Agroforestry systems as a technique for sustainable land management

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Preface

Preface

The Spanish Agency for International Cooperation and Development (AECID) has funded the II Edition of the Advanced Seminar on Agroforestry Systems for Sustainable Land Management within the framework of the Azahar Program on sustainable development and natural resource management. The seminar was organised by the University of Santiago de Compostela, The University of Extremadura, the CSIC (Spanish National Research Council, Estación Experimental del Zaidín, Granada), and the working group on Agroforestry Systems of the Spanish Society of Forestry Science.

The objective of the seminar was to share with scientists, managers, and technicians from the MAGREB countries and Palestine, knowledge of sustainable natural resource management, in particular, on the management of silvopastoral agroforestry systems that consider environmental, economic, and socio-cultural factors. These systems have been promoted by several international organizations such as FAO and the European Union. Agroforestry systems are key to rural development in that they combine income generation with environmental protection (biodiversity conservation, climate change mitigation) and enhanced landscape values.

In this seminar, Spain and Palestine and the MAGREB countries have developed a framework for the short, medium, and long-term cooperation with the establishment and evaluation of agroforestry systems, with an emphasis on silvopastoral systems that consider productive, environmental, and socio-cultural aspects.

The seminar provided a good opportunity to discuss various theoretical and practical aspects of agroforestry in a diverse range of environments (uplands, humid, and dry Mediterranean areas). Several members of forester and farming associations actively participated in the seminar as agroforestry practicioners involved in the management and conservation of authoctonous livestock in agroforestry systems. Special emphasis was also put on agroforestry systems and practices for the sustainable management of forest lands.

The content of this book represents the work presented at the seminar by scientists, university professors, and government technicians, as well as the papers and case studies developed by the participants. We would like to express our gratitude to all the authors and institutions involved for their collaboration. Finally, our most sincere gratitude also goes to the AECID for the financial support that made this seminar possible.

The editors

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General characteristics of the course field sites: Andalusia and Southeast Spain

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Mediterranean pastures and silvopastoral systems. Estación Experimental del Zaidín, Spanish Council of Scientific Research (CSIC). IFAPA-CIFA. Camino de Purchil s/n E-18004 Granada. Spain

The environment of Andalusia

Andalusia occupies a bio-geographic **transition** area between the South of Europe and the North of Africa, comprising a vast representation of the meridian environments of the continent (Mota et al. 1997). The following characteristics describe the Mediterranean climate: 1) a young and active orography; 2) a varied geology and soils; 3) a paleo-ecological history influenced by time and space; 4) a long history of human influence and transformation of the environment.

Geomorphologic units

In Andalusia it is possible to differentiate three large geomorphologic units. The first is the **Sierra Morena (I)**, located in the north of the Guadalquivir valley, with an average altitude of 600 m and the highest elevation of 1,323 m in Sierra Madrona (Jaén). The second is the **Guadalquivir valley (II)**, which is the extensive alluvial plain forming the main river valley in the region, with elevation ranging from 200-400 m. And the third is the Betic Cordillera **(III)**, the so called "Alta Andalusia" (or High Andalusia), that covers more than half of the region's land area, including the highest elevation of the Iberian Peninsula found in the province of Granada (Mulhacén, 3 481 m) (Junta de Andalusia 1989, 2007) (Figure 1).

Associated to these geomorphologic units, other large geological formations may be differentiated like: **Sierra Morena mountain range (1)** which forms its northern boundary with the Central Plateau (Meseta Central). It is composed of Precambrian and Paleozoic rocks formed during the Hercynian Orogeny and shaped by erosion. The **Betic Mountains (2)** form a young geological unit affected by the alpine lift and dominated by calcareous, Mesozoic and Cenozoic materials. And as a third unit, the **Neogene depressions (3)**: peneplains, valleys, and basins in-between mountains isolated after the alpine lift and filled with sediments of continental origin. Today, the most important agricultural lands of Andalusia are found in this unit (Junta de Andalusia 1989, 2007) (Figure 1).

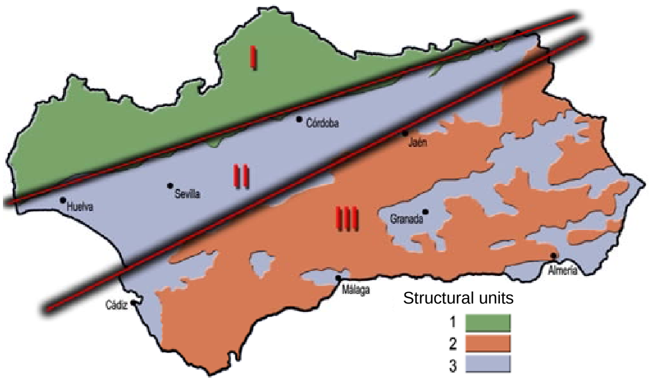

Figure 1. Morphologic and geomorphologic units of Andalusia: Sierra Morena (I), Guadalquivir depression (II), Betic Mountain (III). Geomorphologic units: Sierra Morena (1), Betic mountains (2), Neogene depressions

Climate

Various climatic gradients form the climate of the region (Figure 2). A west-east gradient of **humidity** is generated by the moist air from the Atlantic. This gradient results in an annual maximum precipitation in the West (with more than 2000 mm, the highest of the Iberian Peninsula, in the Sierra de Grazalema, Cádiz), and a minimum humidity in the extreme East, where the most arid soils of Europe are found (Cabo de Gata, Almería), with a total precipitation that seldom exceeds 200 mm of rain per year.

Table 1. Andalusia climate types: Oc=Oceanic; trop=tropical; cont=continental

Climate	Oc	Semi-cont (hot summers)	Subtrop	Semi-desertic	Semi-cont (cold winters)	Mountain
Annual mean temperature (º C)	17-19	17-18	17-19	17-21	13-15	12-15
Annual mean rainfall	500-700	500-700	400-900	<300	300-600	400-1000
Rainfall number of days per year	75-85	75-100	50-75	<50	60-80	60-100
Number of months of the dry period	4-5	4-5	4-5	6-8	4-5	3-4
Annual thermic range (ºC)	10-16	18-20	13-15	13-16	17-20	16-20
Number of frost days	free	2-20	free	0-10	30-60	30-90

A South-North gradient of **continentality** can be seen from the temperate coastal zone at the South, where it never freezes, up to North, with extreme winters. An altitudinal gradient from lowland to upland**,** which locally modifies these regional gradients of temperature and humidity, can also be found. In any case, whatever the variant, the Andalusian Mediterranean environment will never lose its defining characteristics: annual and interannual erratic rains and hot, dry summers. Table 1 shows distinct types of Mediterranean climate in Andalusia and its distribution (Figure 2) (Junta de Andalusia 1989).

