Sardinian rural landscape is composed mainly of livestock landscape. The description of livestock landscape made by Le Lannou (1979) refers to "landscapes so ancient, biblical or Virgilian". These landscapes are similar to those described by Homer in the Odyssey. The same applies to Ithaca, Cyclops Island or the Trinacria, where *cattle of the Sun* grazed in the wild, and pastoral characters such as Polyphemus, Eumeo and Melanzio were present. These descriptive landscape elements, also common in the archaic and pastoral Mediterranean society of the Bronze Age, have been preserved and are highly present in the current Sardinian landscape.

Le Lannou (1979) recognized that the uniqueness of the Sardinia region is based on some fundamental elements such as insularity, geomorphologic characteristics, and "infidelity", which refers to the unfavorable weather conditions of the island, with arid summer and rain concentrated in autumn, typical of the Mediterranean climate. Furthermore, it is very important to understand that the "pastoral activity" is the principal anthropic process that has determined the identity of the Sardinian landscape. According to the anthropologist Giulio Angioni (1989), *the pastoral activity is not a job but a way of life*, thus confirming the Homeric character of the way of life and production system of the pastoral activity, tenaciously tied to a thousand-year-old tradition and marked by two deep changes: the *Editto delle chiudende*, written in the first-half of the XIX century, and the monopoly of the *Pecorino Romano* market, established in the first-half of the XX century.

A valuable characteristic of the Sardinian landscape is the *open field.* It derives from severe communitarian rules that probably trace back to the High Middle Ages, following an evolutionary process similar to the Nuragic period of the Middle and Late Bronze Age (Le Lannou, 1979). The most common scheme is the *vidazzone*, which indicates lands of collective property cultivated as follow land, with rotation of cereals (wheat or barley), legumes (in fertile areas) and pasture, according to the *Komunella* rule, including the surveillance and defense system controlled by the *compagnie barracellari* (Angioni, 1989), which are local and rural police typical of Sardinia.

With the exception of 4 areas (Nurra, Gallura, Sulcis and Sarrabus), Sardinian populations used to live in villages surrounded by vegetable gardens and fruit crops (grapevines, olive trees and almond trees). Besides the *vidazzone,* there was the *saltus*, interpreted more as *res nullius* rather than *res communis*, historically owned by Kings, lords or rich landowners, so that grazing was practiced mainly as slavery (*ademprivio*). *Saltus* is composed of forests, Mediterranean scrub or garrigue. A concentric structure that moves from a rural village in the center towards vegetable gardens and fruit crops, crossing the open fields of the *vidazzone* up to the extended lands of *saltus*, is the basis of the evolution and characterization of the livestock landscape in Sardinia.

Plant formations of *saltus* are very complex from a structural point of view. In fact, between the open field and the woods, there is an intermediate gradient of vegetation that goes from woodland pasture (Meriagos) to grazed woods, with the presence of clear areas and bush areas that are more or less wooded. In addition, landscapes that seem to be mostly natural such as the Supramonte are also part of the livestock landscape.

The geomorphology of Sardinia is characterized by an ancient and eroded eastern area, composed of granite, crystalline schist and Jurassic limestone. In this area, the unfavorable climatic and soil conditions and the remarkable reliefs, with irregular shapes, have favored an extensive and transhumant pastoralism that profoundly marked the lifestyle and character of the local population, which considers that *to exist means to resist* (Angioni, 1989). In contrast, the western sector of the island is mainly characterized by effusive, more erodible and recent rocks, with a prevalent horizontal morphology characterized by basaltic highlands (jars) and trachyte uplands, interrupted by vertical and mildly high rocks, which reduced the possibilities of moving around, thus contributing to the isolation of the population in different villages (Le Lannou, 1979). In this area, climatic and soil conditions are not optimal but are less problematic compared to the eastern area, and pastoral conditions are historically less extreme, being characterized by a short-distance transhumance (e.g. Goceano) or a prevalent sedentary livestock farming (Mannia, 2014).

Landscapes that are historically characterized by a typical rural scenery are those of the areas of Sassari, Logudoro, Marmilla and Trexenta, developed on limestone land and Miocene marl and favorable for cereal cultivation, and those of Campidano, formed in the Quaternary period. In these areas, the environmental and economic conditions have determined a more stratified social structure, as demonstrated by the urban structure of villages and houses, with a typical agricultural courtyard (Angioni, 1989). In addition, there are more stone walls to demarcate the boundaries of closed lands for exclusive use, characterized by the production of grains and sales of pasture to feed transhumant sheep moving from the mountains to the plains. Even today, a semi-intensive sheep breeding system, characterized by irrigated pastures, is practiced in these areas.

The conditions in the Sulcis and Iglesiente zones are similar to those of the eastern part of the island, whereas the Nurra differs from the nearby territory, because of the recent agrarian colonization characterized by *cuile*. The most recent livestock landscapes in Sardinia are those of the agrarian enhancement of Fertilia and Arborea. The latter is a typical case of intensive livestock landscape characterized by irrigated forage crops and a high number of intensive dairy cattle farms.

The landscape named *Meriagos*, i.e. woodland pasture, was defined and classified by Pulina (Pilla and Pulina, 2014). This type of vegetation constitutes a large part of the livestock landscape in Sardinia, covering approximately 110,000 hectares of the island. Meriagos is typical of the north-western of the Mediterranean area, being equivalent to the *Dehesas* in Spain, and the *Montados* in Portugal (Pereira and Pires da Fonseca, 2003). Meriagos are often associated with sheep grazing and naturally evolve into bushland when grazed predominantly by goats, or into woods when grazed mostly by cattle.

2.2.2. Estimation of stoking rate by the Livestock Index

To estimate the impact of livestock on the process of landscape shaping in Sardinia, Italian Statistical Institute (ISTAT) data on animal breeding in the island were collected website and analyzed. Data regarded the number of the main ruminant species (cattle, sheep and goats) raised in the different municipalities of Sardinia in 1930 and 2010. The Livestock Index estimated the animal stocking rate, expressed as number of animals/ha for each ruminant species and as Livestock Unit (LU)/ha for the sum of all ruminant species at a municipality level. This index evidences the level of occurrence and the influence of livestock activity on the characteristics of the landscape and the probability of encountering pastoral life in a territory.

Data were processed using QGIS, a user friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License, and thematic maps were obtained. The methodology applied required several steps. First, the files containing the polygons and the relative ISTAT code of each municipality, available from a database of the Minister of Environment of Italy (website of the National Geoportal), were intersected with ISTAT data on animal reared and the relative municipality code. Then, the polygons of the municipalities were converted into poly-lines, thus reducing the number of vertices by about 80% and simplifying the map images. A numerical value of livestock index was assigned to each vertex of the poly-line that represented the perimeter of a municipality. A triangular interpolation (TIN) was made to obtain a colored map, with a gradient of five colors that corresponded to different values of Livestock Index as follows: white (null), green (low), yellow (low-intermediate), red (intermediate-high), and blue (high).

The method of linear geometry described above allowed to give a weighted value proportional to the perimeter of each municipality. This method was adopted because it is considered more efficient in terms of legible information compared to the information obtained using only the polygon areas. If we had adopted the latter method, a simple mosaic would have been represented, with each single municipality being outlined only by its administrative boundaries. Therefore, it would have been impossible to interpolate the data of the area using the software. Consequently, it would have been necessary to assign the livestock index value to a geometric point represented by the barycenter of the polygon, without considering the weight of the municipality extension and without obtaining georeferenced data with a defined geographical significance.

2.2.3. A brief history of the Sardinia livestock landscape from 1930 to 2010

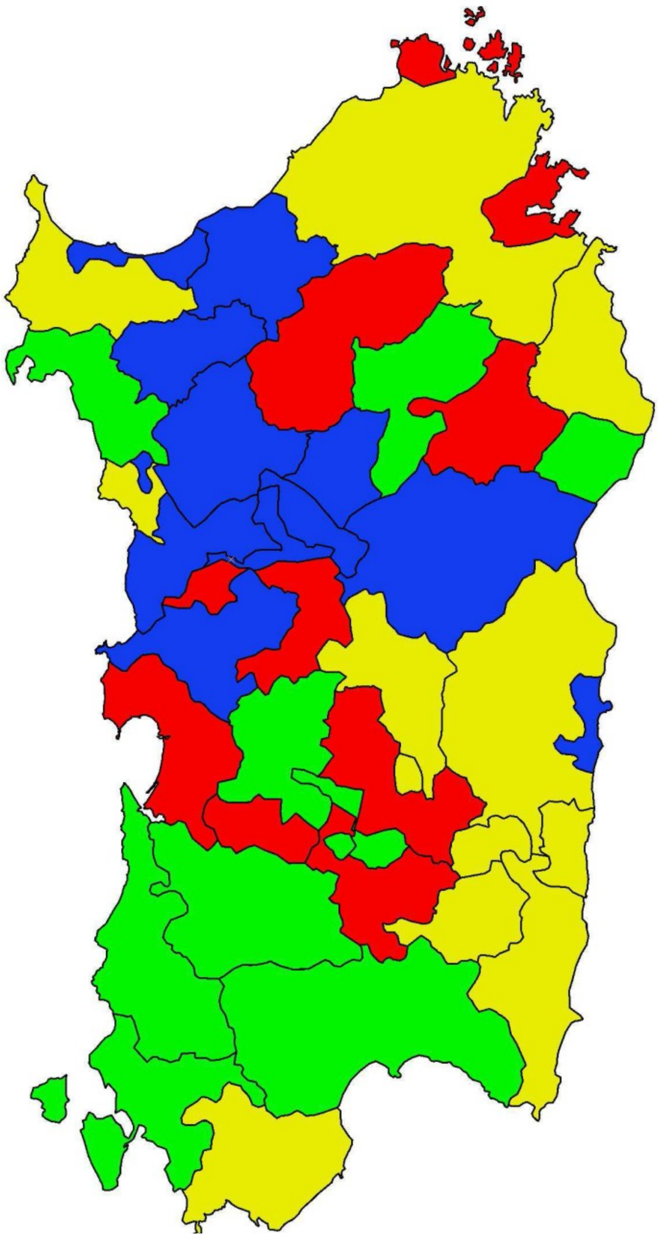
The historical, social and cultural evolution of the Sardinian people over the last 70 years has inevitably changed the landscape, revealing the strength of the relationship between humans and the territory in the past. Still today, the livestock landscape witnesses this relationship through typical architectural features that reveal an extraordinary presence of the past. Since the prehistoric period, pastoral activity was a major or the most important economic activity in Sardinia. In fact, in the first postwar period, this region was profoundly rural, with an agro-pastoral structure where sheep farming and agriculture were conducted using archaic methods. Agronomic practices such as tillage, seeding and harvesting were performed manually, fertilizers were not used and seeds were self-produced. Sheep parturition was seasonal, being concentrated in spring, and was associated with natural forage availability because no external feeds were used. Sheep were milked manually and milk transformation occurred inside simple structures called *pinnette* located near the milking site. Extensive farming systems were adopted and occupied predominantly hilly and mountainous areas. When pasture was not available or was not enough to satisfy the nutritional requirements of the livestock, shepherds moved (transhumance) with the sheep to better lands. Herbaceous and tree crops occupied approximately 30% of the territory, whereas forests occupied only 12.7%. Pastures accounted for approximately 50% of the agricultural surface, depending on the year and climatic conditions, particularly precipitation, in a region where drought had a strong influence on crop growth.

From 1930 to 2010, legislation supporting agriculture, ranging from the law de Marzi-Cipolla up to the Common Agricultural Policy (CAP), has significantly affected the agro-pastoral sector by changing the lifestyle of the population, which migrated from the mountains to the plains in search of better living conditions. Consequently, most livestock farms moved downhill, especially the sheep farms that moved down to the best areas of island once cultivated with cereals and became stable farming systems (i.e. intensive, semi-intensive or extensive). Therefore, the pastoral landscape was largely replaced by an agro-pastoral landscape in the best areas, and by a silvo-pastoral landscape in the worse areas of the island. Because of all these changes, the landscape scenario has evolved considerably as follows: i) fodder crops (meadows, artificial pastures, and cereals for animal feeding) have expanded throughout the island, contributing to the diversification of the landscape mosaic; ii) natural pastures have been subjected to a more rational utilization, with a consequent improvement in species composition; iii) the infrastructure utilized in the production system has been improved, such as livestock buildings for the recovery during the night, milking indoors and milk cooling systems; and iii) the mechanization of farming operations allowed to cultivate lands that otherwise could not be easily cultivated, sometimes causing negative effects on soil resources. Forest has (re)conquered areas once used for animal grazing, reaching a surface of about 40% of the land (ingression of the forest). Livestock farms occupy about 40% of the Sardinian territory, thus subtracting land from cereal cultivation, which in turn has been drastically decreased from 10% to only 2% of the regional surface. Therefore, Sardinia has become the region with the second largest forest area in Italy (National Forest Inventory), showing an increase in wooded area from 13% in 1950 to 52% in 2010 (Pulina et al., 2015).

Livestock landscape has assumed different connotations in the intensive and specialized farming systems with dairy cattle in the area of Arborea and with dairy sheep and goats in the lower Campidano and Nurra. Those areas are characterized by the following: i) well-structured farm buildings with annexed stalls, adequate place for milking and milk storage; ii) irrigated fields and modern mechanical machines that allow for increased productions, and unseasonal seeding and harvesting of forage; iii) livestock feeding based not only on natural pasture, but also on irrigated arable land and external feeds; iv) modern irrigation systems like PIVOT and farm enclosures made of metal net or waste materials, totally or partially replacing the old stone walls and often being in contrast with the surrounding landscape. In brief, in those areas the livestock landscape has gained a connotation of intensification, and natural pasture has been replaced by sowed and/or irrigated lands.

The comparison of ruminant breeding in Sardinia, on the basis of the livestock index (heads/ha), between 1930 and 2010 was illustrated in maps for sheep (Figures 2.1 and 2.2), goats (Figures 2.3 and 2.4) and cattle (Figures 2.5 and 2.6). The total livestock index (LU/ha), as a sum of the three species, in 1930 and 2010 in the island is shown in Figures 2.7 and 2.8. This comparative analysis evidenced the changes in livestock activities that affected the Sardinia agro-pastoral sector during the strong revolutions of the postwar period compared to the current period. Sheep farming in Sardinia had an increase in the average stocking rate, from 1 to 1.3 heads/ha, being concentrated in the hilly areas of the central and north-west zones, but also extending towards the Campidano area (Figures 2.1 and 2.2). Goat farming greatly decreased, passing from an average stocking rate of 0.13 to 0.02 heads/ha, being maintained in the mountainous areas of southern Gennargentu, Sarrabus and Iglesiente, and being abandoned in Gallura and in the northern part of Gennargentu (Figures 2.3 and 2.4). Cattle almost halved, passing from 0.1 to 0.06 heads/ha, disappearing from the mountainous areas, except for those of Gallura (Figures 2.5 and 2.6). However, because of the dominance of sheep over the other species, only a slight reduction occurred in average stocking rate, passing from 0.273 to 0.265 LU/ha. This confirms that over the last 80 years the livestock sector in Sardinia has become more specialized on dairy sheep, which is the typical species of the Sardinia livestock landscape.

SARDINIA 1930



1:1.500.000

Livestock Index (heads/ha)

	0.160-0.675	Low
	0.675-0.962	Low-Intermediate
	0.962-1.270	Intermediate-High
	1.270-2.209	High

Figure 2.1. Livestock Index (heads/ha) for sheep in Sardinia in 1930.

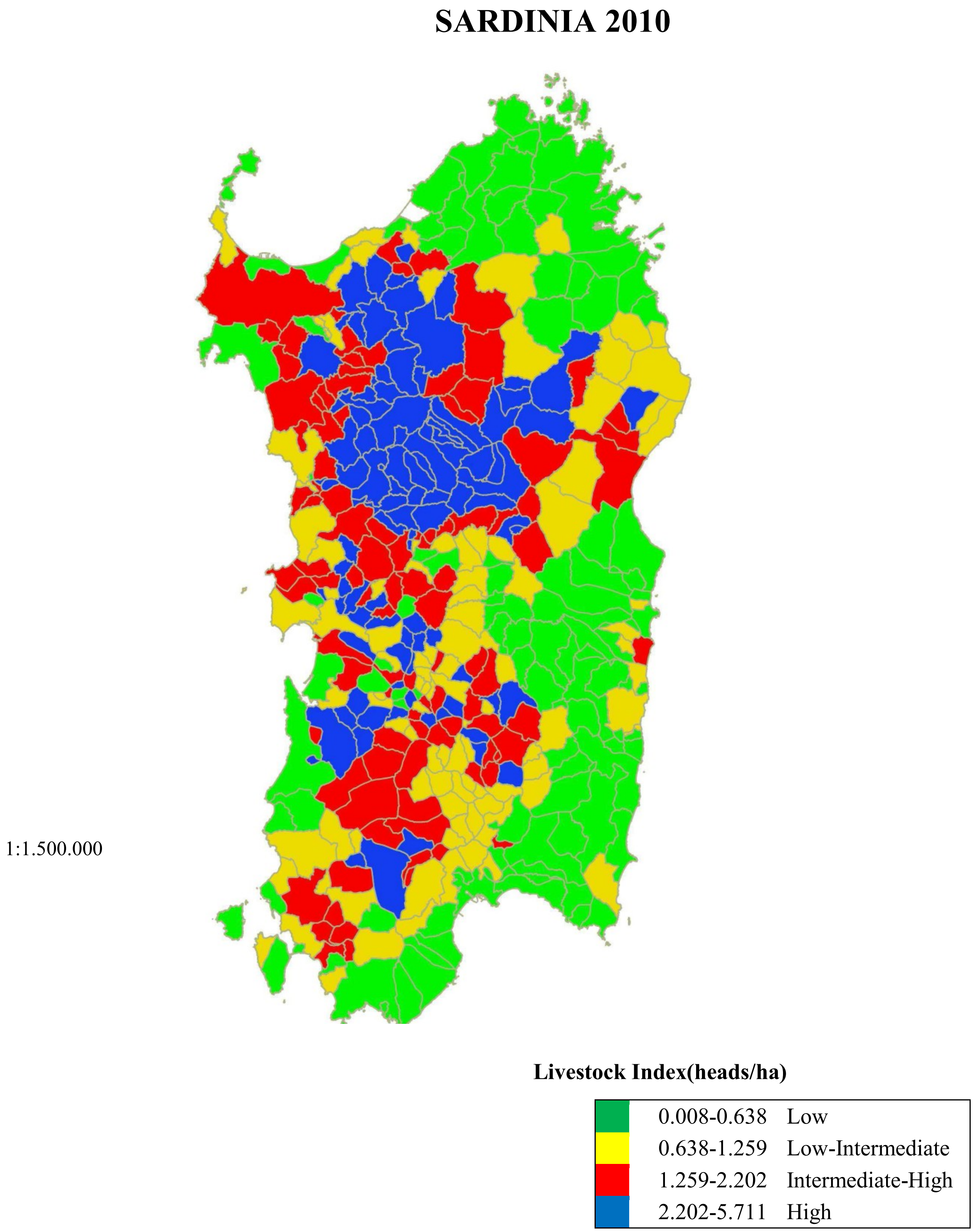
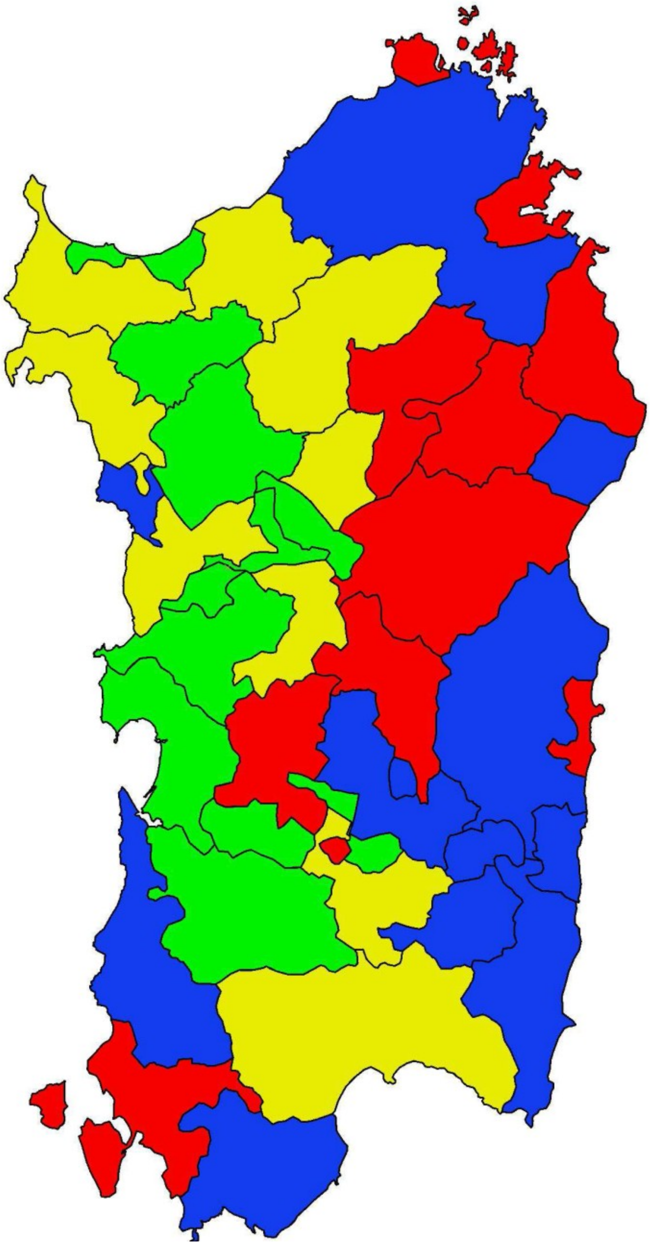


Figure 2.2. Livestock Index (heads/ha) for sheep in Sardinia in 2010.