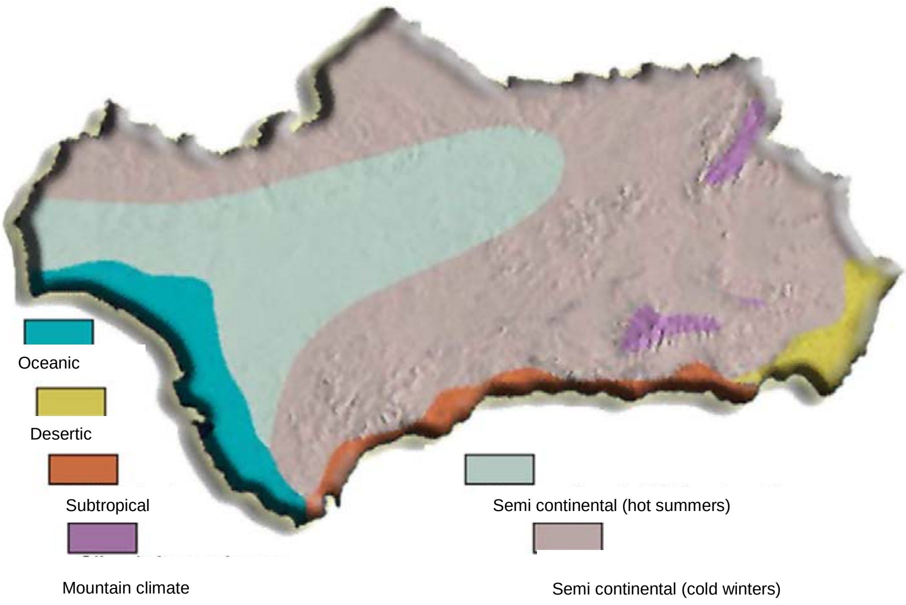

Figure 2. Mediterranean climate of Andalusia.

Landscape and natural areas

Far from the glaciers that covered most part of Europe, these southern lands have always been the refuge of the boreal flora and fauna during the glacial periods. The area supports some subtropical species that represent the only survivors of flora of the Tertiary period. There also are some remnants of African and eastern species that were present here during the drier periods in the Mediterranean basin. The natural landscape of Andalusia is therefore the result of these complex biogeographic, ecologic, and paleoecologic conditions and their interactions. With these elements, humans have directly or indirectly, constructed a mosaic of landscapes and agrosystems that now characterize the region.

Spain has the fourth largest protected area of the European Union. Almost 500,000 hectares are "priority" habitats, and the majority of these belong to the "exclusive" category. Almost 1,650,000 ha within the country enjoy some sort of legal protection (National parks, natural parks, reserves, etc.) (Table 2, Figure 3).

Table 2. Natural parks of Andalusia

Typology	Number	Area (ha)
National Parks	2	136,928.00
Natural Parks	24	1,394,531.95
Natural Sites	32	89,639.20
Natural Reserves	28	14,507.40
Agreed Natural Reserves	3	662.00
Natural Monuments	35	1,014.73
Periurban Parks	19	5,601.21
Protected landscape	1	2,706.00
TOTAL	144	1,647,597.57

Table 2 data shows a region rich in natural resources and valued landscapes. It is easy however, to observe a rapid transformation of the coastal, agricultural, and mountain landscapes.

The Andalusian coastal landscape has been undergoing an intense transformation in the last years due to the high volume of tourists, with irreversible deterioration of its natural resources. Furthermore, the expansion of cultivation in plastic greenhouses has created a landscape not really related to the agricultural landscape. Inland, the abandonment of rural areas and changes in land uses identified by the PAC have also contributed to the uniformity of the landscape.

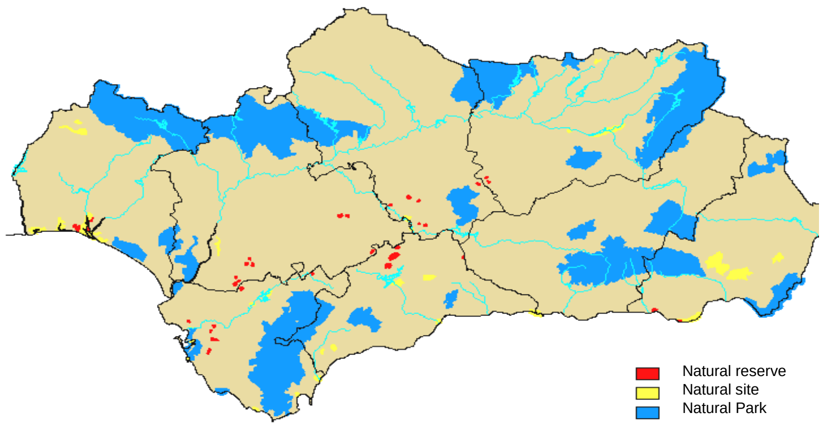

Figure 3. Natural spaces of Andalusia

The mountains have also suffered significant changes, and the abandonment of agriculture resulting from migration and the lack of incentives, coincides with serious soil erosion and subsidies that encourage destructive practices. Fires have continued to be the source of significant changes in the forest landscape, which is also under a varying degree of abandonment. There is also an increasing urbanization pressure occurring in the mountains which is manifested in changes in the population, new infrastructures, and new types of construction.

The abandonment of traditional livestock and grazing practices and the increasing use of enclosures and barns are putting the continuation of some emblematic systems such as the dehesa in danger, and the lack of grazing is facilitating the proliferation of shrub species, transforming open forest stands into dense formations highly vulnerable to fires.

Socio-economic context

Growth and distribution of the population

With a total area of 87,594 km², Andalusia is one of the most extensive regions within the European Union. It is also the most highly populated region in Spain with 7,748,449 inhabitants. Although the density of its population (85.4 inhab km^{-2}) is less than the European average (118 inhab km²), it is higher than the Spanish average (82.7 inhab km^{-2}) (Junta de Andalusia 2002).

The size of the population places Andalusia in the top of the Spanish Autonomous Regions, with population increases that only recently have slowed down. The population is relatively young and tends to be stable in terms of age groups. In the second half of the past century there was a notable incidence of migration, though presently Andalusia has experienced an influx of immigrants.

From the point of view of territorial distribution, the province of Sevilla has the highest population (23.5% of the total population of Andalusia), followed by Málaga and Cádiz with the 18.7% and 15.2%, respectively. Around 10% are found in each of the provinces of Granada (10.9%) and Córdoba (10.3%), making Jaén, Almería, and Huelva the least populated with 8.3%, 8.0%, and 6.2%, respectively.