SARDINIA 1930



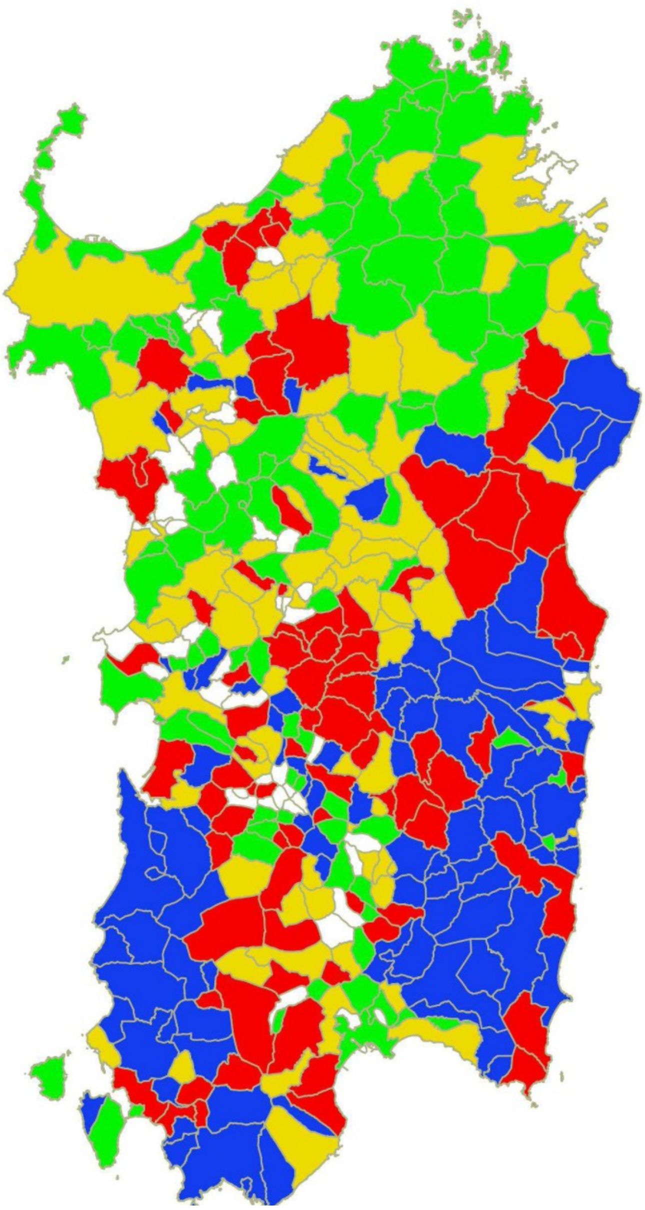
1:1.500.000

Livestock Index (heads/ha)

	0.003-0.070	Low
	0.070-0.131	Low-Intermediate
	0.131-0.234	Intermediate-High
	0.234-0.435	High

Figure 2.3. Livestock Index (heads/ha) for goats in Sardinia in 1930.

SARDINIA 2010



1:1.500.000

Livestock Index (heads/ha)

(green)	0.000-0.002	Low
(yellow)	0.023-0.064	Low-Intermediate
(red)	0.064-0.145	Intermediate-High
(blue)	0.145-1.012	High

Figure 2.4. Livestock Index (heads/ha) for goats in Sardinia in 2010.

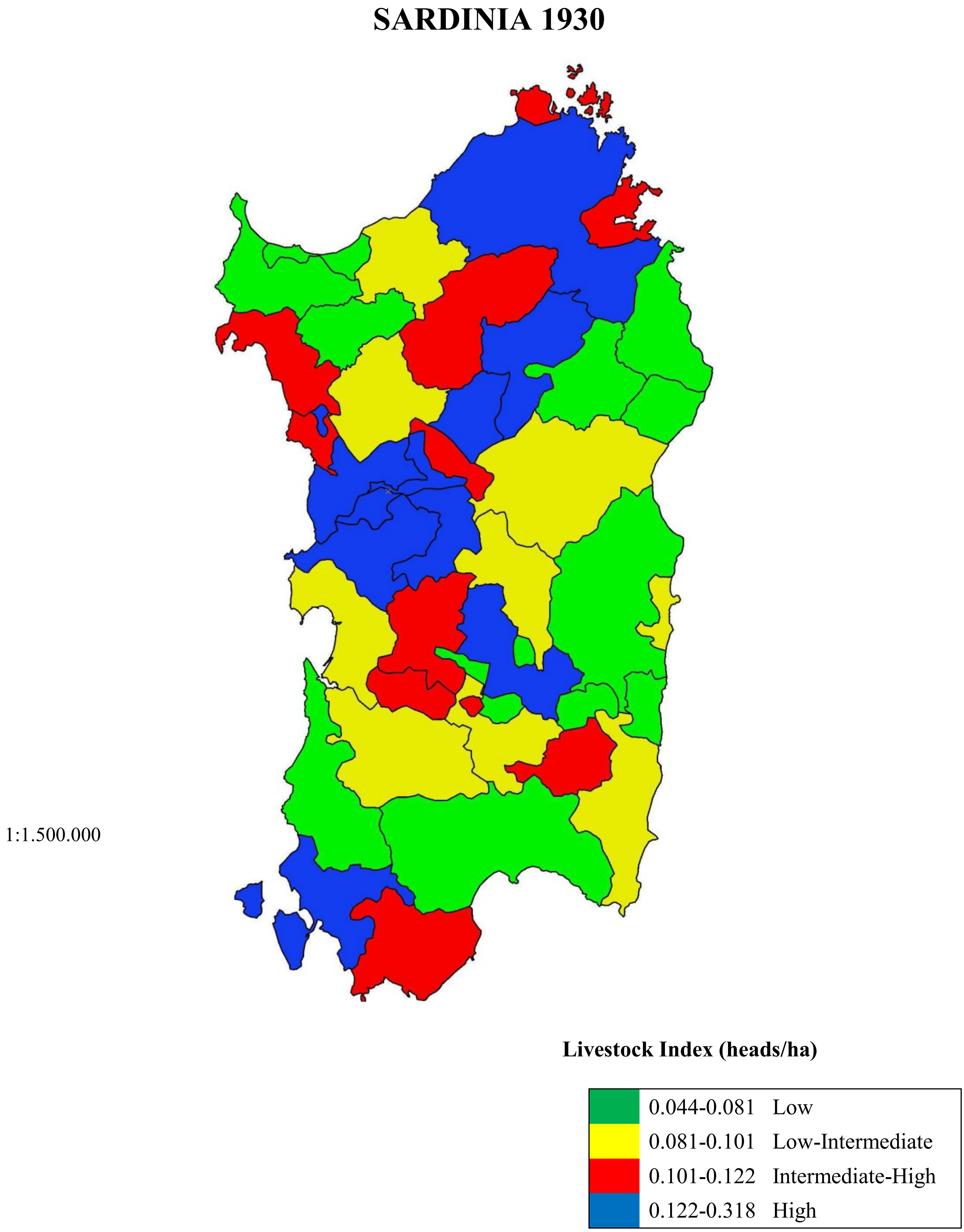


Figure 2.5. Livestock Index (heads/ha) for cattle in Sardinia in 1930.

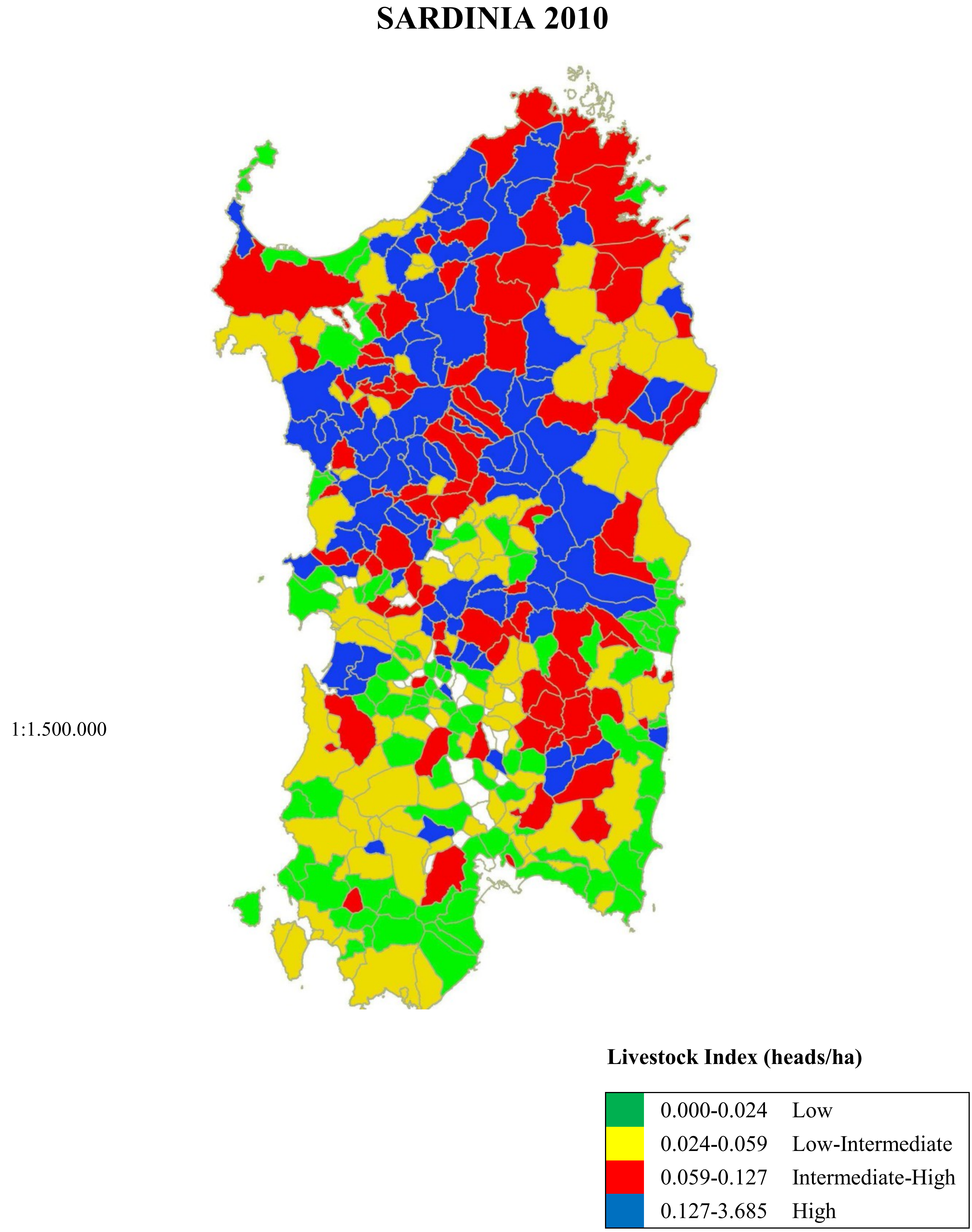


Figure 2.6. Livestock Index for cattle (heads/ha) in 2010 in Sardinia.

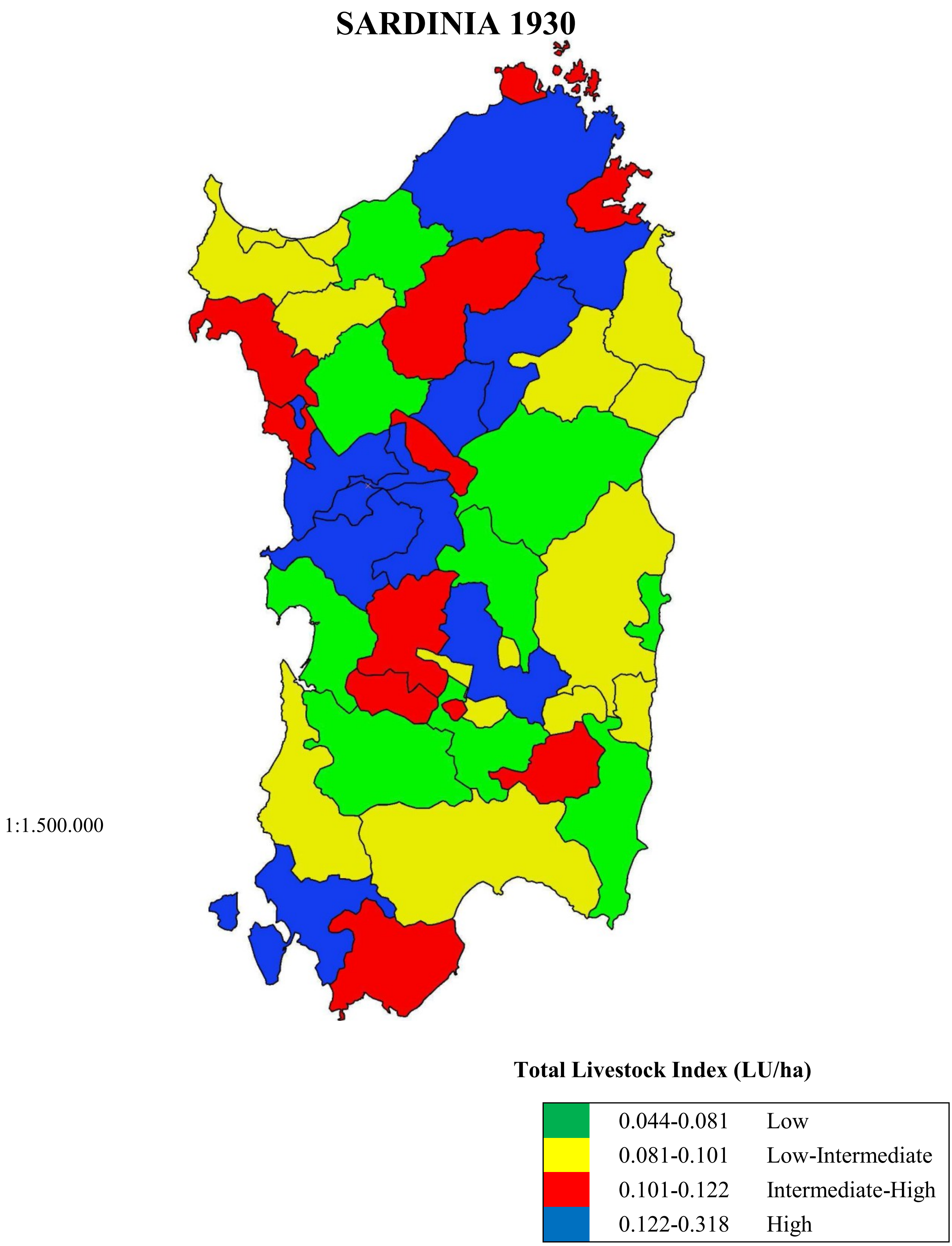
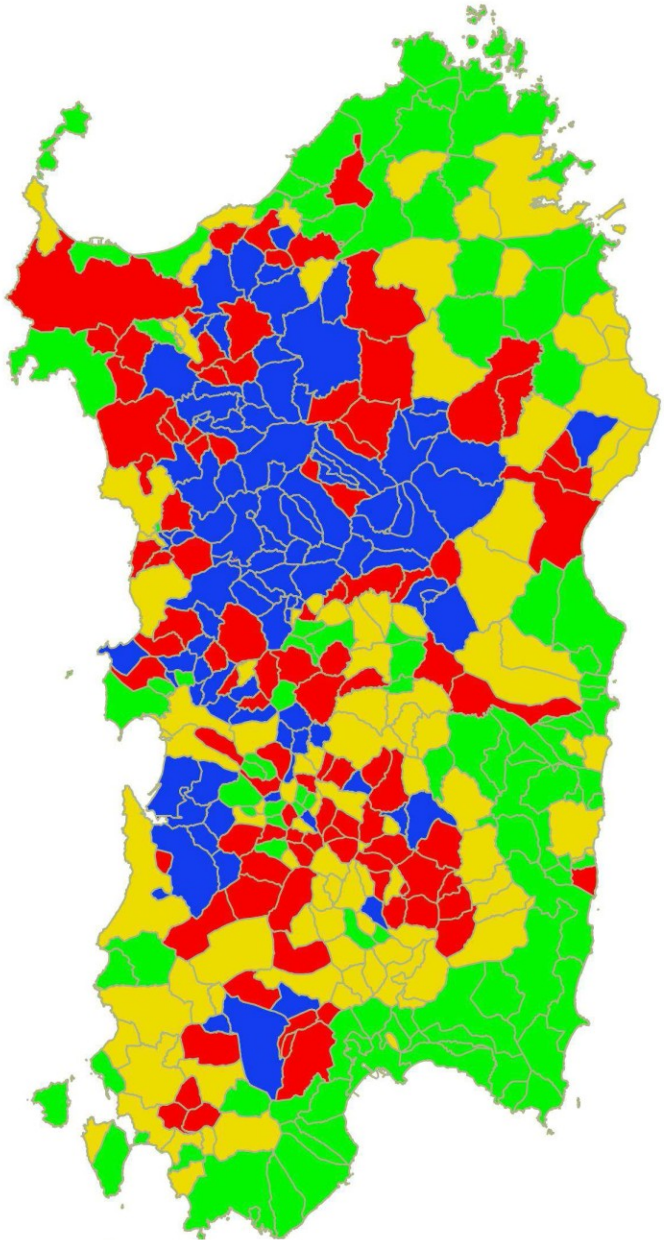


Figure 2.7. Total Livestock Index (Livestock Unit/ha) for cattle, sheep and goats in Sardinia in 1930 .