The analysis of the population evolution shows a higher increase in the population nucleus with more than 100,000 new inhabitants in the last thirty years. Most of these however, are concentrated in the big cities. Although there is an increase in the demographic density in coastal areas, with a corresponding and notable decrease in the population inland, the region of Andalusia still has a large number of rural settlements throughout the region and a group of average-sized cities forming a settlement pattern which is characteristic of the region.

Marginal areas

At present, three types of marginal areas are considered to occupy more than 70% of the surface area of Andalusia (MAPA 2003) (Figure 4):

Zones with r**isk of depopulation/abandonment** (23 % of the surface area of Andalusia)**.** Included in these are those which have the following conditions: unproductive soils which are used only extensively, low agriculture development, and low population density and migration. In these areas, increasingly smaller populations will make it difficult to maintain viable economic and social activities with the consequent risk to the conservation of the natural habitat.

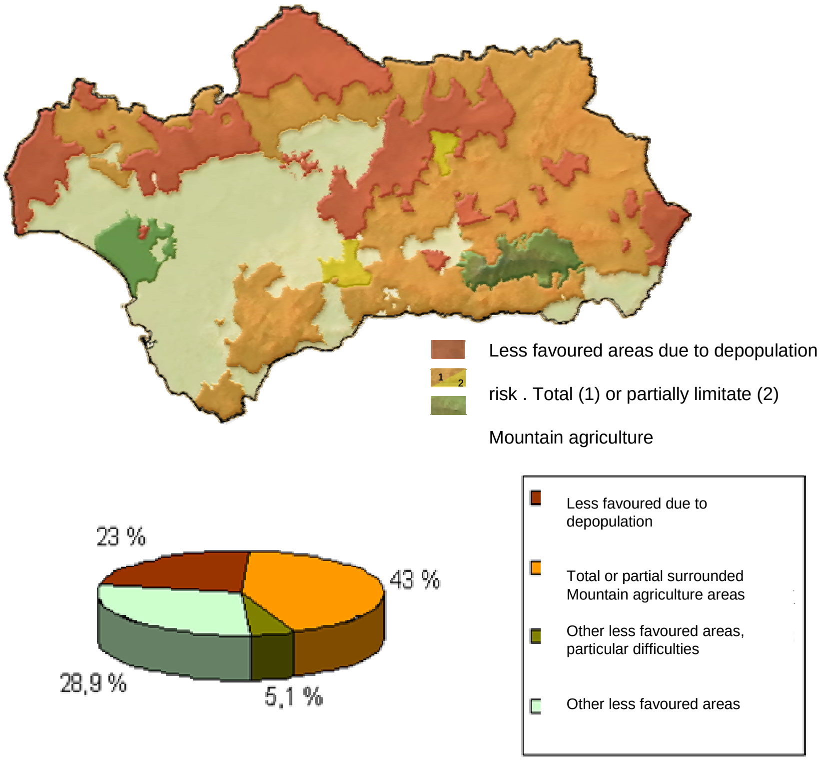

Figure 4. Less favoured areas of Andalusia

Zones of **mountain agriculture** (43 % of the land area of Andalusia)**,** are those above 1,000 m altitude which impose climatic conditions that result in short vegetative periods or those with more than 20 % slope that makes cultivation difficult. In addition are those areas with different combination of altitude and slope: zones higher than 600 meters with a minimum of 15 % slope, except in municipalities surrounded by mountains where 12 % slope is included, and referred to as "partially delimited" mountain agriculture.

Zones with **special difficulties (**5.1 % of the surface area of Andalusia), are those where the productive activities are limited to avoid impact on the natural habitat. These are zones where agriculture should be conducted following traditional practices that generally are an integral part of the landscape and have provided a place for well-defined ecosystems whose conservation is a priority.

The arid Southeast of Spain

Natural context

After Turkey, Spain is the European country with the most arid zones, (19 % of its territory) (Le Houèrou 1993). There are different xeric enclaves in the Iberian Peninsula, but the maximum aridity (annual Pp < 200 mm) is located in the so called "Southeast Region", comprised of part of the provinces of Albacete, Alicante, and most of Granada, Murcia, and Almería (Alcaraz et al. 1989; Montserrat and Fillat 1990). In these areas rainfall is low and erratic. As in all arid zones of the world, water is the most valued resource. The majority of the rivers of Southeast Spain are of irregular streams ("ríos-rambla"), with characteristic torrential episodes that often cause catastrophic flooding (Gil 1993). The annual average temperature is between 15º C and 21º C, and is never lower than 6º C. However in the interior highlands (800-900 m altitude) the Mediterranean continental climate is predominant (Albacete: figure 1), with frequent frosts. The wind is constant and the strong sunlight (around 2,900 hours year^{-1}) results in high levels of evapotranspiration (700 and 1,000 mm) (Gil 1993).

The strong orography of Southeast Spain is another factor that favours the diversification of environmental conditions. As a result, within just a few kilometres, it is possible to move from the hot and dry environment of the coast to the cold and humid high mountains of Sierra Nevada (3482 m.).

The combination of the climatic and orographic characteristics, the geologic history of these lands, and the different glacier and inter-glacier periods of quaternary has resulted in a diverse mosaic of climatic conditions and flora and fauna. Of the 636 Spanish vertebrate species, 400 species are found in Andalusia. With respect to the flora, it has more than 4000 taxa, which is more than half of the plant catalogue of Spanish flora. Spain is the country with the highest number of botanic endemisms in EU (Blanca et al. 1999), with most of them concentrated in the arid zones and in the high Southeast mountains. Sierra Nevada, for example, not only has the richest and most varied flora in the eastern Mediterranean region, but also the highest concentration of endemism in the whole of Continental Europe (Gomez-Campo 1987).

Land uses

The human presence in the south of the Iberian Peninsula can most likely be traced back to more than one million years (Campillo et al. 2006). Later, Arab cultures in the medieval period developed water technologies that have endured up until now (Rodríguez and Sanchez-Picón 2000). Our landscapes still show the presence of terraces (that retain run offs and sediment), *aljibes* or water storage tanks (to collect and accumulate rain water), and wells and watermills (to access the subterranean reserves). Presently, however, traditional agriculture is a residual activity, displaced by intensive greenhouse farming which leads to the drying up of the subterranean sources/water, salinization, and the over-exploitation of land.