SARDINIA 2010



1:1.500.000

Total Livestock Index (LU/ha)

	0.002-0.151	Low
	0.151-0.265	Low-Intermediate
	0.265-0.436	Intermediate-High
	0.436-2.848	High

Figure 2.8. Total Livestock Index (Livestock Units/ha) for cattle, sheep and goats in Sardinia in 2010.

2.3. Livestock landscape sustainability

2.3.1. Introduction

Livestock landscape can be preserved and protected by adopting correct landscape management plans that take into consideration good grazing practices and sustainable livestock stocking rate. If these conditions are not respected, the productive, aesthetic and ecological values of the landscape inevitably decrease. Livestock sustainability in Sardinia was assessed by the CAIA (*Carico Animale di Impatto Ambientale - Environmental Impact by Livestock Stocking Rate*) Index (Pulina et al., 1998a) using an innovative method developed successively by INTREGA s.r.l. (2009) (spin-off ENEA). Data of livestock sustainability reported herein were collected and processed by INTREGA and have been utilized with full permission of the authors and of the Sardinia Region, Division of Agriculture and Agro-Pastoral Reform, which has the copyright of the study. The CAIA2 methodology used in the study performed by INTREGA is reported here in full for a better understanding of the implementation of this method in the study of livestock landscape sustainability. For applicative purposes, relating to the research project "Rural landscape of Sardinia", commissioned by the Sardinia Region for the Regional Landscape Plan (RLP), CAIA2 data and the map of the Sardinia Rural Landscape were intersected in GIS to determine the livestock landscape sustainability of the Asinara Gulf and the Meilogu area. In the future, this application of CAIA2 data and the map of the Sardinia Rural Landscape could be extended to the whole territory of Sardinia. The original model CAIA and its application CAIA2 are described in detail in the following section.

2.3.2. CAIA model and CAIA2 model

In the study of livestock sustainability in Sardinia, grazing intensity was evaluated using the CAIA2 model, which derives from the CAIA model of Pulina and Zucca (1999) and differs mainly for the units of measurement of output. The CAIA model had already been used in studies on livestock grazing impact on a regional scale with results being expressed in a specific unit named *Unità Animali di Impatto Ambientale* (UAIA) that can be translated as *Livestock Unit of Environmental Impact*. However, these results are now difficult to be interpreted for practical purposes, because the animal unit used as reference, the *Capo Grosso Convenzionale* (CGC = bovine head equivalent = 1 bovine, 1 horse, 5 pigs, 10 sheep/goats), has been subsequently replaced by the European Union with Livestock Units (LU), which refer to animal categories on the basis of age rather than weight.

For this reason, in the INTREGA study the CGC unit was replaced with the LU, which was used in the calculations for the development of the new software CAIA2.

When applied on a territory scale, the CAIA and CAIA2 models are integrated with a model of grazing aptitude (Madrau et al., 1998), in order to relate the various grazing activities to the degradation of the territory. Through this integration the influence of grazing animals on soil degradation, vegetation and desertification can be evaluated. This can be done by taking into account the following: i) soil trampling by the single grazing species; ii) impact of grazing species with different feeding behavior on the vegetation; iii) animal production level; iv) farm management; v) suitability of the soil for supporting the presence of grazing animals.

The different feeding behavior of each animal species leads to a different impact on the soil, because soil trampling is correlated not only to body mass but also to how the animal searches for feed. Feeding behavior also influences the vegetation, with sheep grazing almost exclusively herbaceous plants and, to a small extent, small bushes, which instead are normally grazed by goats and rustic cattle. In addition, it is necessary to consider the indirect effects of farmer on soil and vegetation such as the activities done for the cultivation of herbaceous plants (tillage or fire), in order to satisfy the specific feed preferences and requirements of the animal species raised. The production level of the animals should be considered because more productive animals require a higher amount and quality of fodder available. This issue is particularly relevant in lactating animals, whose feed intake can be twice as high as that of non-lactating animals and whose feed ration should have an increased nutrient concentration. The soil aptitude for grazing should be determined by evaluating the quality or vulnerability of the area as a function of factors such as steepness, exposure of slope and soil characteristics.

In the CAIA or CAIA2 model, every action related to the grazing activity and the management system of a livestock farm is identified by sub-coefficients which are summed up to determine the b coefficient, which represents a weighting factor of body weight X of the Livestock Unit (LU) present on a territory with surface S (Pulina et al., 1998b).

Assuming that the minimal impact of an animal species is equivalent to a b coefficient equals to 1, the b coefficient weighs the body weight of a LU according to the following equation:

bweights = ba + bb + bc + bd

where:

ba is related to soil trampling, considering that the specific foot pressure is 1 kg/cm^2 for cattle and 0.5 kg/cm^2 for small ruminants (Pulina et al., 1995), with the difference that sheep tend to graze in groups and goats do not; **bb** regards the impact of the grazing animal on vegetation, being higher for goats than for cattle and sheep, due to the selective pressure that goats exert on shoots of woody plants; **bc** is related to animal productivity, considering that a higher milk production is associated with greater selectivity and a higher intake per unit of body weight in sheep and goats; and **bd** is related to farm management, such as forage surfaces, pasture cultivation, fire use to clear the land for the cultivation of herbaceous plants, management of grazing animals on pasture, distribution of watering points, and feeding system that permitted to break free from the relationship, fodder production and sustainable stocking rate.

On the basis of these elements, the grazing intensity actually present on the territory (named as Actual CAIA2) can be determined by using matrices for a dataset of k data as follows:

$$\textbf{Actual CAIA2} = (X \times B \times b)/S$$

where:

X is the line vector of dimension (1, k), whose values indicate the number of LU for the different species present in each geographical area; **B** is the matrix of dimensions (k, 20) of 20 sub-coefficients bweights (ba, bb, bc, bd); **b** is the column vector of dimension (20, 1) of the 20 sub-coefficients; and **S** is the total reference surface (in hectares). The evaluation of the soil aptitude for grazing in the CAIA2 model is done by using the model to evaluate the soil aptitude for pasture improvement in Sardinia (Madrau et al., 1998). This is an application of the "Framework for Land Evaluation" (FAO, 1976) and the subsequent "Guidelines: Land Evaluation for Extensive Grazing" (FAO, 1988) to the peculiarities of the Sardinian territory and its pastures.

Because of the large variability of pastures in Sardinia, soil aptitude for grazing is evaluated by identifying the different landscape units present on the island, in order to include climate and vegetation among the considered attributes of the territory. The most common types of soil profile are also considered. Then, on the basis of an evaluation scheme, the results obtained by the model to each landscape analyzed are attributed to one of the 5 classes of grazing classification predicted by the model. In fact, the FAO Framework and related methodologies provide a multiple-level assessment of the aptitude, depending on the amount of information available or the desired level of detail. The five distinct classes (S_1, S_2, S_3, N_1, N_2) identify soil aptitude for grazing, the first three classes (S_1, S_2, S_3) identify, in decreasing order, suitable areas for grazing activities and/or pasture improvement, whereas the last two classes (N_1, N_2) indicate unsuitable areas for grazing and/or pasture improvement, in decreasing order.

The model structure includes a set of information on factors that can influence pasture management, conservation and composition (Baldaccini and Vacca, 2006). This is a parametric model that runs in GIS software and is organized in classes with relative scores. Therefore, to each factor described below, it is necessary to define different allocation classes with relative scores whose value increases as the negative effect of the factor increases.

The factors considered are listed and briefly described below:

- Altitude, which influences soil temperature and, together with air temperature, affects the growth of fodder plants and the possibility of exploring the pasture area;

- Declivity, which imposes a physical limit to mechanization and contributes to increased erosion (e.g. by grazing paths);

- Exposure, which influences substantially the amount of heat that reaches the soil, with consequent daily and seasonal changes in air and soil temperature compared to the average temperature in the area, thus affecting the phenology of edible species;

- Vegetation cover, which contributes to soil protection from rainfall and grazing action;

- Surface rocks and stones, which reduce the arable surface and normal plant growth;

- Drainage, which is related to the presence or absence of free water in the soil or on soil surface, and if poor leads to the presence of water in excess long enough to negatively damage crops, modify the pasture flora and impede the use of agricultural machines and grazing activity;

- Soil depth, which is deeply influenced by the nature of the material of origin, and if substantial (deep soil) ensures a higher presence of vegetation cover, due to a greater root development and larger water reserves, thus ensuring a better resistance to erosion and desertification and in the long term (Pittalis, 2002);

- Texture, which influences directly or indirectly many physical properties of the soil (e.g. plasticity, adhesion, drainage and porosity) that can, in turn, affect positively or negatively the use of pasture;

- Available water capacity (AWC), which indicates the effective amount of water available for crops.

Soil sustainability for grazing activity (Sustainable CAIA) is determined by defining the five classes provided by the sustainability model, through the sum of factors performed, by overlaying maps and doing subsequent reclassifications, using the GIS system.

The final evaluation of grazing intensity (CAIA2) consists of the ratio between the grazing stocking rate actually present on the territory (Actual CAIA2) and the grazing stocking rate that could be potentially supported (Sustainable CAIA2). Through their standardization, it is possible to define the grazing intensity index by identifying variable values that ranges between 0 (areas not affected by overgrazing) and 1.5 (areas affected by overgrazing). The determination of the Actual CAIA2/Sustainable CAIA2 ratio and the subsequent reclassification are performed using the *overlay mapping* function of GIS.

Actual CAIA2

The input data and the unit of measures utilized in the ActualCAIA2 model are shown in Table 2.2 and are useful for identifying the livestock number, production level, management system, dimension and geographical location of the farm.

Table 2.2. Unit of measures of input data of the Actual CAIA2 model

Input Data	Unit
Number of sheep, goats and cattle	Numerical values
Farm location	X,Y
Production level of each species	Text from 1 to 2 characters
Breeding management of each species	Text with 1 character
Farming area	Hectares

The Actual CAIA2 can be calculated for a data set of k numbers, where k is the total number of lines of information related to a single animal species and to the entity with available information (i.e. the farm), by using the following relationship expressed in matrix form:

Actual CAIA2 = $(X \times B \times b)/S$

where:

X is the line vector of dimension (1, k) and indicates the number of LU for the different species present in each geographical area, **B** is the matrix of dimensions (k, 20) of 20 sub-coefficients bweights (ba, bb, bc, bd), **b** is the column vector of dimension (20, 1) of the 20 sub-coefficients; and **S** is the total reference surface (in hectares).

The matrix calculation of ActualCAIA2 for different farms is done automatically by a specific script that uses the Visual Basic language and ArcObject for the implementation of the model in GIS. Data input processing occurs spatially in correspondence with the grazing surface of each farm. Below is reported the processing method performed by the script for each component of ActualCAIA2:

X = number of animals × conversion index

where:

X is the line vector of dimension (1, k), whose values indicate the LU of the different species present on a determined farm and geographical area obtained by multiplying the number of animals of a single species on a single farm by the conversion index reported in Table 2.3.

b = Weighting factor of body weight
where **b** is a vector column of dimension (20,1) of the 20 sub-coefficients that, once calibrated, can be considered a constant of the system for weighting the LUs.
After using LU as Animal Unit, the b coefficients used in the CAIA software are changed in order to consider the peculiarities of the grazing species, by expressing the results in a new reference unit, also in the updated version, named CAIA2.

Table 2.3. Index of conversion of animal number to Livestock Unit (LU).

Animal species	Conversion index
Cattle older than 2 years	1.0
Cattle younger than 2 years or being 2 years old	0.6
Sheep	0.15
Goats	0.15

Considering that sheep have a conversion index of 0.15, 1 LU is equivalent to 6.7 goats or sheep. By comparing this value with the reference animal, an adult cattle of 500 kg weight (corresponding to 1 LU), it results that one sheep or goat should weigh about 75 kg (calculated by dividing 500 by 6.7). However, applying the conversion into LU described above would result in a sheep weight about 1.5 times higher than the actual weight of the Sarda breed (75 kg vs. 48 kg). This aspect has been taken into account when allocating coefficients for the matrix calculation in the CAIA2 model, by modifying the values of the CAIA model reported in literature, on the basis of the following considerations regarding the different sub-coefficients (Table 2.4):

- ba (soil trampling): 1 LU corresponds to fewer sheep and goats compared to 1 CGC (*Capo Grosso Convenzionale*, used as measurement unit in the traditional CAIA model), amounting to 6.7 animals compared to the 10 animals considered in the CAIA calculation. Therefore, the sub-coefficients relative to soil trampling were modified from 0.3 to 0.2 for sheep and from 0.2 to 0.13 for goats, because of the lower number of sheep and goats present in 1 LU. In this way, the GIS software takes into account the smaller trampling caused by a lower animal number. The sub-coefficients relative to cattle were not changed because the CGC and LU can be considered equivalent. The only distinction made in the class of cattle in CAIA2 was the division into 2 groups: one group with animals older than 2 years and the other with animals younger than 2 years, as reported in the LU coding (Table 2.3).

- bb (feed selection)**:** Many studies have shown that larger animals (e.g. cattle) select fewer plants during grazing compared to smaller animals (e.g. sheep and goats). This is because of the different digestive capacity of ruminants, which allow bigger animals to digest more fibrous feed, thus being less selective about what they eat (Van Soest, 1994). Furthermore, larger animals have more difficulty in selecting feed, because of the larger size of their oral apparatus (Van Soest, 1994). In order to take into account different feeding behaviors, the feed selection coefficient used for cattle was modified, becoming lower than that used for sheep and goats.

- bc (production level): Being production level equal, animals with larger size have a lower ingestion level than smaller animals (Cannas et al., 2007a), because energy requirements for maintenance are not proportional to body weight (BW) but to metabolic weight (MW), i.e. MW = BW × 0.75. Therefore, smaller animals must ingest, proportionally, a greater amount of energy than larger ones (Cannas et al., 2007b). In the CAIA2 model, the sub-coefficient correlated to the production level of the animals was modified and adapted to cattle, being lower than that used for the smaller ruminant species (sheep and goats).

- **bd** (breeding characteristics)**:** The calculations performed by the CAIA model refer to extensive Sardinian farms, where pasture is the main feed source. However, currently the regional livestock scenery has changed noticeably, being characterized mainly by highly productive livestock, large use of concentrates, and reduced grazing on pasture. Intensive breeding conditions are predominantly indoors, with a smaller utilization of the territory. For this reason, this sub-coefficient was reduced and modified according to animal species and breeding conditions.

The impact parameters described are considered valid for all Sardinian farms, except for the irrigated areas, which are based on specialized fodder production, with infrequent grazing on fresh

forage. In these areas animals graze at most on the stubbles that remain after threshing. Because this type of grazing is minimally invasive, the considered parameters do not assume a relevant value.
The study conducted by INTREGA s.r.l. (2009) led to the production of several maps which illustrate on a regional level the values of Actual CAIA2 (Figure 2.9), Sustainable CAIA2 (Figure 2.10), and Final CAIA2, derived from the ratio between the Actual CAIA2 and the Sustainable CAIA2 (Figure 2.11). In addition, a comparison made between the sustainable stocking rate and the actual stocking rate for the different historical geographic regions of Sardinia (Figure 2.12) shows a first index of sustainability of livestock landscapes in Sardinia, expressed as LU.

Table 2.4. Values of sub-coefficients to calculate the b coefficient in CAIA 2 model.

Animal species	ba	bb	bc		Production level	bd		Type of breeding
Cattle	0.6	0.4	bc1	0	Rustic	bd1	0	Extensive
			bc2	0.2	Crossbreed	bd2	0.2	Semi-extensive
Sheep	0.2	0.2	bc1	0.13	Low	bd1	0.13	Extensive
			bc2	0.27	Intermediate	bd2	0.40	Semi-extensive
			bc3	0.40	High			
Goats	0.13	0.4	bc1	0.13	Low	bd1	0	Extensive
			bc2	0.27	Intermediate	bd2	0.13	Semi-extensive
			bc3	0.4	High			

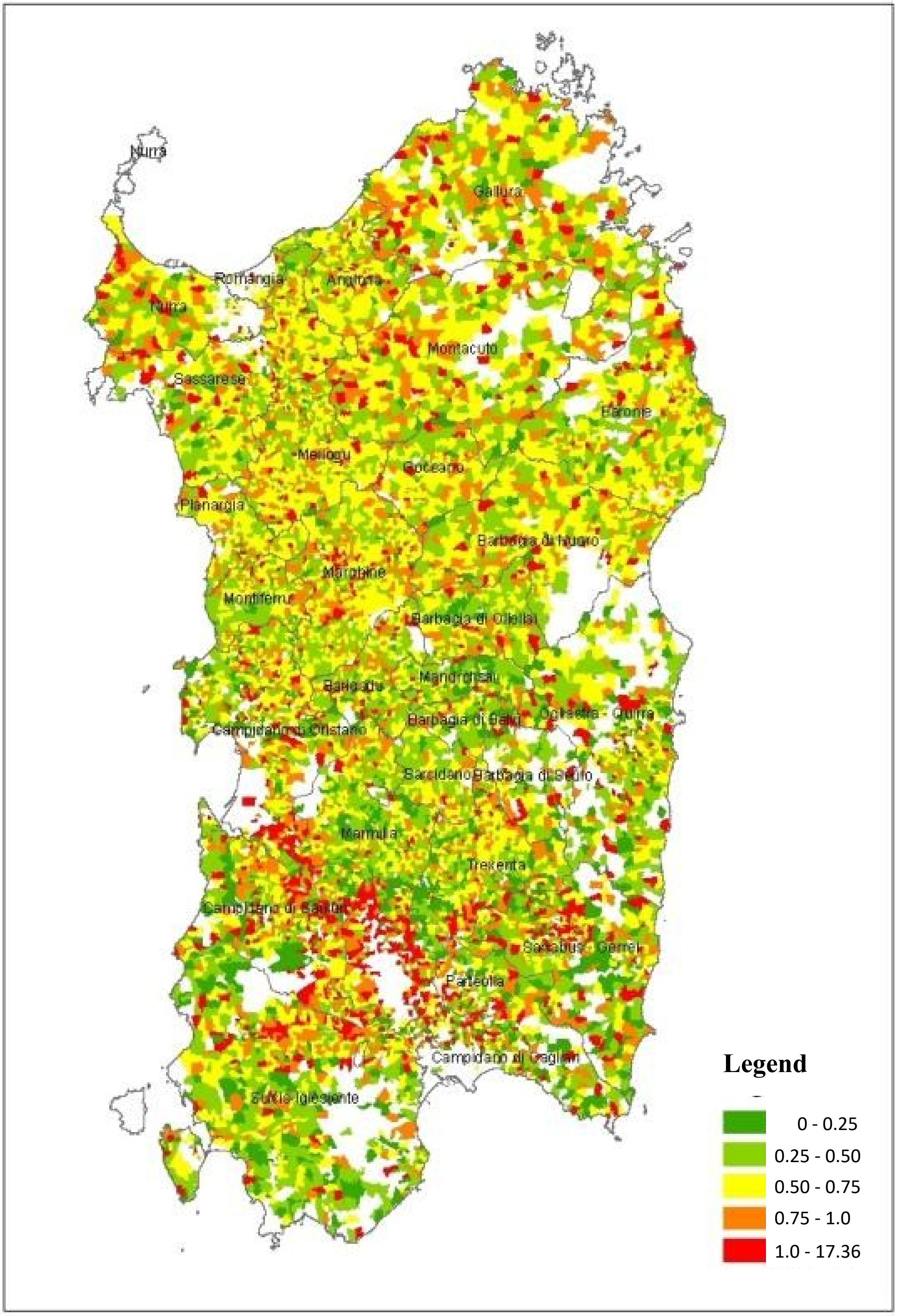


Figure 2.9. Map of Actual CAIA2 Index (INTREGA s.r.l., 2009).