With respect to the land use, a larger part of the land is used for cultivation (55 % of which: 35-40% irrigated, 65 % dryland agriculture), followed by non-agricultural lands (29 %), meadows and pasture lands (16 %), and forestlands (15 %) (MAPA 2002). The pastoral use is not limited to meadows and pastures, but includes land planted with cereals (dryland) and forests, as many of the wooded shrub species are eaten by the livestock and 20% of non-agricultural lands are occupied by steppe and shrubs. This results in a total of 65% of the territory that could be used for pasture (Robles and González-Rebollar 2006).

Final considerations

The diagnosis of our environment and the sustainable use alternatives for the management of its resources can not be based only on environmental characteristics. In Southeast Spain it is not possible to underestimate the reality of the landscape that surrounds us, how it responds to historical variables, both natural and unnatural, that have influenced human activity for centuries.

Our so called *natural landscape* is, in fact, an agrarian landscape. We can point to the Neolithic people as its first creators, but we will not make the mistake of attributing to the Neolithic the relevant elements that still make up this landscape. Our agrarian environment may have originated between 6000 and 8000 years ago, but the investigation of the natural systems and agro systems and the study of their distribution patterns, natural dynamics, and ecological interactions, reveal their roots in an more ancient past. We are speaking of one area of the world where man's presence seems to be documented from more than one million years ago, and in which the large herbivores of the past (the "designers" of the plant landscape) have been found in the main archaeological sites until recent times (Robles et al. 2001).

Therefore, we could ask ourselves: do we want to conserve a strictly natural heritage or the result of human action on the natural environment?

From these doubts, questions regarding conservation policies and to a large extent, development policies, emerge. The concepts of *protection*, *exploitation*, or *perturbation*, are in the middle of the debate.

In this context, to develop lines of investigation of the silvopastoral systems of Southeast Spain, means not only to address agrosystems adopted to extreme and changing climatic conditions, but to give value to the circumstances associated with its history and dynamic evolution, while not ignoring the constraints imposed in the past by factors such as fire, the pressure of herbivores, and human activity. And furthermore, to not neglect the obvious socioeconomic factors, by recognising the repercussion of the market on the landscape.

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The land and its resources, livestock, and forestry: Livestock resources of Andalusia

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Introduction

The natural resources of the land are taken into consideration from the perspective of how they support human activity. Human activity determines how the physical environment is perceived and in turn, determines how the landscape itself will be shaped. The agricultural exploitation of an area is conditioned by physical factors (basically soil and climate), and by the demographic and economic pressure on said territory, as well as the distinct perspectives of the national, regional, environmental, and local policies, most notably those of the Common Agricultural Policy (PAC).

Table 1. Development of agricultural macro-magnitudes (2nd estimation 008. MAPA)

Final Agricultural Production 2007	Euros (Millions)
Crop Production	24346.6
*Animal Production	14295.9
PFA	38642.5

*Animal production represents 38% of the PFA

One of these human activities is livestock production, which for Spain represents 38% of the final agricultural production (FAP). This value is lower than that of the European Union (EU) overall, in which it accounts for 50% (Table 1).

Table 2. Development of agricultural macro-magnitudes in Andalusia 2005 (Source: Junta Andalusia. Regional Government Department of Agriculture and Fishing, 05.03.08)

Final Agricultural Production in Andalusia 2005	Euros (In Millions)
Crop Production	8935.39
*Animal Production	1323.80
Other	297.59
PFA	10556.89

*Animal production represents 12.5% of the PFA

Table 3. Livestock census in 2005 (MAPA 2006)

	Spain	Andalusia	%Andalusia/Spain
Bovine	6484442	791712	12.2
Ovine	22749483	3146572	13.8
Goat	2904690	1107228	38.1
Porcine	24884022	2220807	8.9
Porcine (extensive)	2037853	691466	33.9
Total	59060490	7957785	13.5

The animal production in Andalusia is particularly low, contributing only 12.5% to the FAP (tables 2, 3 and 4), and holding the last place among all the Spanish regions in its relative contribution to the FAP.

Table 4. Livestock farming by province in Andalusia 2005 (%). (Source: MAPA 2006). Al: Almería; Ca:Cádiz; Córdoba: Co; Gr:Granada, Hu:Huelva; Ja: Jaén; Ma:Málaga; Se:Sevilla

	Al	Ca	Co	Gr	Hu	Ja	Ma	Se
Bovine	0.2	30.9	30.0	2.9	9.8	4.2	2.0	19.8
Ovine	9.3	8.3	17.3	20.4	11.3	8.2	6.5	18.8
Caprine	18.7	15.6	5.7	16.7	3.5	2.8	14.4	22.8
Porcine	17.5	9.2	11.5	5.6	9.4	5.9	14.5	26.4
Porcine (extensive)	0.0	15.6	19.6	0.0	28.7	0.0	3.6	32.5
Total	8.7	17.1	19.0	7.8	11.4	5.0	7.8	23.2

Furthermore there is a strong contrast between areas of high and low altitude in Andalusia, with the western part of the region standing out mostly for its large number of cattle, swine, and poultry (table 5).

Table 5. Development of agricultural macro-economics in Andalusia. Anuario 2005 (In millions of euros. Regional Government Department of Agriculture and Fishing, Andalusia 03/03/08)

Province	PFA	Crop Production	Animal Production	Other
Almería	1936.60	1763.28	124.00	49.32
Granada	996.88	827.22	138.92	30.74
Jaén	1899.20	1753.60	108.99	36.61
Málaga	888.57	698.34	159.70	30.53
Cádiz	830.44	632.81	171.57	26.06
Córdoba	1524.81	1238.29	244.83	41.69
Huelva	675.83	567.05	83.90	24.88
Sevilla	1804.44	1454.79	291.14	58.51

The decline of livestock production in both Spain and Andalusia began in the last century, following the Spanish civil war, when an accelerated increase of grain production occurred with the ploughing of woodlands, pastures, and uncultivated old agricultural land. This in turn resulted in a decline of flocks, especially sheep and goat, whose food was dependent upon the above mentioned resources. Later, the migration from the rural areas to the cities and the growing support of intensive livestock production strengthened by our entrance into the EU, provoked the abandonment of extensive livestock production methods and a rural depopulation, especially in the more disadvantaged areas.

Throughout Europe, in the middle of the last century, a great change in agricultural and livestock production has occurred, a period that has been called the ¨bountiful years”. This has drastically altered the model of a natural economy, replacing it with one of productivity. This is characterized according to Bowler (1996), by a resulting intensification through the use of inorganic fertilizers and pesticides, fodder composites and medical additives. Furthermore, advanced bio-technologies have been introduced accompanied by a potent mechanization, combined with farming concentration (lowering the number of farms while reaching greater dimension), as well as the specialization in cultivation (i.e. monoculture) or animal species.