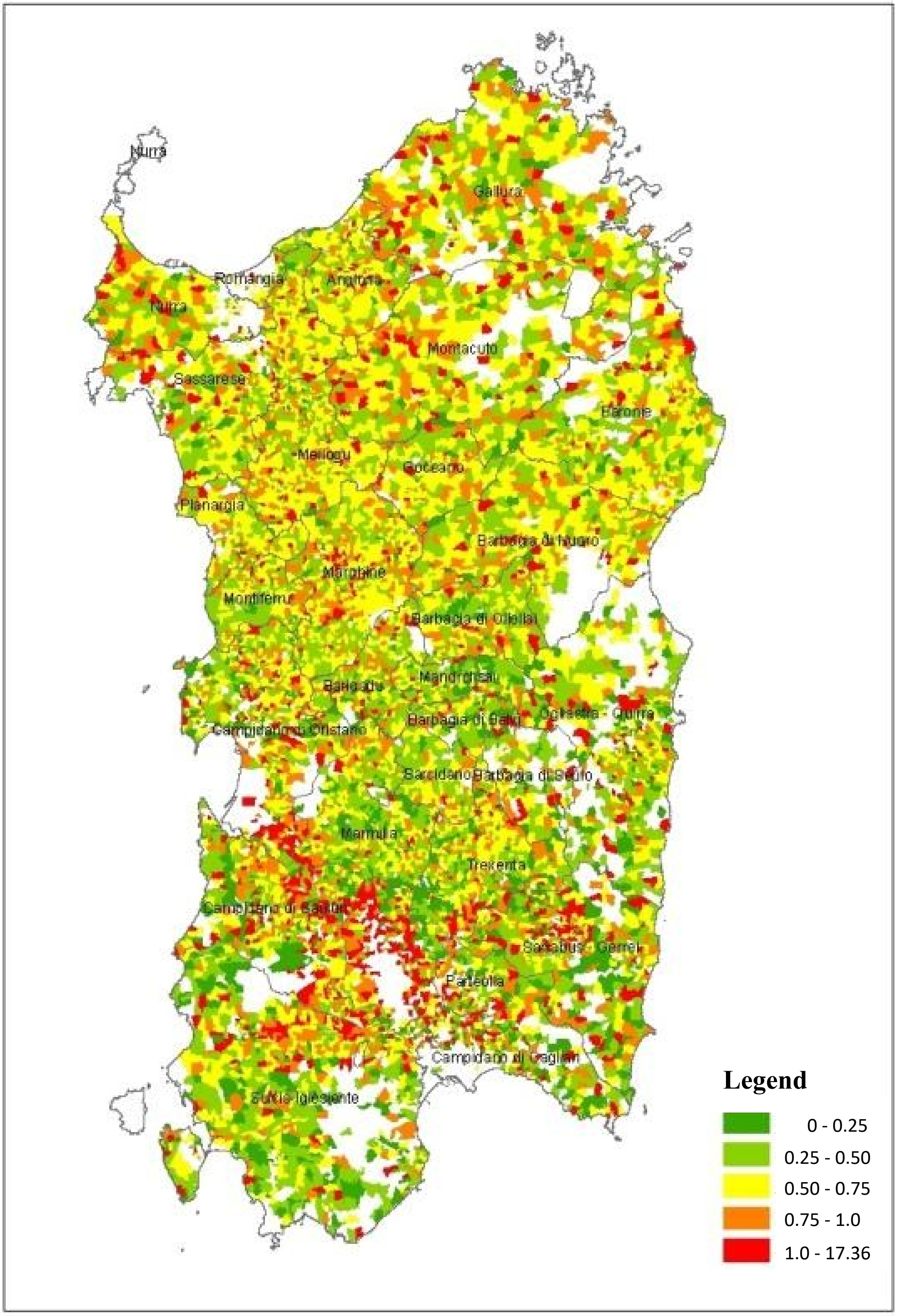


Figure 2.10. Map of Sustainable CAIA2 Index (INTREGA s.r.l., 2009).

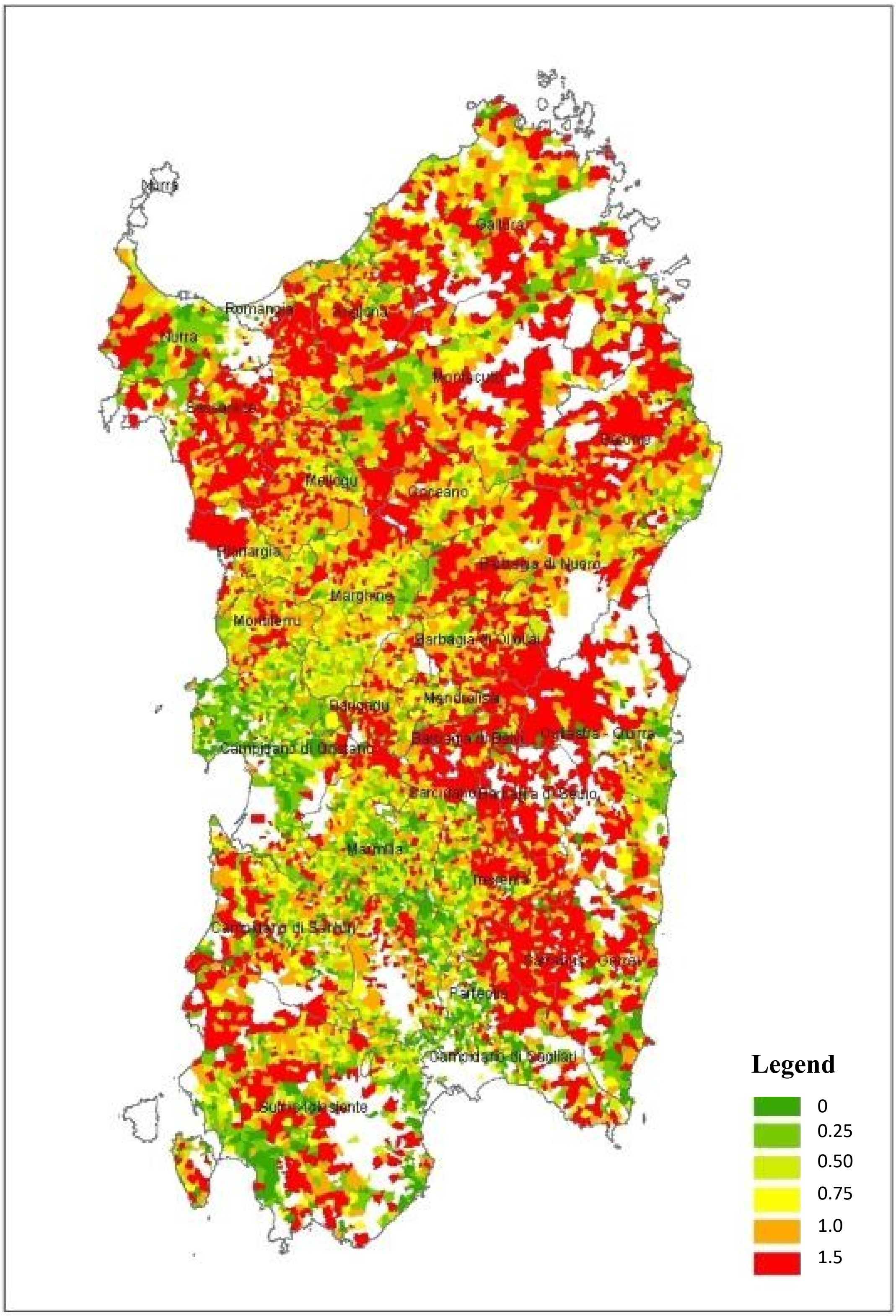


Figure 2.11. Map of Final CAIA2 Index (INTREGA s.r.l, 2009).

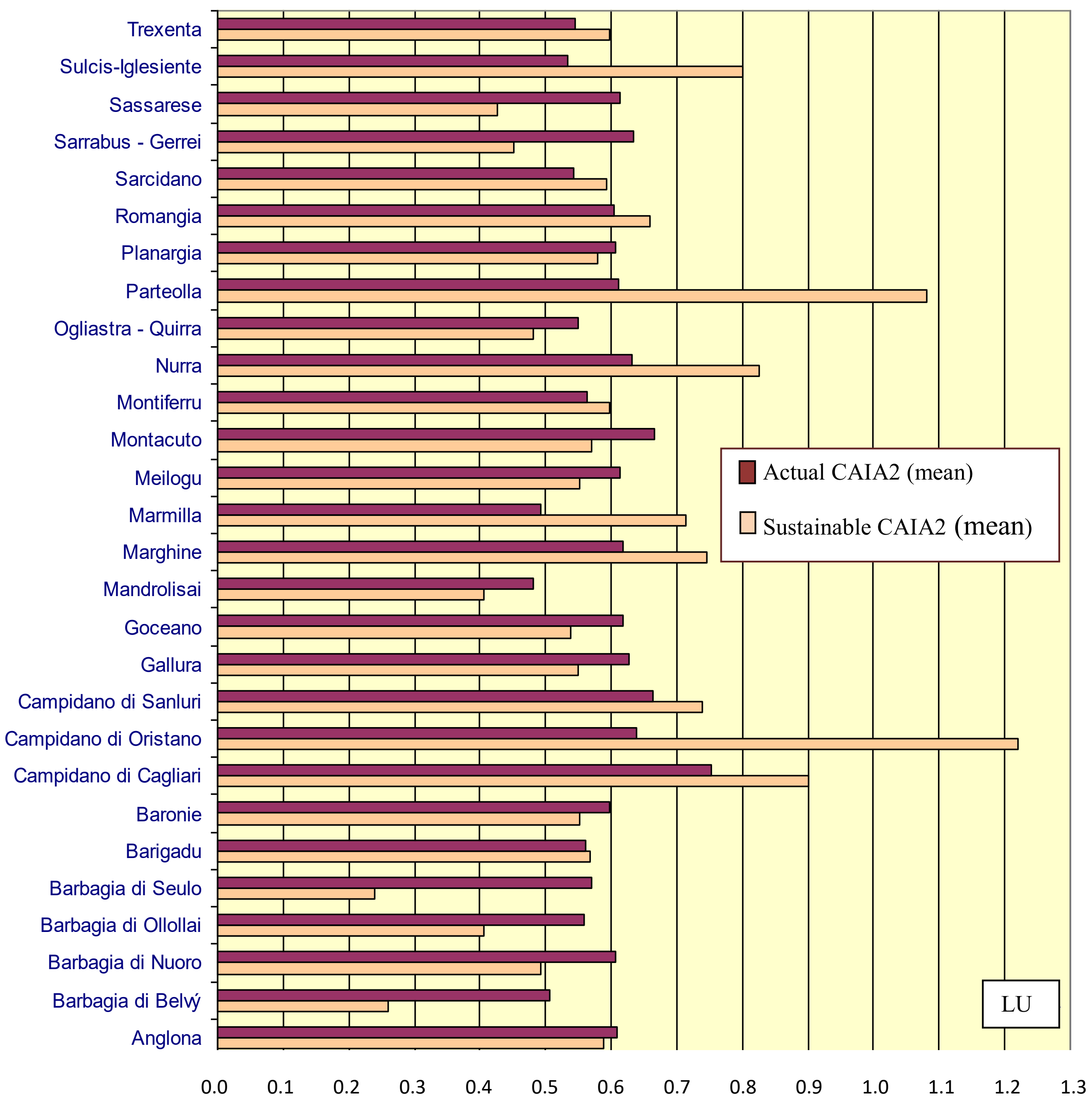


Figure 2.12. Comparison between Actual CAIA2 and Sustainable CAIA2, expressed as Livestock Unit (LU), for each historic area of Sardinia (INTREGA s.r.l., 2009).

2.4. CAIA2 model and livestock landscape sustainability – Analysis of two landscape areas of interest of the Regional Landscape Plan (RLP)

In order to give an example of the application of the CAIA2 model to the Sardinian Rural Landscape, thematic maps of *Livestock Sustainability Indices* were made for two areas: Asinara Gulf and Meilogu (Figure 2.13). Maps were obtained by overlaying the CAT. I and CAT. II classes of the landscape from the Map of Rural Landscape of Sardinia with the relative values of the CAIA2 model, using the Geoprocessing intersect of GIS. In particular, an intersect was made between the two types of data and a subsequent operation called dissolve was conducted to match adjacent map sheets with the same index of grazing impact.

The derived information, visible on the table of attributes in GIS, allowed us to quantify the surface (expressed in hectares) affected by different levels of grazing impact and to present the results in thematic maps (Figures 2.14, 2.15, 2.16, 2.17). The Landscape identified as CAT.I (Figures 2.14 and 2.16) shows a first general classification of the landscape into two main categories: rural landscape and non-rural landscape. The rural landscape is in turn divided into agricultural landscape, rural settlement and natural landscape. The agricultural landscape in turn is classified into cultivated, forest and livestock landscape.

The non-rural landscape is divided into industrial and urban settlement landscape. Overall, the landscape categories identified in the maps of Figures 2.14 and 2.16 are the following: cultivated, forest, livestock, industrial, rural settlement, urban settlement and natural landscape.

The Landscape identified as CAT. II (Figures 2.15 and 2.17) is divided into two main categories, rural and non-rural landscape, which are in turn subdivided into sub-categories. As a result, a total of 23 sub-categories of landscape were identified in the map of the Asinara Gulf (Figure 2.15), whereas 18 sub-categories of landscape were identified in the map of the Meilogu landscape (Figure 2.17).

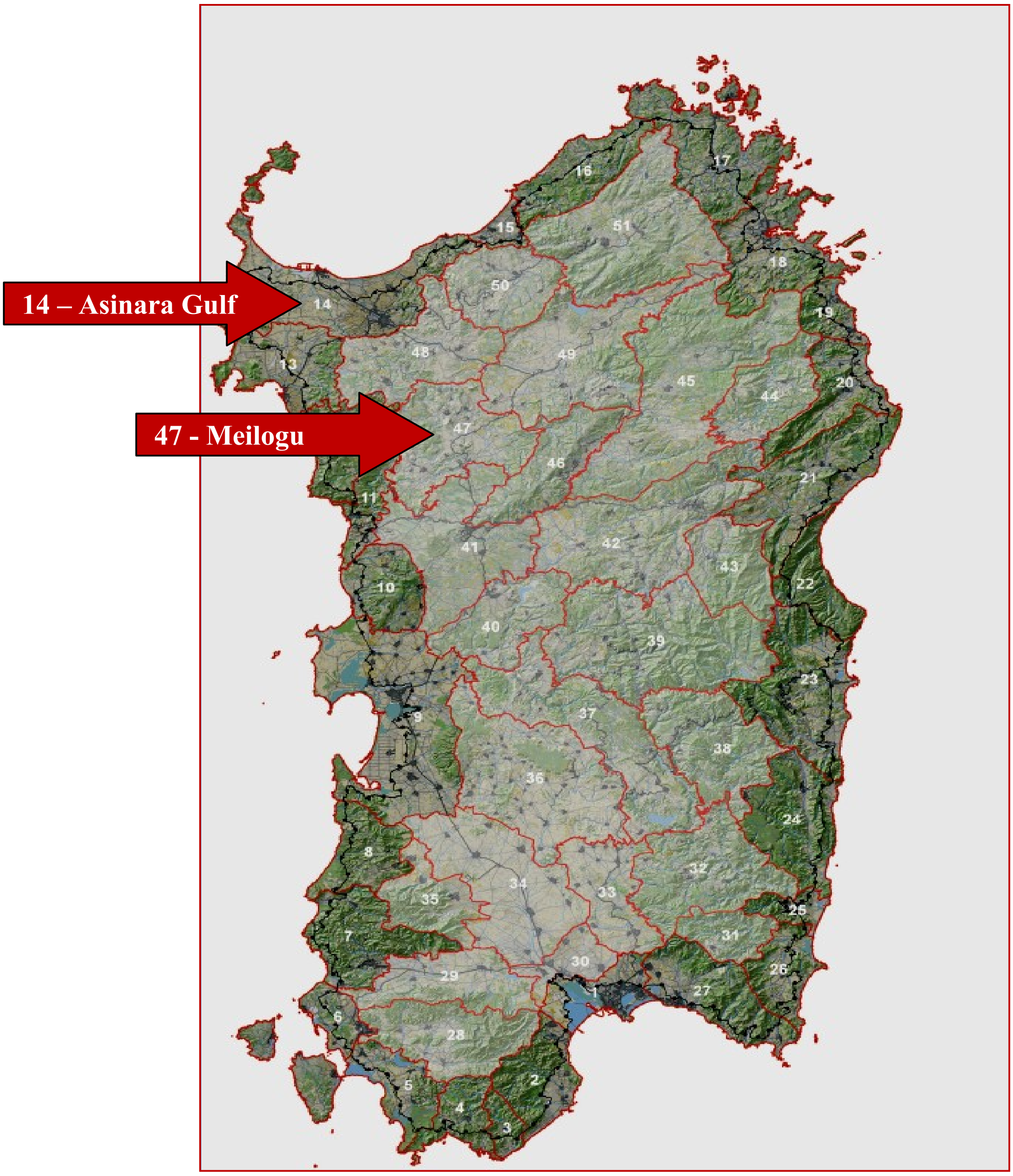


Figure 2.13. The two subregions Asinara Gulf and Meilogu where has been applied the CAIA2 model and livestock landscape sustainability (Modified from Program of Regional Landscape Plan of Sardinia Region, 2015).

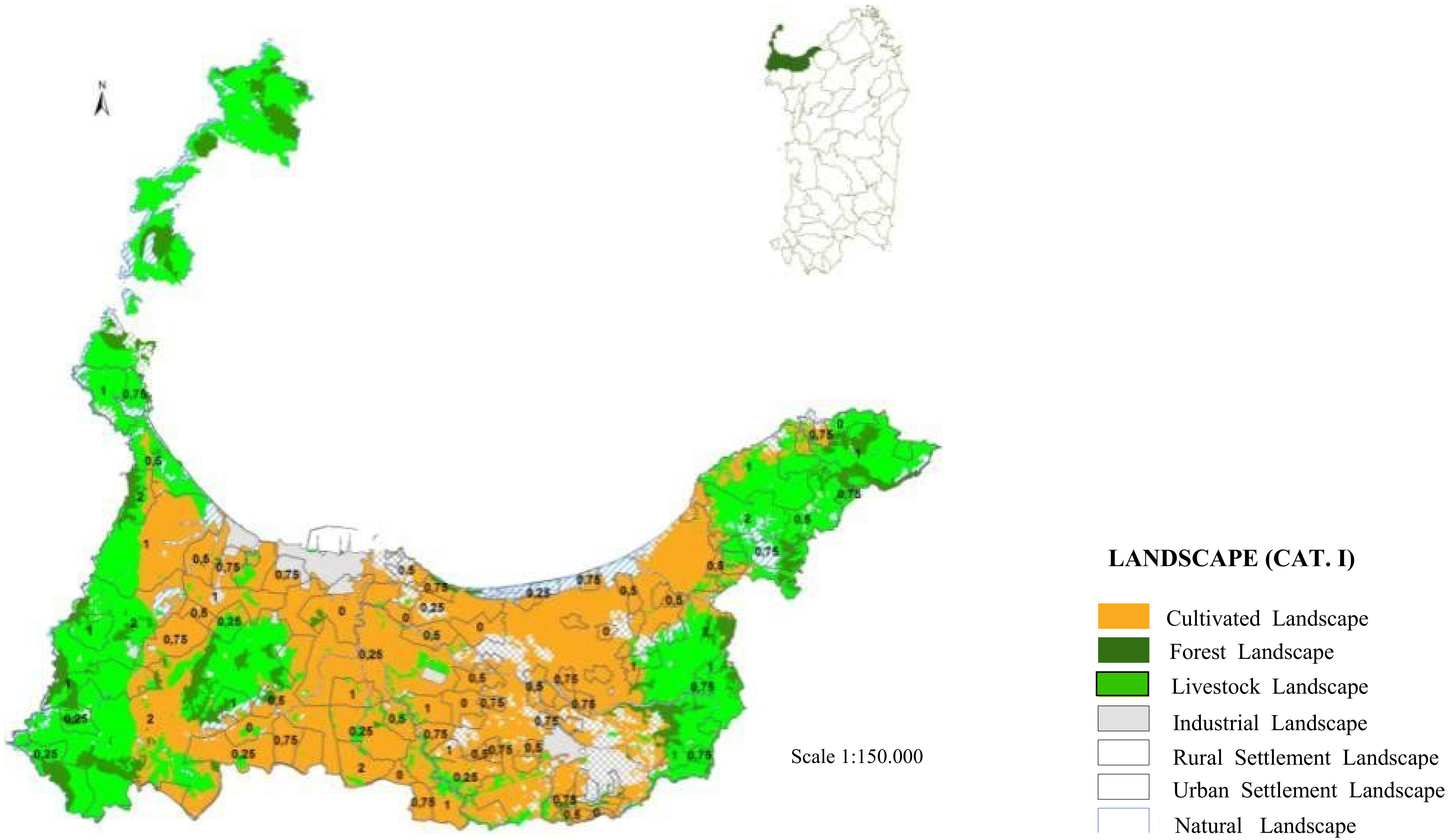


Figure 2.14. Map of Rural Landscape (CAT. I) and Livestock Sustainability Index in the Asinara Gulf

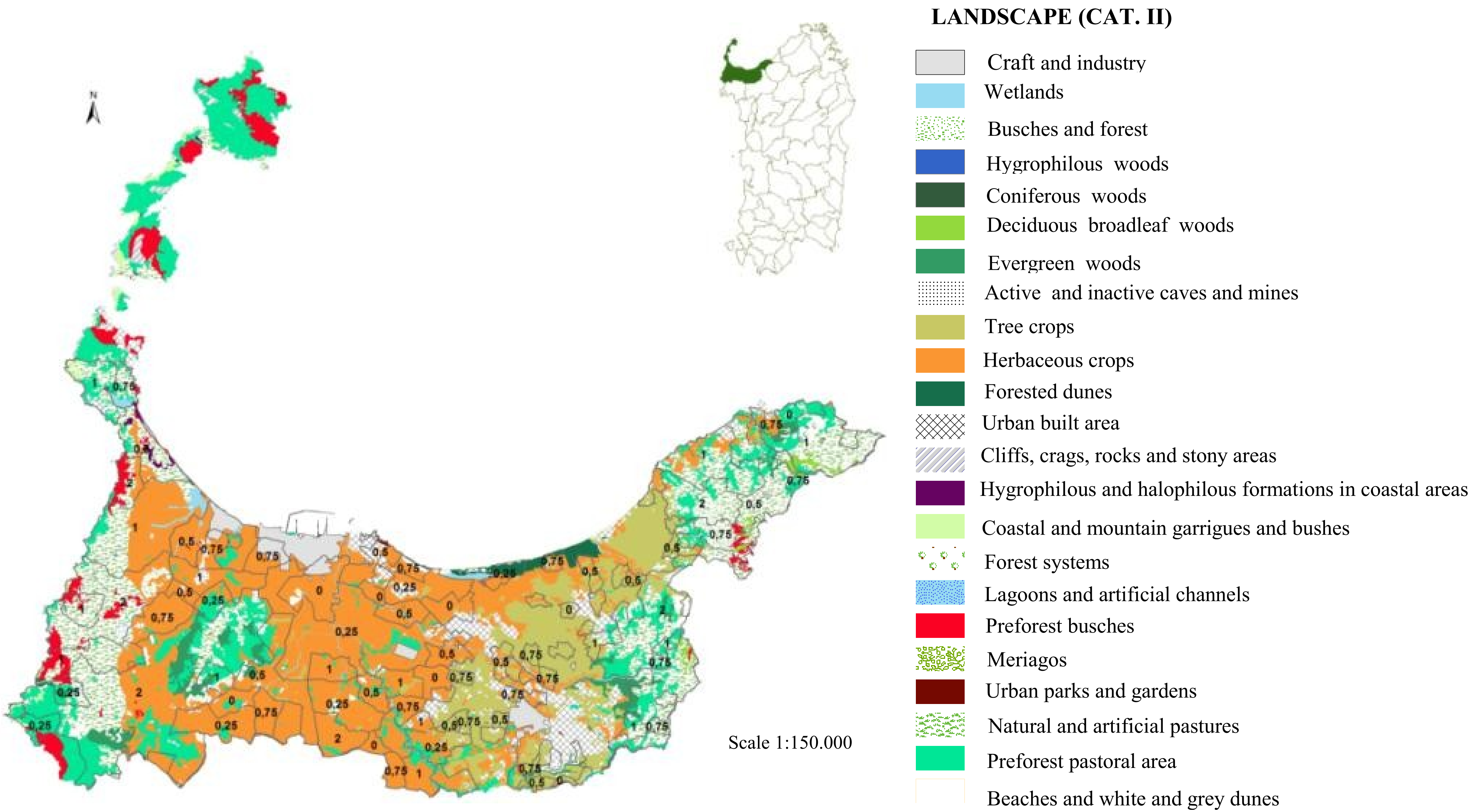


Figure 2.15. Map of Rural Landscape (CAT. II) and Livestock Sustainability Index in the Asinara Gulf

The analysis of livestock sustainability, obtained by overlaying the CAT. I and CAT. II classes of the landscape from the Map of Landscape of Sardinia with the relative values of the CAIA2 model, reveals that 69% of the territory of the Asinara Gulf is subjected to grazing, out of which 33% is over-grazed, 22% is moderately over-grazed and the remainder is properly grazed (Table 2.5). This means that the area of the Asinara Gulf has a great possibility for maintaining the current livestock configuration. However, over-grazing is concentrated in the landscape categories of livestock and forest (Figure 2.14.) confirming that livestock raised in these areas deeply influences the form of landscape.

Table 2.5. Livestock sustainability and grazing impact in the Asinara Gulf.

Livestock Sustainability Index	Livestock Sustainability Level	Grazing Impact	Surface ha	%
0	Very high	Ungrazed surface	3,057	5
0.25	High	None[1]	10,055	17
0.5	Intermediate high	Light[2]	8,067	14
0.75	Intermediate	Intermediate[3]	5,109	9
1	Intermediate light	Moderately high[4]	12,897	22
1.5	Very light	Very high[5]	19,402	33
		Total grazed surface	**58,587**	**69**
		Total surface	**80,712**	**100**

[1] No impact if managed properly.
[2] Light impact of grazing.
[3] Intermediate impact of grazing.
[4] Moderately overgrazed.
[5] Overgrazed.

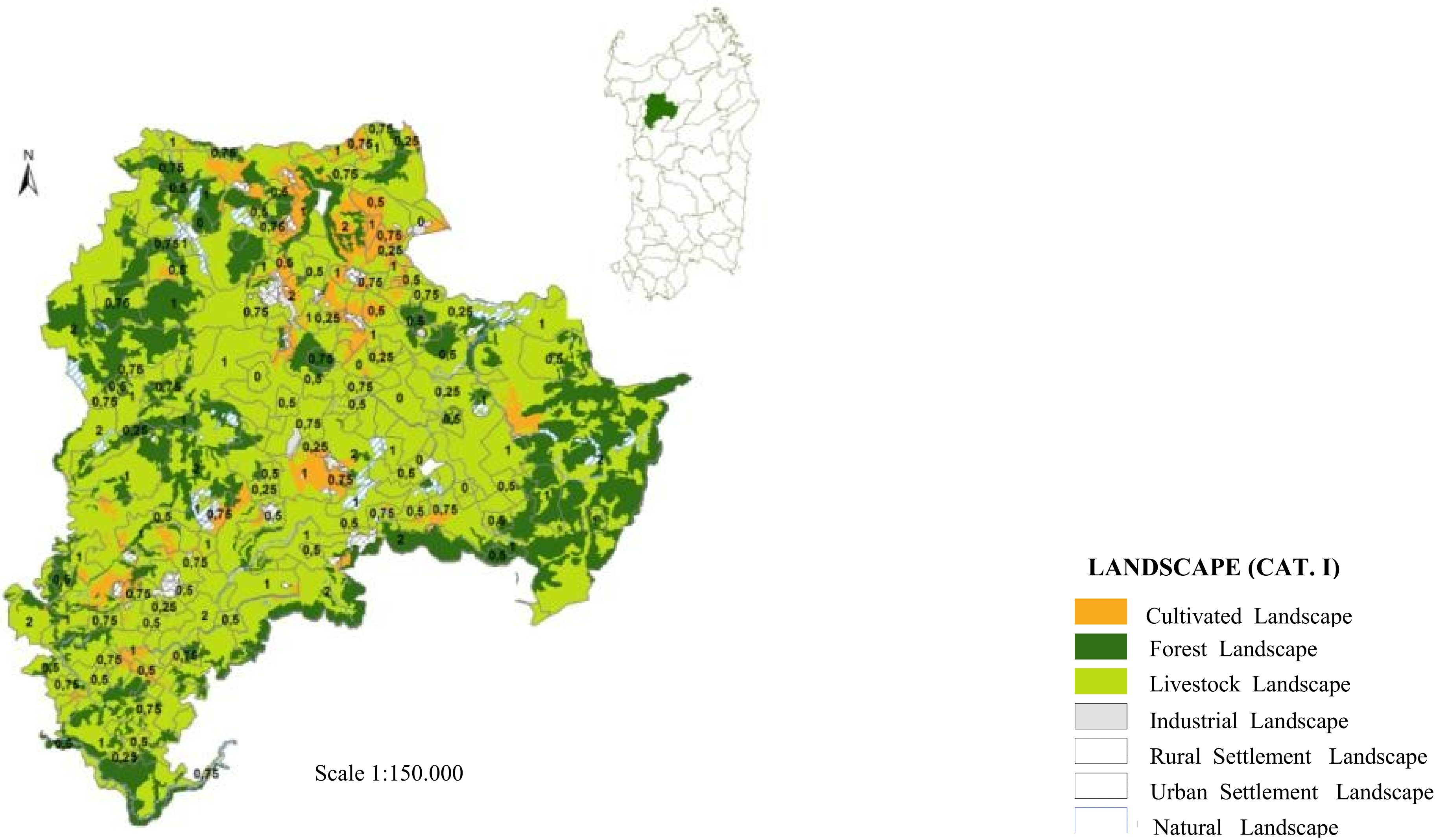


Figure 2.16. Map of Rural Landscape (CAT. I) and Livestock Sustainability Index in the Meilogu area.

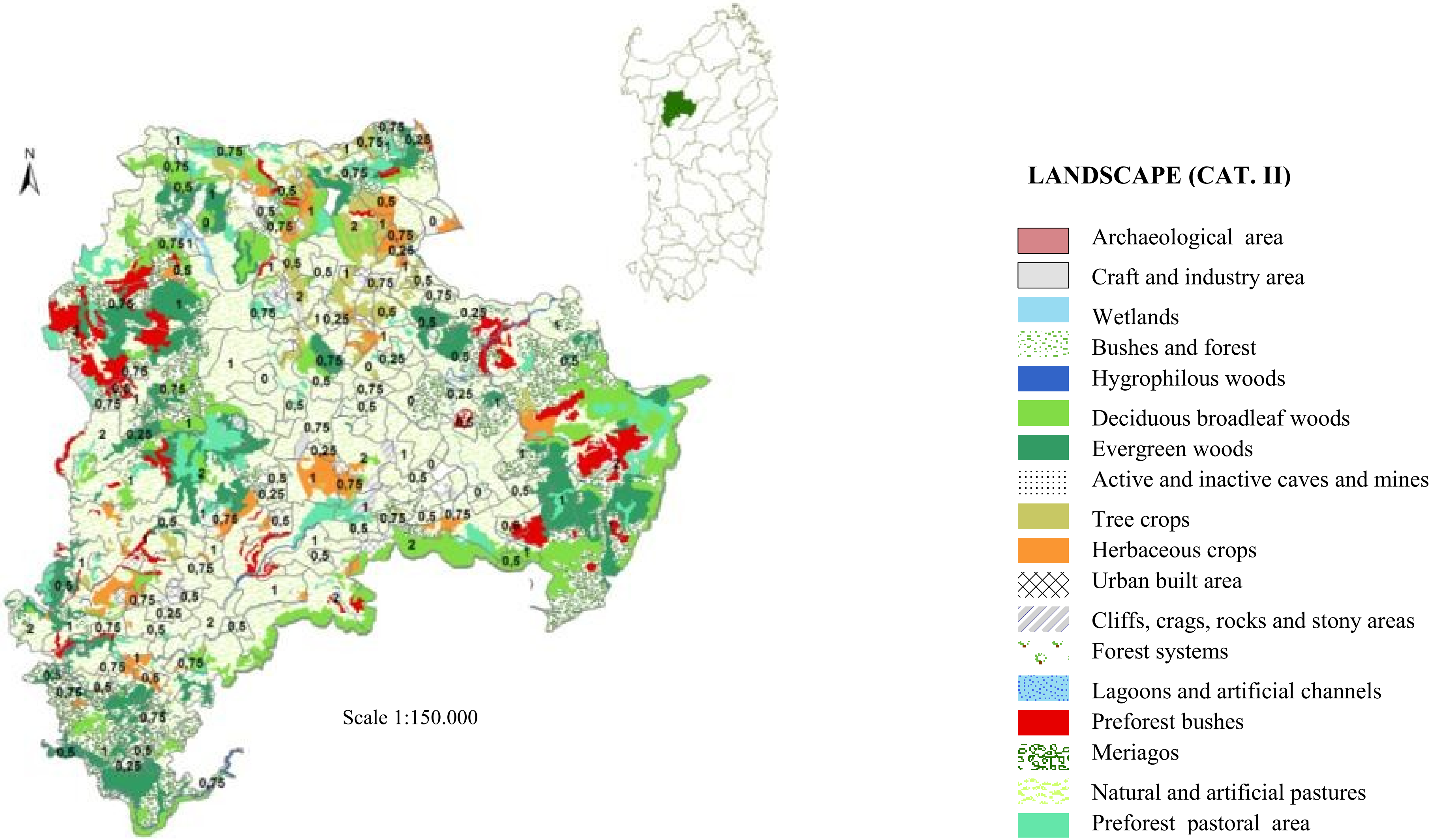


Figure 2.17. Map of Rural Landscape (CAT. II) and Livestock Sustainability Index in the Meilogu area.

The analysis of livestock sustainability, obtained by overlaying the CAT. I and CAT. II classes of the landscape from the Map of Landscape of Sardinia with the relative values of the CAIA2 model, reveals that 99% of the territory of Meilogu is subjected to grazing, out of which 41% is over-grazed, 26% is moderately over-grazed and the remainder is properly grazed (Table 2.6). Overgrazing is concentrated mostly in the livestock and forest landscape categories (CAT. I), particularly in the natural pastures, artificial pasture and Meriagos (Cat. II), whereas natural evergreen and deciduous forests are less affected by grazing.

Table 2.6. Livestock sustainability and grazing impact in the Meilogu area.

Livestock Sustainability Index	Livestock Sustainability Level	Grazing Impact	Area ha	%
0	Very high	Ungrazed surface	1,080	2
0.25	High	None[1]	3,835	6
0.5	Intermediate high	Light[2]	7,634	13
0.75	Intermediate	Intermediate[3]	6,820	12
1	Intermediate light	Moderately high[4]	14,800	26
1.5	Very light	Very high[5]	23,513	41
		Total grazed surface	**57,682**	**99**
		Total surface	**58,103**	**100**

[1] No impact if managed properly.
[2] Light impact of grazing.
[3] Intermediate impact of grazing.
[4] Moderately overgrazed.
[5] Overgrazed

2.5. Conclusions

The livestock landscape is certainly the most important aspect of the geographical characteristics of Sardinia. Its current structure is the result of historical and remote processes, some of which still occur in the current dynamics of environmental changes. A large part of the regional land surface is directly or indirectly allocated to livestock production, which constitutes a vital sector for the economy of the Island. Livestock activity is an important way to utilize and valorize large areas in Sardinia, particularly marginal areas that would otherwise risk abandonment. In addition, livestock-related activities play a crucial role in the protection of the territory, ensuring the management and control of many areas located very far from existing infrastructure. It is important to highlight that extensive and intensive livestock production is a key element for the implementation of effective landscape management and protection actions, including the continuous monitoring of the economic flows associated with this activity. In addition, it would be necessary to determine the social and anthropological aspects that should be considered to avoid and fight against the degradation of the valuable landscape framework in Sardinia, in order to be able to act on the principal variables of landscape evolution.

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CHAPTER 3

3. Using a GIS technology to plan an agroforestry sustainable system in Sardinia

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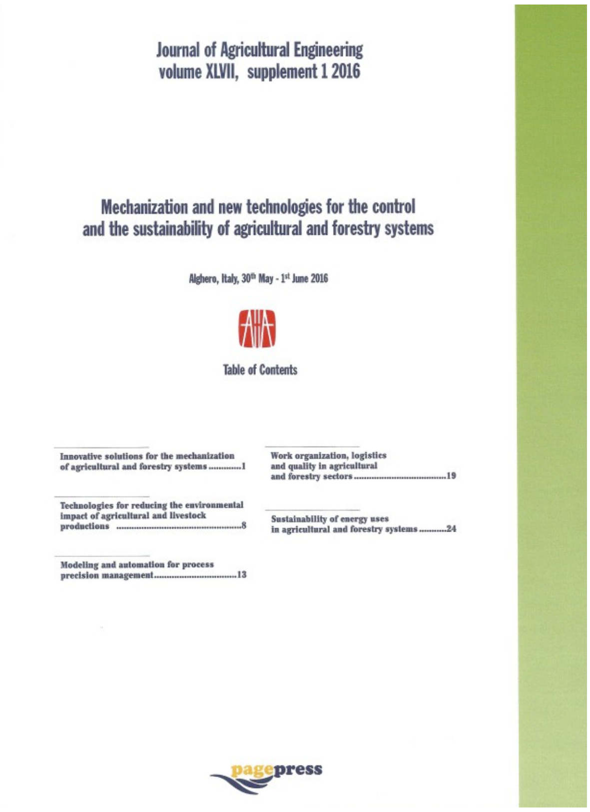
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USING A GIS TECHNOLOGY TO PLAN AN AGROFORESTRY SUSTAINABLE SYSTEM IN SARDINIA

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Key words: Agroforestry, GIS, Sustainability, Sardinia.

3.1. Abstract

Agroforestry systems are gaining interest in Europe because of their ecosystem services, namely biodiversity preservation, soil formation and retention, cultural heritage values preservation and fire hazard prevention, besides their main purpose as food, fiber and fuel production. In the Mediterranean area, silvopastoral system is the oldest method of land use, going back to the Neolithic period, and even today represents one of the most widely-used agroforestry systems in Europe. Overgrazing is unanimously recognized as one of the main driving forces of ecosystem degradation. This study was conducted with the aim of quantifying the area of livestock agroforestry in a Mediterranean ecosystem (island of Sardinia, Italy) and evaluate its sustainability in terms of grazing impact. By using GIS software ArcMap 10.2.2, the Sardinian Nature Map, integrated with the vegetation landscape map, was overlaid with the map of livestock grazing impact CAIA, developed by INTREGA (spin-off ENEA), to survey the forest (lato sensu) surfaces under grazing for Meriagos (local agro-silvo-pastoral systems; classified "Dehesa 84.6" according to CORINE-Biotopes system), bushlands and woodlands. The grazed surface and grazing impact varied for Meriagos, bushlands and woodlands. A proper stocking rate would be essential to preserve the productivity and the landscape value of these systems.