The current environmental/agricultural policies are actually designed with an interest in reverting to such a model in order to occupy those lands through the development of an integrated livestock production that generates food of high quality. In other words, to return to more traditional agricultural practices, as indicated by Josefina Gómez Mendoza (2001), in which there is relatively low impact on the physical environment and where natural resources are managed in semi-natural circumstances conditions more akin to those modelled by the diversity of the countryside.

The Institute of Statistics of Andalusia, shows vast areas of land that could potentially be used for extensive livestock production during most of the year, both as natural grasslands and rough grasslands (750,653 ha), open woodlands (1,517,868 ha), previously agricultural, uncultivated land (687,211 ha), fallow land (611,319 ha), together with the cultivated fodder (145,772 ha) that surpass 40% of the total area of Andalusia. Properly managed, these areas could support huge herds and flocks comparable to those in other regions of Spain and those supporting livestock in other areas throughout the EU.

The Council of Agriculture and Fishing of the governing body of Andalusia has approved a regulation for an integrated farming production (BOE, 10.01.06), which will support a movement toward more sustainable practices and natural production methods. These methods, being more respectful of the environment, would ensure quality and safety of foodstuff as well as the conservation of the environment, while promoting the health and well-being of the animal.

Andalusia also stands out in its range of low-impact livestock farming in relation to its effect on soil. Based on the statistics of the Ministry of

Agriculture, Fishing, and Food (2006) 1267 of 2428 of the certified farms belong to Andalusia and constitute more than 50% of the total of nationally certified farms. Likewise, 293,824 of the 489,222 organic livestock and beehives in the nation are found in Andalusia.

The national census of cattle totals 6,463,547 animals compared to the 77.37 million throughout the EU, in other words representing 8.35% of the total bovine population of the European Union. This percentage puts Spain in third place as far as bovine population in the EU-25. The production of beef (715,331 t) totals 6.2% of the FAP, and milk production (6361.8 million litres) totals 6.6% of said final production.

Since the incorporation of Spain into the Common Market, there has been a reduction in the census of cows that produce milk, and contrarily, an increase in cows raised for beef, constituting 64% of the total cattle census.

Andalusia counts 791,712 bovines, 12.2% of the national census, distributed among 13,000 farms, which are located mostly in the provinces of Cádiz, Córdoba, and Sevilla.

In 2006, the EU-15 reported 95 million ovine, placing Spain in second place (with 23-24 million) behind Great Britain where there are 28 million, and Italy at a distant third with 11 million sheep. In 2007, in Spain, the production of lamb was 236,000 t (tons) of meat and 409.3 million litres of sheep milk.

In Andalusia, there are 18,300 sheep farms that shelter more than 3 million head, which represents 13.8% of the national total. The provinces of Granada, Sevilla, and Córdoba, are of particular note.

With regard to goat livestock, the Spanish census reports 2.8 million head, coming in second among countries in the EU behind Greece (5.9%) with 12 million animals. Our goat farms produced 11,800 t of meat in 2007, from the slaughter of goat kids, and produced 468,600 t of milk, used mostly for the production of cheeses, both pure and mixed. In our region, the number of goat farms exceeds 8000, with more than 1.1 million animals distributed throughout the provinces, with the greatest concentration in Málaga, Sevilla, Almería, Granada, and Cádiz.

After Germany, Spain is the second greatest producer of pork, with more than 2 million pigs in intensive farming conditions, representing 8.9% of the national census. These farms are concentrated mostly in the provinces of Sevilla, Almería, and Málaga. In addition, more than 700,000 pigs are raised in extensive farming conditions, principally those of the Iberian type, and are distributed primarily in the provinces of Sevilla, Huelva, Córdoba, and Cádiz.

The poultry farming census in Spain was reported at 47.23 million in 2006, supporting agricultural revenue with an egg production of 743.2 million Euros. Andalusia reported a population of over 6.05 million laying hens in 2004 (11.5% of the Spanish total), distributed among 5452 farms, and with an annual production of 118 million dozen eggs.

The production of poultry is one of the most important in Spain in that it represents the fresh meat most consumed in the country, second only to pork. In 2006, the final product of poultry yielded 1831.2 million Euros. In Andalusia this sector of meat production reported in 2004 was 228612 t, representing 18.4% of the total poultry produced in Spain, following Cataluña (MAPA 2006).

In Spain, the economic contribution of apiculture is 61.52 million Euros which represents 0.44% of the final farming production (MAPA 2007). Regarding the apiculture in Andalusia, 3000 farms were counted with more than 518,000 beehives.

The marine aquaculture of Andalusia, in 2005, produced 7400 t of fish, mollusc, and crustacean, generating 38.4 million Euros. Regarding continental aquaculture, the production in the same year was 2225 t, made up mostly of rainbow trout.

To conclude this introduction, we believe that it is important to note that all of the information regarding livestock records in Andalusia is derived from a unique database: Information System of Farm Management in Andalusia (SIGGAN). This information system is managed from the Regional Agricultural Offices and is available to assist farmers by providing consultations through the PIGAN (information points for the farmer). This organization registers and identifies animals, and is an important means of managing Andalusian livestock farming, through strict registration, improvements, animal health and assistance or tracking, that is, in all those areas that contribute to food safety.

Andalusian Farming in the presence of the new Common Agricultural Policy (PAC)

The duality of intensive and extensive livestock farming methods in the past decades in Andalusia, as in many other places, is set up in favour of the intensive method. This type of management leads to monetary growth and an increase in the number of animals, and is based on farming or ranching practices that are more distanced from the environment and its natural resources, and oriented toward the areas of the greatest consumption. Intensive livestock farming, as indicated by Soler et al. (2007), is characterized by increased monetary profit, but supported by high inputs of productive resources and also high sums of capital investment.

Previously, the PAC coined the concept of a European model of livestock production, determining the fulfilment of diverse requirements in the methods of animal production. The first of these is the production of safe and healthy food, and to ensure this, a set of prohibitions beginning with animal feed or fodder were established, by means of a list of prohibited prime materials. The second is certain restrictions in the use of specific zoo - sanitary products, as well as strict conditions for the use of molecules, and in particular the waiting periods. The third requirement sets out norms for the well-being of animals and imposed conditions for the farms, in design of facilities, shelter capacity, and livestock transport and slaughter. Furthermore, community norms were established with respect to the environment, requirements of notable importance over the next years.