Key words: Livestock-agroforestry, GIS, stocking rate, Sustainability, Sardinia

3.2. Introduction

A new challenge in agriculture is to develop sustainable production systems able to guarantee food and nutritional security and safety to feed the growing world population, without damaging the environment. Current production systems, in particular livestock, are considered one of the main causes of environmental degradation and pollution. In the last years, the sustainability of livestock farming systems has been the object of many studies, particularly on climate change, quality of life of the population and quality of agro-ecosystem services provided to society. Recently, several studies have suggested how to reach sustainable systems, capable of producing more, using fewer natural resources and improving animal welfare. In this context, multifunctional land-use systems are useful to safeguard ecosystems services and production from degradation. The integrated crop-livestock-forestry (ICLF) would adequately respond to these needs, in comparison with traditional specialized systems, which clearly separate livestock from crop production activities.

One of the ICLF land use systems is agroforestry, which combines trees and shrubs with agricultural crops or livestock. The most common types of agroforestry in Europe include wood pasture, grazed orchards, grazed forest, forest farming and silvoarable and silvopastoral systems. The ICLF systems are present especially in southern Europe, especially in Spain (Dehesas), Portugal (Montados), and Greece (Valonia Oak Forest), which contribute with 8.9 million ha (Bernués et al., 2011) to the maintenance of European rural landscapes and to the management and conservation of High Nature Value (HNV) farmland in Europe (Henle et al., 2008 cited by Bernués et al., 2011). Recently, these systems have been re-evaluated in Italy for their environmental, agricultural and livestock production sustainability. The ICLF benefits can range from diversification of the agricultural landscape and growth of biodiversity (Mosquera-Losada et al., 2009; Nerlich et al., 2013; Fagerholm et al., 2016.) to improvement of animal welfare (Burtscher, 2004). This paper estimates the total agroforestry area and the grazing impact by ruminants in Sardinia (Italy), in order to estimate the sustainability and potential development of agroforestry in our region.

3.3. Materials and Methods

This study was conducted by overlaying the Sardinian Nature map (Camarda et al., 2015), integrated with a vegetation landscape map, with the Sardinian CAIA (*carico animale di impatto ambientale*, i.e. environmental livestock stocking rate) map using a geographical information system (GIS) software ArcMap 10.2.2.

Sardinian Nature Map and vegetation landscape

The Sardinian Nature Map was made (1:50.000 scale) based on the CORINE biotopes manual, with the correspondence to the classification systems of EUNIS and Nature 2000. This GIS is useful for environmental management, in order to create a unitary framework, comparable among the different Italian and European regions. The Nature Map was based on spectral responses (7 bands) of the satellite Landsat and took into account lithological characters, soil, moisture, heat and, more in detail, vegetation cover and chlorophyll. It was produced first in the automatic route (Classification unsupervised), and then in the non automatic route (Classification supervised). Subsequently, it was validated through field measurements. The survey points (over 10,000 in the whole island) were identified on the field and then located on a card with a serial number, and identified by the acronym WPCN (way point *carta della natura, i.e.* way point nature map), followed by a progressive number, using the GPS system. The information system adopted allowed an instant view, in both geo-referenced images and IGM (*Istituto Geografico Militare, i.e.* Italian Military Geographical Institute) maps. In the present study, forest was considered as a broader concept (*lato sensu*) compared with the legal definition of forest provided for by the Italian law (Legislative Decree 18 May 2001, n. 227 art. 2), because in our Region the term forest includes *Meriagos* (local agro-silvo-pastoral systems; classified "Dehesa 84.6" according to CORINE-Biotopes system), *Matorral* and *Chaparral (Regional Law 2016, n. 8).*

Sardinian CAIA Map

The Sardinian CAIA Map was developed by InTReGa Srl (spin-off ENEA). The calculation of the CAIA indicator of environmental livestock stocking rate (Pulina and Zucca, 1998) involves the determination of the *actual* CAIA, integrated with the *sustainable* CAIA, which comes from the model on land suitability for grazing of Madrau et al. (1998). The *actual* CAIA, expressed in livestock unit (LU), calculates the intensity of grazing currently present in the territory. It takes into account the different behavior of grazing animals, through the calculation of sub coefficients (b) which consider land trampling by the animals, grazing impact on the vegetation, animal productivity and farm management.

On the basis of these assumptions, the *actual* CAIA was determined by a matrix for datasets of size K as follows:

Matrix $(X \times B \times b)/S$

X = vector of size (1, K), indicating the UBA in the area considered;

B = incidence matrix of size (K, 20) of the 20 sub coefficients of the b weighting factor;

b = column vector of size (20, 1) of the sub coefficients;

S = total area considered (ha).

Livestock and farm data were extracted from a database of the Sardinia Region.

The *sustainable* CAIA represents an application to the Sardinian livestock system of Framework for Land Evaluation (FAO, 1976) and guidelines: Land Evaluation For Extensive Grazing (FAO, 1988). It considers the Sardinian different landscape units, climate and vegetation, identifying 5 classes of suitability for grazing (S1, S2, S3, N1 and N2). The first three classes identify the areas suitable for grazing or for pasture improvement, in decreasing order, whereas the other two are not suitable for grazing and do not have the potential for pasture improvement. The five classes were implemented in GIS, with mapping overlay functions and subsequent reclassifications. The final grazing intensity (*final* CAIA) was calculated by the ratio between *actual* CAIA and *sustainable* CAIA and then classified, according to a grazing impact index , into the following groups: 0 = ungrazed surface, 0.25 = none (no impact if managed properly), 0.50 = light (light grazing impact), 0.75 = medium (medium impact by overgrazing), 1.0 = high (high impact by overgrazing); 1.5= very high (severely affected by overgrazing).

3.4. Results and Discussion

In Sardinia, forests *lato sensu* (Figure 3.1) cover a surface of 1,319,378 hectares (54% of the total island area), out of which 1 million hectares are grazed (76% of total) (Figure 3.2). The forest area is composed of Meriagos (8.6%) (Figure 3.3), bushlands (48.9%) (Figure 3.4) and woodlands (42.5%) (Figure 3.5).

The results obtained by overlaying the Sardinian Nature map and vegetation landscape map with the CAIA map of livestock grazing impact are reported in Table 3.1. The percentage of grazed surface within vegetation type is, obviously, the highest for Meriagos (96%) and the lowest for the woodlands (72%). Very high impact of grazing occurred in more than half of the grazed surface (521,576 ha), as shown in Figure 3.6, with a maximum for bushlands and a minimum for Meriagos (Table 3.1).

In conclusion, the livestock agroforestry system is an important environmental resource for animal production in Mediterranean areas. However, it would be fundamental to reduce stocking rates to avoid the potential harmful effects of overgrazing on landscape productivity and value. In some cases, agronomic interventions could be done to improve soil fertility, productivity potential and thus land sustainability, in order to support a higher stoking rate. In Europe, the new Common Agricultural Policy (CAP; EC Regulation 1306/2013), promotes, in line with the Europe 2020 strategy, the competitiveness and sustainability of agricultural production. There is potential for the development of agroforestry systems, and policy makers should make the appropriate choices to support farmers.

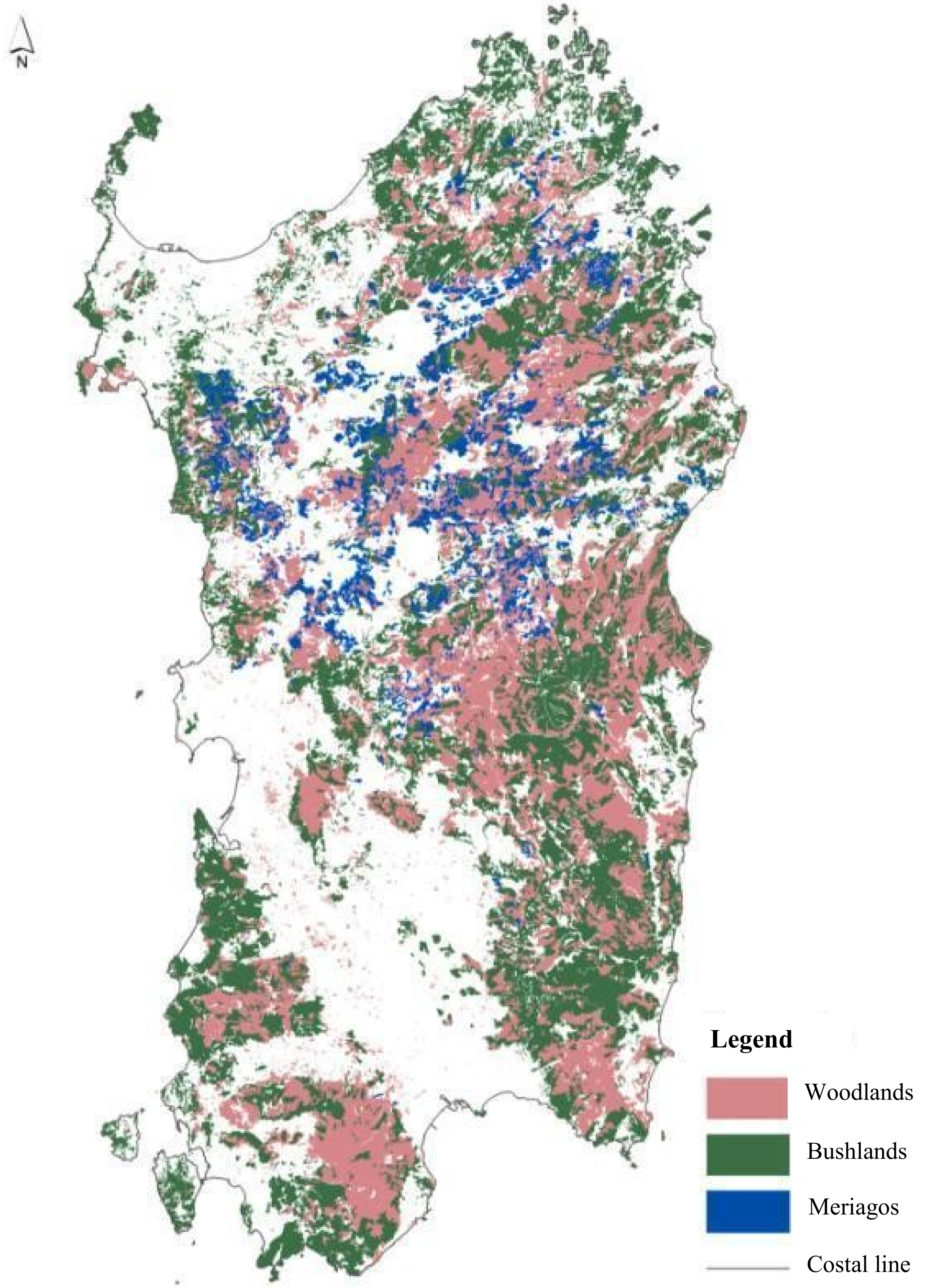

Figure 3.1. Agroforestry surface in Sardinia.

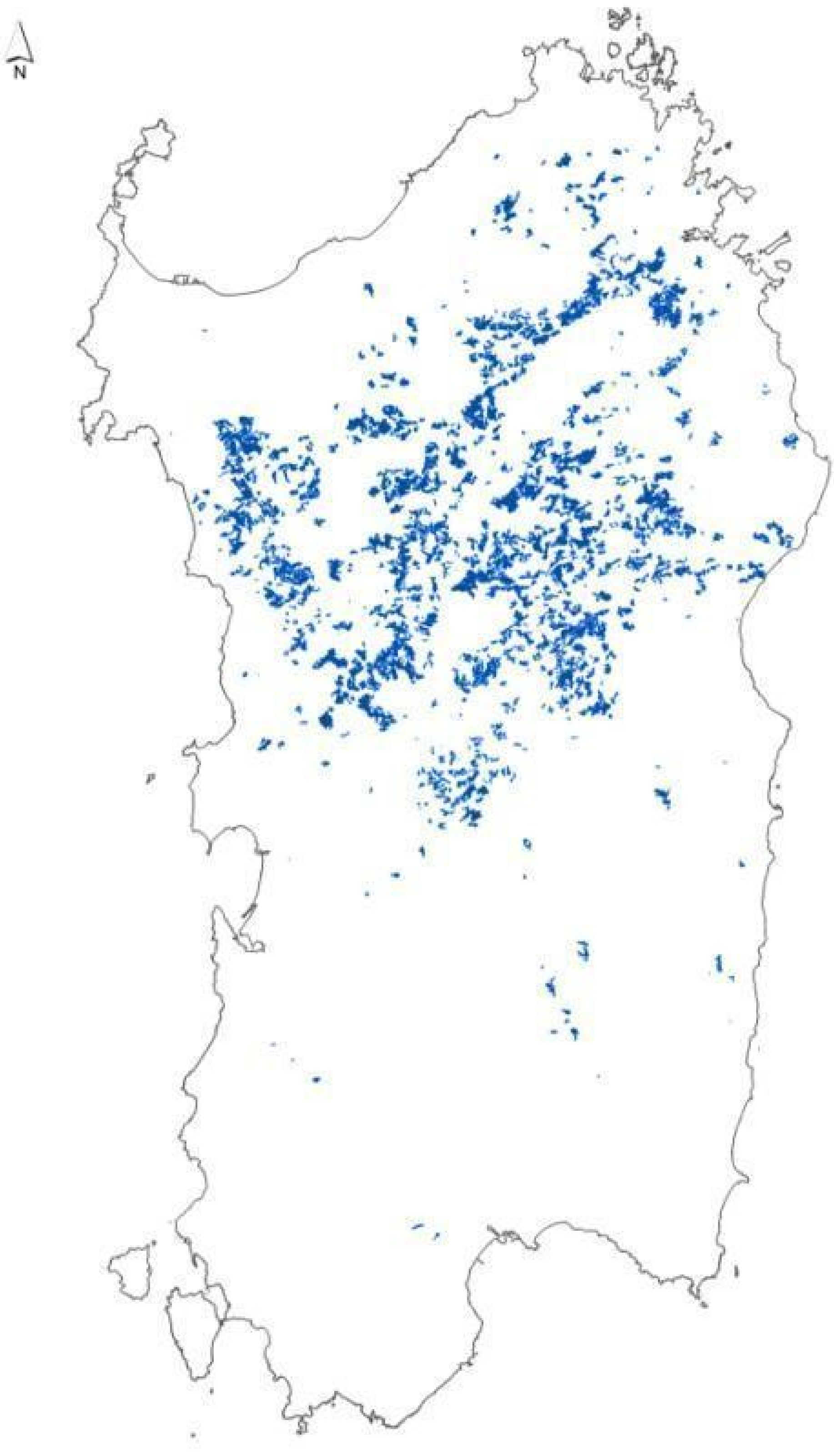

Figure 3.2. Meriagos surface in Sardinia.

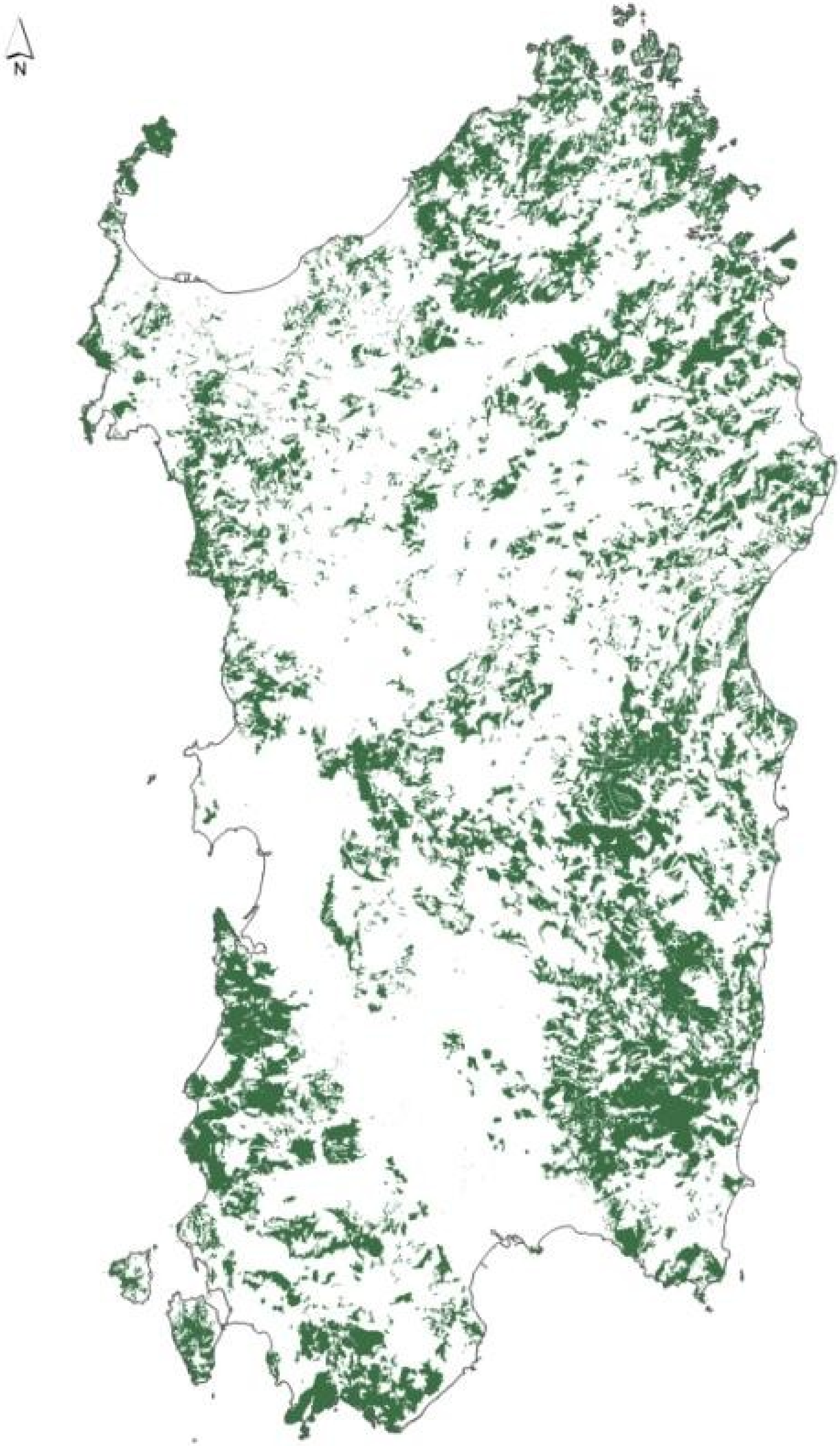

Figure 3.3. Bushlands surface in Sardinia.

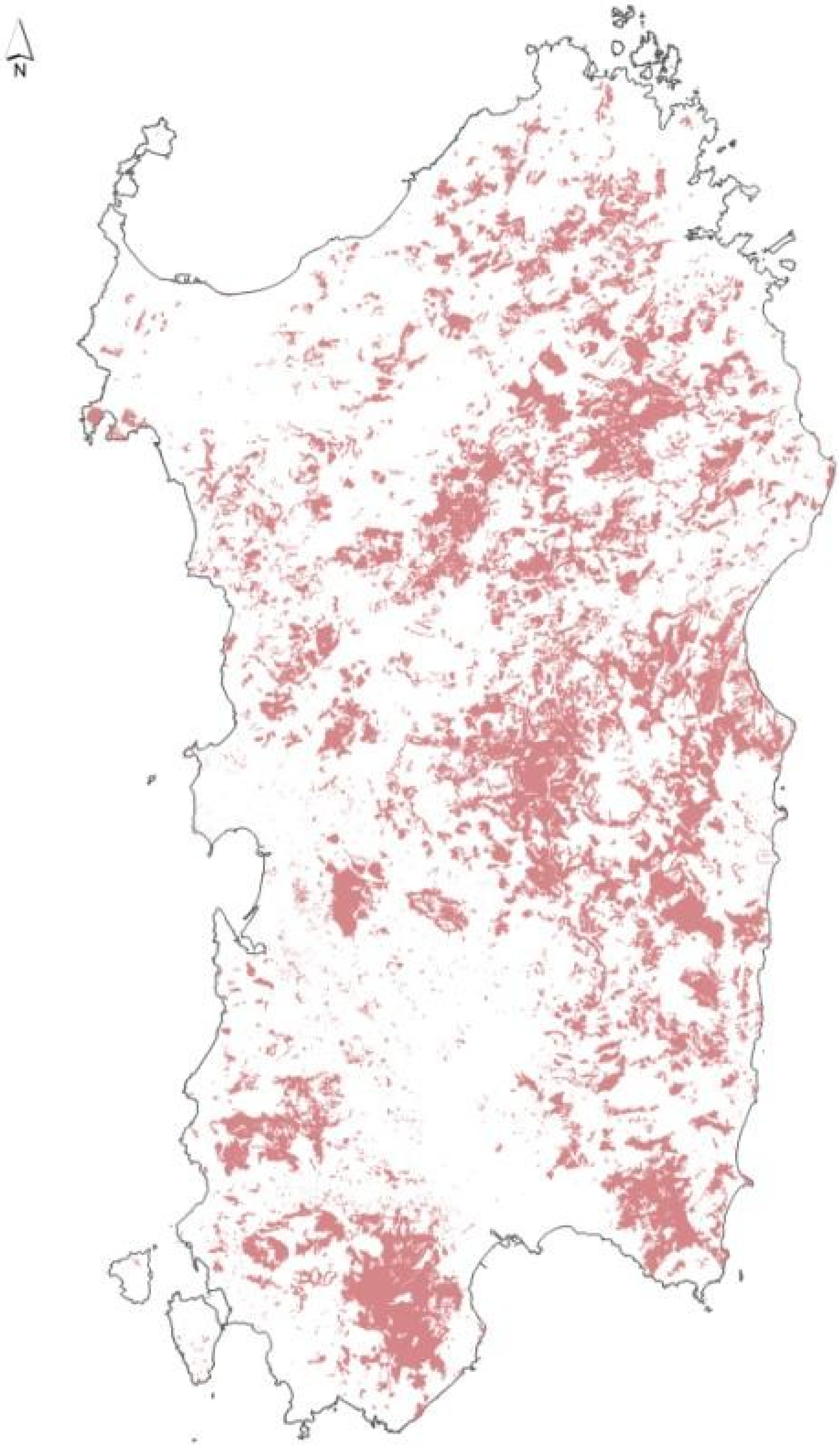

Figure 3.4. Woodlands surface in Sardinia.

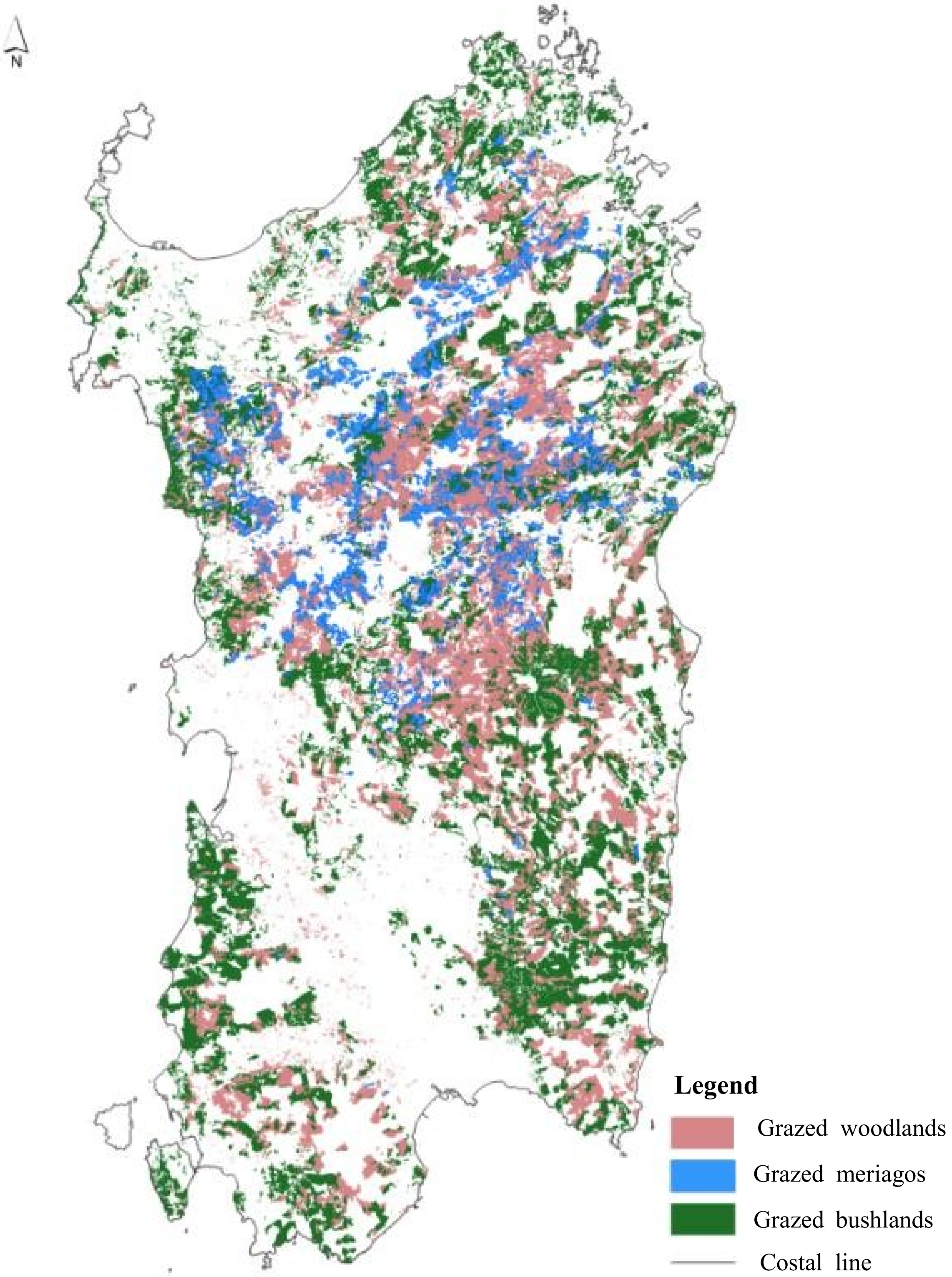

Figure 3.5. Grazed agroforestry surface in Sardinia.

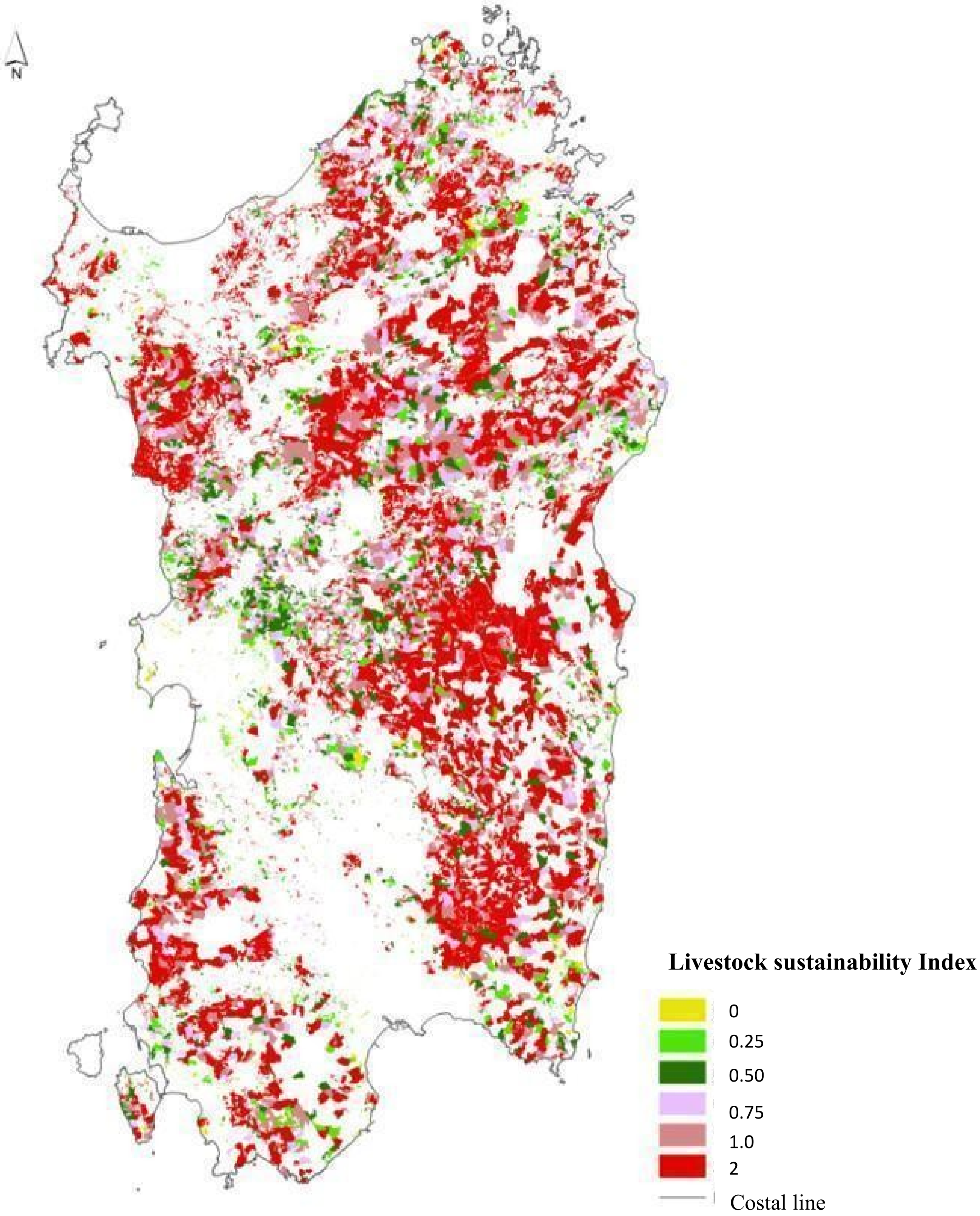

Figure 3.6. Agroforestry and Livestock Sustainability Index in Sardinia.

Table 3.1. Livestock agro-forestry area and grazing impact in Sardinia.

MERIAGOS			BUSHLANDS			WOODLANDS		
Grazed surface (ha)	**Grazing impact***	**%**	**Grazed surface (ha)**	**Grazing impact***	**%**	**Grazed surface (ha)**	**Grazing impact***	**%**
10.361	none	10	29.636	none	6	29.122	none	7
15.726	light	14	43.198	light	9	42.625	light	11
18.165	medium	17	48.686	medium	10	43.424	medium	11
29.249	high	27	88.808	high	18	82.712	high	21
35.183	very high	32	279.956	very high	57	205.437	very high	51
Total grazed surface	108.684	96	Total grazed surface	490.284	76	Total grazed surface	403.319	72
Total surface	112.668	100	Total surface	645.726	100	Total surface	560.984	100
Ungrazed surface*	3.984	4	Ungrazed surface*	155.442	24	Ungrazed surface*	157.665	28

*Grazing impact (*Final* CAIA) index:

0 = ungrazed surface;
0.25 = none (no impact if managed properly);
0.50 = light (light grazing impact);
0.75 = medium (medium impact by overgrazing);
1.0 = high (high impact by overgrazing),
1.5 = very high (severely affected by overgrazing).

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CHAPTER 4

4. A preliminary study on a new approach to estimate water resource allocation: the net water footprint applied to animal products

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A preliminary study on a new approach to estimate water resource allocation: the net water footprint applied to animal products

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4.1. Abstract

We propose the Net Waterfootprint (WFPnet) method to estimate the water footprint (WFP) of food products, in alternative to the current WFP method, based on absolute values. We compared the WFP and WFPnet methods for cattle milk and meat production in different feed efficiency (high and low) and crop water use efficiency (WUE; high, medium and low) scenarios under Mediterranean conditions. The WFP values were, on average, much higher than the WFPnet values for both meat and milk. The WFPnet method appears to be able to properly quantify the water consumption needed for animal food production.

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Keywords: Evapotranspiration; water use efficiency; milk; meat; ecological footprint; livestock; cattle; environment; crop; ruminant.

4.2. Introduction

Agriculture accounts for 92% of the world's water consumption (Hoekstra and Mekonnen, 2012a). Among foods, animal products are considered to be the highest consumers of water (Mekonnen and Hoekstra, 2012). The reduction in the pressure on water resources from food products is a major challenge for humanity, and knowledge of water consumption is relevant for national governments to plan and assess their environmental policy and food security (Hoekstra and Mekonnen, 2012b).

Water FootPrint (WFP) is an indicator that measures the quantity of water used for the production of a unit of goods or services, looking at both direct and indirect water use of a consumer or producer (Hoekstra et al., 2011). The main approaches to calculate WFP are based on the Water Footprint Network (WFPN; e.g. Hoekstra et al., 2011; Water Footprint Network, 2015) and the Life Cycle Assessment (LCA; e.g. Ridoutt and Pfister, 2010; De Boer et al., 2013) methods. Some authors account for blue water only, such as Hoekstra and Hung (2002) for WFPN and Ridoutt et al. (2010, 2012) and De Boer et al. (2013) for LCA, whereas others recommend including also green water data to calculate WFP (Falkenmark and Lannerstad, 2005). The blue water is the fresh surface water and groundwater (freshwater lakes, rivers and aquifers); the green water is the rainwater stored in the soil or remaining temporarily on the soil top or vegetation, which eventually evaporates or transpires through plants; and the grey water is the polluted part of the used water (Hoekstra et al., 2011).

The WFP of animal products is expressed as the volume of freshwater (good quality water) used to produce a kg of product. In the livestock sector, the sum of blue and green water used to produce feeds accounts for more than 99% of the total consumed water (Brown et al., 2009; Pulina et al., 2011). Until now estimations of WFP of animal products using the WFPN and the LCA methods have been hardly comparable (Table 1).

Table 4.1. Comparison between calculations of the water footprint of animal products using the Life Cycle Assessment (LCA) and the Water Footprint Network (WFPN) methods.

Authors	Method	Product	Water Footprint	
			Irrigated Farms	Rainfed Farms
Ridoutt et al. (2010)	LCA (Water deprivation)[1]	1 kg Milk		1.9 L H_2Oe[2]
Ridoutt et al. (2012)	LCA (Water deprivation)[1]	1 kg Beef Cattle LW[3]		3.3-221 L H_2Oe[2]
De Boer et al. (2013)	LCA (Consumptive water use)	1 kg FPCM[4]	66 L H_2O	16 L H_2O
	LCA (Water deprivation)[1]	1 kg FPCM[4]	33 L H_2Oe[2]	7.9 L H_2Oe[2]
Mekonen and Hoekstra (2012)	WFN	1kg Milk	1000 L H_2O	
		1 kg Beef	15400 L H_2O	
		1 kg Eggs	3300 L H_2O	
Chapagain and Hoekstra (2004)	WFN	1 kg Chicken meat	4300 L H_2O	

[1] Water deprivation is the net reduction in the amount/availability of freshwater in a watershed or/and an aquifer.
[2] L of H_2O equivalents/kg of product, obtained by multiplying each value of consumptive water use by the relevant water stress index (WSI; Pfister et al., 2009), summed up for the entire production cycle and normalized, by dividing it by the global average WSI.
[3] Live Weight.
[4]Fat and protein corrected milk.

Vanham and Bidoglio (2013) made a critical review on the volumetric WFP methodology used by the WFPN, showing that the development of the WFP concept is still incomplete. The LCA method also has some limitations related to its focus on blue water only. Therefore, the methodology of calculation of WFP has a large impact on the final calculated values and needs to be improved in order to obtain comparable results and plan effective mitigation strategies.

The green water is often considered less important than the blue and grey water, because it normally generates low, or even negligible, opportunity cost. However, among food products, green water is the main component of the WFP. Many authors have considered the total evapotranspiration (ET) when calculating the green water using the WFPN method (e.g. Rost et al., 2008), but the ET related to the grass actually consumed was taken into account rather than the total ET for grazing lands (Mekonnen and Hoekstra, 2012).

In our opinion, the green water should be included in the calculation of the total WFP, considering that the ET of crops and pastures is the main way in which water from soil and plants goes back to the atmosphere. From a holistic point of view, the ET in a typical land will occur even in the absence of production or in the presence of natural vegetation cover. Thus, based on the principle of alternative opportunities, we believe that the amount of green water of a certain food product should not be considered in absolute terms. Instead, it should be calculated considering the differential evapotranspiration (ΔET) between the total ET of a crop or pasture assessed for the WFP calculation and the ET of a hypothetical scenario (e.g. forestland or shrubland) of a natural cover on the same land surface. Therefore, we propose a new method to estimate the WFP of food products, named **Net Waterfootprint (WFP_{net})**, in alternative to the actual concept of WFP of a product, usually expressed in absolute terms.

This paper compared the estimations of the WFP method and the new WFP_{net} method for cattle milk and meat production within a biological range of production efficiency in a Mediterranean scenario.

4.3. Materials and Methods

Initial considerations for the calculation of Net Waterfootprint (WFP_{net})

The WFP_{net} considers that blue water should be definitely included in the calculation because it represents the water to be supplied to the target production process. The WFP_{net} also states that the green water should be taken into account for WFP estimations, and should be calculated subtracting from the water consumed by a cultivated crop the amount of water consumed by a spontaneous natural cover (forestland or shrubland) that would take place in the same area if the crop were stopped. In fact, the evaporation from these lands would occur even in the absence of crop production.

The green water consumed by a given crop, mainly composed of rainfall and soil storage, can be estimated similarly to the water evaporated from the area of a given crop. Therefore, the crop water consumption can be considered approximately equal to the ET, being negligible the rainfall water intercepted by the plants and soil evaporation (Nisbet, 2005; Katerji et al., 2008). Recent agronomic studies highlighted that, from a policy point of view, WUE, expressed as kg of crop biomass/L of water, can be a more useful measure of water resource consumption than ET *per se* because it refers to the effectiveness of the available resource for human purposes (Hatfield et al., 2001). The WUE (kg of biomass/L of water) can be calculated as follows:

WUE = Yield/Water consumption or ET,

where yield is the actual marketable crop yield (kg/ha), water consumption is the amount of water consumed during the crop cycle (m^3/ha), and ET is the actual crop water consumption by evapotranspiration (m^3/ha).