In 2006, Spain began to apply PAC, which had been approved in 2003, changing the paradigm of production support for other support conditioned by means of rural development, conservation of agrosystems, and the increase of employment in disadvantaged areas, all of which are associated with extensive and semi-extensive farming methods.

PAC´s new reforms for the years 2008 and 2013, and in accord with Massot (2007), will address the disengagement of the production support and ultimately the surface that favoured the big farms consolidating the economic inequality between the producers. For this, the Community authorities have demonstrated a preference for the Single Payment (Pago Único), that most benefits smaller or family farms that are integrated in the rural setting and facilitate occupation of the same.

In the future, there will likely be a decrease of direct support on the part of the EU in the form of this Single Payment, or in those funds ¨attached¨ by the State Members in favour of funds directed to rural development that generate social and ecological benefit, thereby channelling these funds toward extensive method farming, especially those livestock systems producing high quality produce, such that the continuation and growth of these approaches is guaranteed, and consequently the expanded development of disadvantaged areas within Andalusia.

In this century, PAC went from an expense of 50,000 million Euros annually, representing 50% of the Community budget, to 43% in 2004, and the expectation is that it will be reduced further over the next several years (33% in 2013).

Equine farming in Andalusia

In regard to equine farming, Andalusia is known for its horse livestock, with a population of 69,372 horses of which more than 52,000 are Spanish Purebreds (Pura Raza Española). This breed is raised on 52% of the horse farms in Spain, and generates 210 million Euros in commerce (National Association of Spanish Purebred Horse breeders. Agroinformacion.com 12/07/2007).

The Spanish Purebred (Pura Raza Española) is actually classified as the ¨caballo andaluz¨ (Aparicio 1997), named so ultimately for the emerging importance of the horse population in the South, and because this is where the species originated. In accordance with the company Sanidad Animal y Servicios Ganaderos (Animal Health and Farm Services) TRAGSEGA S.A. (2003), 47.6% of the population of this breed is in Andalusia, followed by Cataluña (9.36%), Castilla-León (8.92%), and Castilla-La Mancha (8.2%).

Furthermore, the equine breed ¨Marismeña¨ recorded in the official catalogue as one of the livestock breeds in Spain under ¨protección especial¨ (special protection) is also found here. There are 300 of these purebred mares located in Doñana National Park (Herrera García and López Rodríguez 2007). The breed Hispano-Árabe (Hispanic-Arabian) can also be found in Andalusia, with a census of 4638 on record in the Libro Registro (Registration Book).

Table 6. Equine farming Census in Andalusia. 2006*

	Horse	Mule	Ass	Total
Almería	1635	229	413	2277
Cádiz	6637	508	297	7442
Córdoba	2765	294	214	3273
Granada	7687	746	596	9029
Huelva	9499	1657	714	11870
Jaén	6263	428	418	7109
Málaga	8962	601	503	10066
Sevilla	25924	2083	1435	29442
Andalusia	69372	6546	4590	80508

*DGPAgraria/Estadisticas/estadisticasagrarias/censoequino 06

Among other equine species, Andalusia maintains a population of 6546 farm mules that fulfil farm work and transport. One breed, "Gran Raza Asnal Andalusia", originates from the countryside of Córdoba (Jordano 1974), with a population of roughly 290 animals in Andalusia of the 4590 counted. The census of farm equines in Andalusia is shown in table 6.

Cattle farming in Andalusia

Cattle or extensive ranching

The extensive bovine management in Andalusia is reflected in the 434,282 cattle found there. They are distributed among the following indigenous breeds: Retinta, Berrenda en negro, Berrenda en colorado, Cárdena andaluza, Mostrenca palurda or Marismeña, Negra andaluza and Pajuna. The largest proportion of these populations is found in the western area of Andalusia, coinciding with the vast area of dehesas. The number of ranches and livestock are presented in table 7.

Table 7. Extensive cattle ranching in Andalusia *

Province	Number of Farms	Census
Almería	29	823
Cádiz	2804	138167
Córdoba	1963	98870
Granada	247	7212
Huelva	1473	62687
Jaén	364	30841
Málaga	235	7562
Sevilla	1354	93100
Andalusia	**8469**	**434282**

*SIGGAN (Andalusia Government, November 2006)

In Andalusia, more than 300,000 calves are born of those breeds mentioned, or hybrid by indigenous cows with bulls of foreign, improved breeds (Charolés or Limusine), but the majority are fattened and slaughtered in other Autonomous Communities, with the consequent loss of all the added value (Díaz and Santos 2007).

As with other species, the large majority of the animals are destined for meat production, leaving Andalusia still living, which accounts only for a total number (steer, calves, cows, and bulls) of 116,729 cattle slaughtered, with a carcass weight of 26,746 tons. The consumption of beef in Spain is quite low; 7.7 kg per person, per year, compared to the 20 kg (per person, per year) of average consumption in the EU overall.

Dairy cattle

In 2005, Spain counted a total of 1017934 dairy cows, with a total of 77,164 or 7.6% of the dairy cows of the country in Andalusia. This number reflects a continuing decrease since 1986, in which 121,552 animals were counted. At present the milk quota is 450,663.03 t, which represents 7.34% of the national quota (MAPA. Secretaría General Técnica. Boletín 09/10/06). The milk cow is distributed mainly throughout the Pedroches in Córdoba, the Valley of Gualdalquivir, the areas of Jérez and Chipiona in Cádiz, and in Vega, Granada.

Table 8. Frisona milk cows in Andalusia *

Province	Number of Farms	Census
Almería	27	443
Cádiz	499	7180
Córdoba	760	26861
Granada	103	4055
Huelva	54	70
Jaén	82	3654
Málaga	165	2248
Sevilla	394	6904
Andalusia	2084	51415

*Regional Government Department of Agriculture and Fishing (2007)

The breed that is the principle milk producer in Andalusia is the Frisona, or Holstein Friesian (an American breed) with a total number of animals (including calves, cows, and bulls of all ages) of 104,012 head in our Region. These are distributed among 2084 ranches $farms^{-1}$. A cow census of over two years old Frisona milk cows according to province is shown in table 8.

Fighting bull breed

One resource very particular to Andalusia is the fighting bull or fierce livestock, ¨toro¨, which occupies large areas of pasture, dehesas, and natural parks in Andalusia, the community that dedicates the most land to the growth and selection of fighting bulls; an area of 151,135 hectares. It is important to consider that it was in Andalusia where the principal foundational breeds were developed (i.e Vistahermosa). We must remember the importance of the Vistahermosa breed, which was developed in the municipality of Utrera (Sevilla), and from which practically 95% of all fighting bull breeds were derived (Jimenez et al. 2007).