Focusing on food production, the yield of cultivated areas can be destined to human nutrition either directly or indirectly. the latter occurring when cultivated products are consumed by livestock or wild species and humans take advantage of the nutrients provided by animal products. In this sense, the yield of a land area not covered by cultivated crops and not involved in livestock or hunting activities can be considered equal to 0. The water consumption of a land area depends on the vegetation and climate characteristics. In particular, ET is often higher for forests than for rainfed crops (Nisbet, 2005). In Mediterranean areas, where precipitations range between 400 and 1000 mm/year, ET of oak woodlands ranged from 350 to 600 mm/year, reaching ET values higher than precipitation in very dry areas or arid periods (Baldocchi and Xu, 2007), whereas WUE ranged from 0.11 to 2.8 kg of marketable yield/m^3 of water consumed (rain + irrigation) for cultivated crops with a dry matter content higher than 80% (Katerji et al., 2008) and showed values of 3.0 and 3.4 kg of marketable yield/m^3 of water consumed for dry alfalfa and irrigated corn silage, respectively (Dono et al., 2013).

In this study, a comparison of WFP and WFP_{net} methods was performed for cattle meat and milk scenarios, as presented below.

Calculation of the Water Footprint (WFP) and the Net Water Footprint (WFP_{net})

The water footprint (WFP) can be calculated with the following formula:

WFP = water for feed production (green + blue) + drinking water (blue) + servicing water (blue)

where water for feed production (green water + blue water) is equal to the water consumed by the crops (rain water, soil water and irrigation) needed to produce the animal feeds, being equal to ET (m^3/ha); the drinking water is the water drunk by the animals; and the servicing water is the remaining water consumption in the farm for other animal needs and facilities.

The net water footprint index proposed in this paper calculates the water consumed to produce an animal product considering that the system boundaries are within farm gate. Based on the initial considerations reported above, the net water footprint index (WFP_{net}) can be calculated as the amount of water consumed in a generic production process of meat and milk, considering the additive contribution of the green and blue water as follows:

WFP_{net} = [consumed biomass for each type of feed used/WUE of the crop] (green + blue) – virtual water of the natural cover replacing the crop (green) + drinking water (blue) + servicing water (blue)

where the first term represents the water for feed production (green water + blue water), which is the water consumed by crops including rain water, soil water and irrigation supply, being equal to

ET (m^3/ha); the virtual water of the natural cover indicates the evapotranspiration (ET; m^3/ha) of a natural cover that would replace the considered crop in the same land surface if crop production were abandoned, representing an opportunity cost of the system; the drinking water is the water drunk by the animals; and the servicing water is the remaining water consumption in the farm for other animal needs and facilities.

Scenarios for WFP and WFP_{net}

The water footprint and the net water footprint index were calculated for typical scenarios of milk or meat production, with different levels of feed efficiency and WUE of an irrigated crop. High feed efficiency referred to a typical farm using specialized breeds for milk or meat production and/or having highly efficient animal management practices, with low feed dry matter intake (DMI) per unit of milk and meat produced. Low feed efficiency referred to the use of dual purpose cattle breed and/or poor management practices at farm level, thus leading to lower animal performance, i.e., a high feed dry matter intake (DMI) per unit of product. For each of those 4 scenarios, we assumed typical animal performance and dietary composition data. Considering the most common conditions of specialized production areas in the Mediterranean region, we assumed that forages and grain were produced from rainfed and irrigated lands. To simplify, we assumed that grains from irrigated lands were corn grains, for which the three possible levels of WUE were simulated. In total, 12 scenarios of WFP and WFP_{net} values were calculated for the different combinations of 2 products, 2 levels of feed efficiency (i.e., animal performance) and 3 levels of corn crop WUE (Table 4.2).

Table 4.2. Water footprint (WFP) and Net water footprint (WFP_{net}) for cattle milk and beef production in high and low feed efficiency systems with high, medium and low water use efficiency (WUE) scenarios.

	Meat		Milk	
	High Feed Efficiency	Low Feed Efficiency	High Feed Efficiency	Low Feed Efficiency
Carcass weight, kg	350	250		
Milk yield, kg/year per cow			9000	5500
Dry matter intake, kg/kg product	20	30	0.75	1.30
Drinking and service water consumption, L/kg product	71.4	100.0	6.7	10.9
Water consumed for forages and grains				
Using Scenario 1, high WUE: WFP, L/kg product	8143	15600	334	717
Using Scenario 2, medium WUE: WFP, L/kg product	9810	16600	413	853
Using Scenario 3, low WUE: WFP, L/kg product	12961	18491	560	1109
Water consumed for forages and grains				
Using Scenario 1, high WUE: WFPnet, L/kg product	2230	690	131	16
Using Scenario 2, medium WUE: WFPnet, L/kg product	3880	1680	208	150
Using Scenario 3, low WUE: WFPnet, L/kg product	6929	3509	351	397
Final Water Footprint (WFP)				
Using Scenario 1, high WUE: WFP, L/kg product	8214	15700	341	728
Using Scenario 2, medium WUE: WFP, L/kg product	9881	16700	419	864

Table 4.2. (continued) Water footprint (WFP) and Net water footprint (WFP_{net}) for cattle milk and beef production in high and low feed efficiency systems with high, medium and low water use efficiency (WUE) scenarios.

Final Net Water Footprint (WFPnet)				
Using Scenario 1, high WUE: WFPnet, L/kg product	2302	790	137	27
Using Scenario 2, medium WUE: WFPnet L/kg product	3951	1780	215	161
Using Scenario 3, low WUE: WFPnet, L/kg product	7001	3609	358	408

[1] L/kg: liters of water consumed per kg of animal product produced

Calculation assumptions for animal products

For estimates of both WFP and WFP_{net}, high feed efficiency for meat production was assumed to have 20 kg DMI per kg of meat produced, assuming 6000 kg of DMI (for the entire cycle of the cow-calf and growing finishing phases) and 300 kg of carcass weight as reported for Italian beef cattle by FAOSTAT (2013). Low feed efficiency was set to have 30 kg DMI per kg of meat and assuming 7500 kg of DMI for the entire cycle and a carcass weight of 250 kg for a less efficient system (Table 4.2).

High and low feed efficiency for milk production were set to have 0.75 and 1.30 kg of DMI by the herd per kg of milk sold for a milk yield of 9000 and 5500 kg of milk per year per head, respectively (Table 4.2), as previously observed in a sample of 285 dairy farms surveyed for carbon footprint estimation in Southern Italy (Atzori et al., 2013).

Using those parameters, water consumption for drinking and services, expressed as L per unit of product, was calculated based on Brown et al. (2009) as already used by Pulina et al. (2012) for similar estimations. Animal diets were estimated considering typical feeding practices for the considered categories to obtain the required amounts of forages and concentrates produced in rainfed and irrigated lands. Reference rainfed forages were pasture and grass, forages from irrigated lands were assumed to be corn silage and alfalfa, and the reference grain from irrigated lands was assumed to be corn grain.

Calculations assumptions for crops destined to animal feed

Yields and water consumption for reference crops were gathered from Dono et al. (2013) and Katerji et al. (2008) to calculate the consumed water and the WUE for each feed category. Furthermore, three possible scenarios were hypothesized for corn grain production considering a high, medium and low WUE (from 1.38 to 8.00 kg of product per m^3). The lowest WUE considers unfavourable conditions and

whereas the highest WUE refers to forecasted future agronomic techniques (soil, fertilizers, water management, genetics, etc.) for cultivated crops.

Water consumed by natural cover of forest land and shrubland was assumed to be equal to 3500 m^3/ha, which were the lowest values suggested by Baldocchi and Xu (2007) in order to maintain a conservative approach in the estimation of WFP_{net}.

In order to obtain the values of blue water and green water consumption, expressed as litres of consumed water per kg of animal product, calculations were done separately for irrigated and rainfed forages and grains used for feed production and then summed up.

4.4. Results and Discussion

To evaluate the estimates of the water consumption for cattle milk and meat production, the main results of the calculations using the WFP and WFP_{net} methods are reported in Table 4.2.

For meat production**,** total green water consumption considering the water used by rainfed crops showed a WFP equal to 3714 and 10371 L per kg of biomass for high and low efficiency scenarios, respectively. Total blue water consumption for forage irrigation varied from 3429 L to 4629 L per kg of meat for high and low feed efficiency, respectively. As reported in Table 4.2, water consumed in the feed production process, expressed as L per kg of carcass meat, depended on the amount of each type of feed used in the diet. Total water (blue + green) consumption for forage and grain production ranged from 8143 L to 18491 L per kg of meat for the high feed efficiency, high WUE scenario and the low feed efficiency, low WUE scenario, respectively. By summing up the total water consumption for forage and grain production and the drinking and servicing water, the calculated total WFP ranged from 8214 L to 18591 L per kg of meat for the high feed efficiency, high WUE scenario and the low feed efficiency, low WUE scenario, respectively (Table 4.2). These values are in agreement with the literature on the WFPN approach, with an average value of 15400 L of water to produce a kg of cattle meat in irrigated farms (Mekonen and Hoekstra, 2012; Table 4.1). From our findings, low feed efficiency conditions, associated with a low animal performance, led to a higher WFP compared with the high efficiency conditions, with +91%, +69% and +43% WFP for high, medium and low crop WUE scenarios, respectively.

When the water calculation considered the fact that the natural cover has a considerable water uptake for ET, which was subtracted from the agricultural water needs, a strong reduction in WFP was observed, as demonstrated by the values obtained with the WFP_{net} approach (Table 2). In fact, for the calculation of the net green water consumption, 100% of the yearly water consumption by natural woodland-shrubland was subtracted from the values of water consumption by the rainfed forages and grains, whereas only 15% of it was subtracted from the irrigated forages and grains, accounting for the summer evapotranspiration of the natural cover only (Katerji et al., 2008). In our study, the net green water use in rainfed areas allocated to livestock production was negative, in agreement with Nisbet (2005).

The total net water consumption for forages and grains ranged from 690 to 6929 L of water per kg of meat for the low feed efficiency, high crop WUE scenario and the high feed efficiency, low WUE scenario, respectively (Table 4.2). The total WFP_{net}, obtained by summing up total net water consumption for forages and grains and the drinking and services water, ranged from 790 to 7001 L of water per kg of meat for the low feed efficiency, high crop WUE scenario and the high feed efficiency, low WUE scenario, respectively (Table 4.2). Those values of water consumption calculated with WFP_{net} were equal to 5% and 54% of those obtained with the WFP calculation, respectively. As expected, the WFP_{net} was higher for high feed efficiency scenarios, in which a large amount of feed from irrigated land was used in animal diets, than for low feed efficiency scenarios. The WFP_{net} values for meat are closer to the values obtained by Capper and Bauman (2013), who calculated a 3600 kg of water consumption for very high performance systems of meat production considering an average crop WUE.

For milk production, total water consumed for forages and grains, expressed as L of water per kg of milk, depended on the amount of each type of feed used in the diet, and ranged from 334 to 1109 L per kg of milk for the high feed efficiency, high crop WUE scenario and the low feed efficiency, low crop WUE, respectively (Table 4.2).

The total WFP, composed of the total water consumed in the feed production process and the drinking and services water, ranged from 341 to 1120 L per kg of milk for the high feed efficiency, high crop WUE scenario and the low feed efficiency, low crop WUE scenario, respectively (Table 4.2). Those values are in agreement with the values reported in literature using the WFN approach, with an average value of 1000 L of water to produce a kg of cattle milk in irrigated farms (Mekonen and Hoekstra, 2012; Table 4.1). From our findings, compared to the high feed efficiency scenario, low animal performance associated with low feed efficiency resulted in a higher WFP, which was equal to +214%, +216% and +198% for high, medium and low crop WUE, respectively.

The WFP_{net} of total consumed water for milk production ranged from 26 to 408 L of water per kg of milk for the low feed efficiency, high crop WUE and the low feed efficiency, low WUE scenarios (Table 4.2). Those values of water consumption calculated with the WFP_{net} method were equal to 4% and 63% of those calculated with the WFP method, respectively. As expected, the WFP_{net} was higher for high feed efficiency scenarios compared with low feed efficiency scenarios because a large amount of feed from irrigated land is used in animal diets in the first case. . From our results it appears that the production system with low feed efficiency had a lower WFP_{net} than the high feed efficiency scenario. This depended mainly on the larger use of rainfed land of the studied low feed efficiency livestock system, which is consistent with the typical livestock practices of the Mediterranean region, where a low amount of blue water is destined to livestock production.

4.5. Conclusions

Estimations of WFP and WFPnet carried out in this preliminary work highlight the differences between the two methods, with values of WFP being, on average, much higher than WFP_{net} values for both meat and milk. These differences confirm that the development of the WFP concept is still incomplete. The WFP_{net} method appears to be able to properly quantify the water consumption needed for animal food production, and we believe that the aspect of the green water source and destination should be updated. This work should stimulate discussions for further ecological considerations on the water balance in the planet and encourage a broad and detailed calculation to obtain values of WF_{net} specifically measured on real farm conditions and territorial scale.

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CHAPTER 5

5. Final remarks and Conclusions

5.1. Final remarks

Food is the door that allows us to go inside the culture and civilization of a region, a nation or a community, thus revealing to consumers the most unknown aspects of its history and traditions (Carlo Petrini, Fair Gusto 2016, Turin). Food is also livestock, genetics, agriculture, biodiversity, landscape and environment. Although these elements are in part external factors of the production process, they affect the quality and safety of food products, thus influencing directly the health, wellbeing and other aspects of local populations.

In industrialized countries, where there has been an increase in the spread of diseases linked to over-nutrition, such as obesity and diabetes, the population is willing to change eating habits, with a greater interest in organic production or vegetarian diet. In addition, intensive livestock production has been increasingly accused of harming animal health and welfare. This cultural and social change in eating habits should be taken into consideration in new ago-food development plans, in contrast to the consumerism culture focused mainly on the amount rather than the quality of food consumed. Analysts of the food sector believe that we are witnesses to a change in the food

paradigm, especially in American, where the "take way" food, such as McDonald's, has reigned for decades. This type of food has also colonized other cultures, such as European countries. Currently, the food model is changing, from the production and consumption point of views. In fact, there has been a major increase worldwide, particularly in the United States, of urban gardens, These areas have been created mainly for two reasons: a) in response to the unexpected urbanization of recent years, with a depopulation of rural areas and consequent land abandonment and drastic reduction in agricultural production, and b) due to the growing public concern about the quality and safety of the food available in the market.

Policies should get away from the logic of multinational enterprises, by planning appropriate strategies of intervention to ensure food security, through high quality and sustainability of agro-food products, with particular attention to the safeguard of environment, ecosystems, water resources, population health, animal welfare and landscape. However, this will not be sufficient, if plans for education and information of the population around nutrition are not implemented, starting from childhood. This actions aim at promoting correct choices of food products, whose quality and origin characteristics should be described on a special label attached to the product.

Globalization facilitates the exchange and transfer of goods across continents, from producing to not self-sufficient countries, on the one hand, but it penalizes local production systems, constituted by many small farms, on the other hand. In Italy there are millions of small agricultural farms which are experiencing the negative effects of globalization, because they are not able to compete with the cheaper products that arrive at the market. In the past few years, there has been a change from a mainly local production system to a highly globalized system, which is making many small agri-food producers to go out of business, with consequent depopulation and abandonment of rural areas. This theory is corroborated by the example of what has been happening to milk and derived products. For example, a large amount of dairy milk sold or processed, or both, in Italy is imported at a very low price from countries like Bulgaria, and part of Roman pecorino cheese is produced using sheep milk from Romania rather than milk from Sarda sheep. All this negatively affects the production chain and marketing, confounding uninformed consumers, who are attracted by products available at a lower price but with uncertified origin.

Consequently, Italian local producers, who are subject to rigorous quality control, are penalized, whereas those of other countries may be not. In particular, Italian producers must respect the Common Agricultural Policy (CAP) and regional RDP obligations, to ensure the quality and conformity of products to phytosanitary standards, and so on. Consequently, these producers are not protected from multinational speculations, which often put products of doubtful origin, such as those without appropriate phytosanitary certification, on the market. It is clear that the Italian agri-food sector, represented by many small production farms connected with the territory, could be saved and further protected by Community policies and by the choices of consumers, who should be well-informed. Finally, in the context of globalization, it will be possible to save the Italian agri-food system , if products of high quality continue to be produced and if consumers receive correct information about production sustainability, including livestock production, to counteract the massive, generalized and very often biased media campaign against products of animal origin and intensive production.

In conclusion, the Sardinian livestock landscape, especially the *Meriagos*, must be safeguarded and protected, not only because it represents the agro-pastoral culture, but also because it is a significant component of agro-forestry systems, which offer important ecosystem services, as it occurs in the *Dehesas* and *Montados* of Spain and Portugal. Livestock landscape is able to ensure sustainable production with low environmental impact and low water footprint.

The economic development of Sardinia must start from the territory, by avoiding the abandonment of the land and the consequent depopulation of rural areas. Regional and European Community policies should still do a lot to support the agro-food sector, focusing not only on the production process, but also on the externalities involved, mainly the landscape and agro-forestry systems. Effective information campaign should be conducted to enlighten consumers about the excellence of Sardinian products and production processes, by giving details about the internal and external aspects of production process which enhance their value and specific characteristics.

5.2. Conclusions

The livestock landscape is certainly the most important aspect of the geographical characteristics of Sardinia. Its current structure is the result of historical and remote processes which continue to occur, in part, in the current dynamics of environmental changes. A large part of the regional land surface is directly or indirectly allocated to livestock production, which constitute a vital sector for the economy of the Island and is an important way to utilize and valorize vast areas, particularly marginal areas that otherwise would risk abandonment. In addition, livestock-related activities play an crucial role in the protection of the territory, ensuring the management and control of many areas located very far from existing infrastructure.

It is important to highlight that extensive and intensive livestock production is the key element on which effective landscape management and protection actions should be implemented, including a continuous monitoring of the economic flows associated with this activity. In addition, it would be necessary to evaluate the social and anthropological aspects that should be considered to avoid and fight against the degradation of the valuable landscape framework in Sardinia, in order to be able to act on the principal variables of landscape evolution.

The Sardinian agro-forestry system, which is an important component of the livestock landscape, covers approximately half of the territory of the Island and is an essential environmental resource and food source for livestock in this Mediterranean region. However, it would be fundamental to reduce the stocking rate, with the aim of minimizing the effects of over-grazing on the landscape, so that a sustainable production model could be obtained. Furthermore, in some rural areas it would be necessary to implement adequate agronomic practices, in order to improve soil fertility, productivity and thus the ensure the sustainability of the agro-forestry system and livestock landscape. European Community policies have been supporting the competitiveness and sustainability of agricultural production, by defining the guidelines for the sustainable development of the territory.

As in the rest of Italy and large part of Europe, in Sardinia there is a great potential for the development of the agro-forestry system and livestock landscape. Therefore, policy actions should be mainly directed towards the support of the livestock landscape, by helping farmers properly.

Another critical aspect for the sustainability of livestock production, especially in the Mediterranean area characterized by extensive drought, is the assessment of the environmental impact by determining the water footprint, i.e. water consumption per unit of milk or beef meat produced. A new method to estimate the water footprint of livestock production, namely net water footprint (WFP_{net}) was compared with a traditional method, namely WFP. The WFP_{net} method evidenced the sustainability of cattle production (meat and milk) in a low feed efficiency production system, where pastures and natural meadows are the main food sources, rather than in a high feed efficiency production system. The first case, with greater sustainability, is found in great part of the extensive and semi-extensive livestock farms in Sardinia, in which approximately 80% of the diet is based on pastures and natural meadows.

In conclusion, this study on the environmental impact of livestock, based on two externalities, i.e. landscape and water footprint, evidenced the sustainability of livestock production in Sardinia. This information could be fundamental for future decisions made by the Regional Landscape Plan. However, it would be very important to conduct the assessment of the water footprint of sheep and goats, the main ruminant species of the island, starting from field data that could be collected on a representative sample of small-ruminant farms and then used for calculations using the most appropriate methodology.