Spanish fighting bulls consist of 135,000 animals of reproductive age, more than 40,000 in Andalusia, that are integrated in four ranching/farming associations: the “Unión de Criadores de Toros de Lidia” (Fighting Bull Breeders Union) or UCTL, that represents 334 of the most prestigious ranches, 130 of which are Andalusian; “Asociación Nacional de Ganaderías de Lidia” (National Association of Fighting Bull Ranchers) which includes 406 members, 88 of which reside in the South, and the rest distributed between the “Agrupación Española de Ganaderos de Reses Bravas” with 203 members, and “Ganaderos de Lidia Unidos” with 166 of which 132 members are Andalusian. And finally, the remaining 48 are registered as fighting bull ranchers. Throughout Spain, in 2005, there were 1157 fighting bull breeding businesses, occupying roughly 540,000 hectares of dehesa where 32,648 fighting bull calves were branded.

Regarding the environmental interest, Lorca (2007) indicates that the fighting bull acts as a defender of the environment, representing an ecological value of the first order, and is a crucial factor in the maintenance and survival of the dehesas. In general, livestock constitutes the principle productive source of the dehesa in that at the same time it provides protective control of invasive scrub or brush, it provides fertilizer and accelerates the nutritive cycles, all factors resulting in an improvement of the pasture.

The economic importance of bullfighting is shown to us by the "Asociacíon la Mesa del Toro" (2008) which reports the annual movement of 2500 million Euros in Spain, generating nearly 4 million work days, with 1200 cattle companies, 378 permanent jobs, and 2950 temporary jobs. Furthermore, 17,000 festivities are celebrated in 5600 municipalities, and 40 million seats sold a year, reflecting the position of bullfighting as the second most important spectacle of the masses in the country.

In Andalusia, during 2007, 1208 bullfights were celebrated (major festivities: corridas, novilladas, and rejones), the highest figure in the last decade, in which 5800 head participated in bullfights, and with the attendance of 3,068,653 spectators, which represented an increase of 9.2% from the year before (WEB Consejería Gobernación. Junta de Andalusia 2008). The bullfight ranchers receive Community subsidies for extensive bovine management that reached 224.15 Euros per nursing calf, a year.

Sheep farming in Andalusia

Ovine production is the most important, at least based on the number of animals in Andalusia, numbering 3,146,552 animals in 2005 and representing 13.8% of the national total. 96.4% of these were farmed in extensive management systems, with the remaining fraction raised in intensive systems and destined for the production of milk. The provinces of Córboda with 30% of the Andalusian count, followed by Granada (17.5%) and Sevilla (15%), are where this sector of farming is concentrated. The distribution according to province is shown in table 9.

The principal breed raised in Andalusia is the Merino, with 26% of the total merino sheep in Spain, and located mainly in the north of the provinces of Huelva, Sevilla, and Córdoba. Another species is the Merina de Grazalema, considered in ¨danger of extinction¨ with only 4500 head, occupying the National Park of the same name and the Sierras of Cádiz and Ronda. Also, there is the Merina negra with 514 animals, found in Western Andalusia. In order to improve the Merino breed, especially in the production of meat, a number of crosses with foreign breeds have been conducted: Merino precoz, Landschaf, Merino Fleischschaf, and Ile de France.

Table 9. Extensive ovine farming in Andalusia *

Province	**Number of Farms**	**Census**
Almería	1207	222504
Cádiz	1016	122852
Córdoba	3785	887150
Granada	2012	516093
Huelva	2387	257558
Jaén	1630	305324
Málaga	1184	202124
Sevilla	1652	438298
Andalusia	**14873**	**2951903**

*SIGGAN (Andalusia Government, November 2006)

The Segureña breed is the second largest population in Andulucia, is concentrated primarily in the north of the provinces of Granada and Almería, and also can be found in their coastal zones where agricultural sub-products can be used as in the Sierra Morena in Jaén (¨pontonera¨) where fine quality meat from ¨corderos ligeros¨ (light lamb) is produced (Cano 2001).

There are small numbers of other breeds in Andalusia that are in danger of extinction: the Churra Lebrijana or ¨marismeña¨, located in Lebrija, and in the marshes of the Doñana National Park, with roughly 200 of reproductive age (Juárez et al. 2007); the Montesina ¨ojinergra or ¨granadina¨ found in the countryside of Iznalloz, Montefrío, Alhama, and Alpujarras in the province of Granada, the Sur Sierra, Mágina Sierra and Carzorla Sierra in Jaén, and the Alto Andarax in Almería, with 6000 animals very influenced by the Segureña.

In counting the total number of animals (lambs and mature sheep) slaughtered, the annual statistic from MAPA (2006) reports 14,466,613 animals in Spain, and of those, 394,130 in Andalusia (2.72% with 13.8% of the national livestock), indicating the departure of living animals that are not slaughtered in this region. This is reflected in the statistics concerning meat production: 4909.5 t compared to the national total of 231,453 t (2.12%).

In evaluating sheep in so far as milk production, there are three breeds that stand out: Churra, Manchega, and Latxa. The milk of these breeds is used for cheese production, largely at the industrial level. In Andalusia, 3.6% of the census is produced through intensive management and with the goal of improving the production of milk from the sheep breed ¨Lacaune¨, which has been imported from France. The register of the Spanish Association of Lacaune Sheep Ranchers shows 29,500 sheep of reproductive age in Andalusia distributed among the provinces of Córdoba (17000), Huelva (5500), Jaén (5000), Sevilla (1000), and Granada (1000). Two other breeds that have been imported (from Israel) with the goal of improving milk production, are Awassi and Assaf. The second breed comes from the first when crossed with the German breed: East Friesian.

According to the annual statistics of MAPA (2006), sheep milk production in Andalusia was 1,722,000 litres in 2005, and was produced throughout the provinces of Huelva (1,026,000), Sevilla (540,000), Cádiz

(81,000), Granada (63,000), and Córdoba (12,000). These low figures do not correspond to the number of indigenous sheep being milked nor to the high population of sheep that have been selectively introduced.

Goat farming in Andalusia

The Andalusian goat is the most important in Spain, as much for the sheer population as for milk production, and is counted among the most important indigenous breeds on a worldwide level, including Malagueña, Granadina, and Florida.

In 2005, a total of 2,904,690 animals were counted in Spain, 1,107,228 of those in Andalusia, which represents 38.1% of the total population, yet producing more than 50% of the nation´s milk, further confirming the genetic quality of the breeds found in Andalusia.

Table 10. Intensive goat farming in Andalusia *

Province	Farms (number of)	Census
Almería	745	73862
Cádiz	689	72141
Córdoba	165	21009
Granada	465	69975
Huelva	71	3603
Jaén	216	13479
Málaga	775	172074
Sevilla	492	70091
Andalusia	**3618**	**496238**

*SIGGAN (Andalusia Government, November 2006)

Goat farming is divided between intensive management for the production of both milk and meat from young animals, and extensive and semi-extensive methods which are used in the production of meat and the production of residual milk once the kids have been weaned.

The distribution of goat farms dedicated to milk production according to province is shown in table 10. Those provinces with the highest production are Málaga with 34.7% of the dairy goats of Andalusia, followed by Almería

(15%), Granada (14%), and Sevilla (14%), which also are the provinces with the highest goat milk production (in millions of litres): Málaga 75.03; Almería 49.34; Granada 32.85; Sevilla 29.05; Córdoba 23.04; Cádiz 20.00; Jaén 9.39, and Huelva 8.41.

Table 11. Extensive goat farming in Andalusia *

Province	Number of Farms	Census
Almería	662	72992
Cádiz	228	36850
Córdoba	260	49294
Granada	439	66868
Huelva	991	55368
Jaén	521	34948
Málaga	564	102392
Sevilla	345	71808
Andalusia	4010	490520

*SIGGAN (Andalusia Government, November 2006)

The extensive management farms (table 11) contain animals not selected from the breeds with high milk production aptitude, and denote hybrid and indigenous breeds that are chosen for their exceptional meat. The Blanca celtiberica found in Almería with some 2800 head; the Blanca serrana andaluza or the Blanca cordobesa, spread throughout the mountains of the provinces of Córdoba, Granada, Almería, Huelva, Jaén, and Sevilla, with a total of roughly 9000 animals. Also included is the negra serrana or castiza de capa negra or cardena, located in the province of Jaén with 6800 animals, and finally the Payoya or ¨montejaqueña¨, found in the Sierra de Grazalema Natural Park and extending to the Serranía of Ronda, a goat known for its milk that is used in the production of ¨payoyo¨ cheese (González Casquet 2005; Herrera and Luque 2007).

Porcine farming in Andalusia

Of the 24.88 million pigs that Spain reported in the 2005 census, Andalusia had 2.22 million, 9% of the national total and of those, 762,421 were Iberian Pigs that make use of the ¨montanera¨ (acorns), with 84,560 animals of reproductive age (Livestock Farming Census. Service of Studies and Statistics and the SIGGAN Program Regional Government Department of Agriculture and Fishing of Andalusia 2006) (Table 12).

In totalling the white pigs that are produced intensively, one finds a high concentration in the provinces and Almería, Sevilla, Málaga, and Jaén, that constitute 79% of the density of this breed of pig in Andalusia, with a large increase in the last years. These swine actually belong to precocious foreign breeds, introduced many years ago (Large White, Landrace, Pietrain, Blanco Belga, Wessex Saddleback, Duroc Jersey), as well as their hybrids.

Table 12. Distribution of porcine farms in Andalusia 2005 (SIGGAN 2006)

Province	Porcine (Intensive)	Porcine (Extensive)
Almería	475498	0
Cádiz	65165	39214
Córdoba	98622	219703
Granada	162530	2766
Huelva	80096	240531
Jaén	221670	2763
Málaga	375471	27776
Sevilla	418224	229663
Andalusia	**1897276**	**762421**

The great majority (90%) of the extensive systems are found in Huelva, Sevilla, and Córdoba. The animals used in this type of system are from different lines of Iberian swine as well as their hybrids with improved breeds of dark-skinned swine, especially the Duroc, and having previously yielded inferior results with the Large Black, Berkshire, and Tamworth.

In table 13, the production of swine in 2006 expressed in tons, as well as the number of animals slaughtered in the various provinces are noted, as reported by the Annual Statistics of the Regional Government Department of Agriculture and Fish of Andalusia.

Table 13a. Animals slaughtered and pork production in Andalusia 2006

Province	Number of Animals	Meat (tons)
Almería	85117	6502.0
Cádiz	64609	6502.0
Córdoba	252440	24658.6
Granada	345438	31537.6
Huelva	362844	46829.0
Jaén	460417	32952.9
Málaga	1649310	122141.8
Sevilla	224983	18609.4
Andalusia	3445158	289556.6

Table 13b. Production of ham and cured ¨paleta¨ (shoulder) in Spain*

Product	Units
Cured ham from white pig	33222000
Cured shoulder from white pig	3612893
Iberian ham:	2699287
acorn	439984
acorn, pasture, supplements of grain	615437
commercial feed	1643866
Iberian shoulder:	1993320
acorn	370758
acorn, pasture, supplements of grain	448497
commercial feed	1174065
Total units	41527500

*CONFECARNE 2003

Our country has a self-supply rate of 125% with the swine sector being the most important in regard to exportation, totalling 21% of production. This exportation has been directed to countries within the EU and Asia (Singapore, Japan, North Korea, and Hong Kong). In 2007, a new record was achieved with regard to the exportation of Spanish pork, with 736,000 tons exported at a value of 1,350 million Euros. Recently an agreement has been signed (15/11/07) with the People's Republic of China regarding meat and cured meat product exportation. The exportation of pork presents certain difficulties, one being that some of our areas suffered the Aujeszky sickness which must still be eradicated. Most importantly however, the average cost of pork production in the EU is 1.32 Euros per kilo, while in other countries, like Brazil for example, the average cost is 0.73 Euros per kilo, thus creating difficult competition.

Worldwide, Spain is the leading producer of cured hams and "paletas" (i.e. pork shoulder) with a production exceeding 41.5 million units in 2003. Ham represented 86.5% of this total, and "paletas", the remaining 13.5%. Spain is also the greatest consumer of these products, and consumes on average 5 kilos per year per inhabitant.

Rabbit production in Andalusia

According to Angulo (2003), the rabbit is without doubt the mammal most numerous along the Iberian Peninsula, while Cruz reported (2002) that insofar as the domesticated rabbit, there were 2,983,737 females of reproductive age, with a total of 16,323,081 animals of varying age and sex. In that same year, 8.1% of that total could be found in Andalusia. More recently, in our region, according to the General Register of Farming (14/02/2007) of the Regional Government Department of Agriculture and Fishing of Andalusia, roughly 94,000 rabbits are raised.

The EU-25 production of rabbit meat was 515,000 tons in 2005. The foremost producer in the EU is Italy at 225,000 tons, followed by Spain at 108,000. This figure corresponds to the slaughter of 91 million animals, which puts Spain in second place in production in the EU and third place in production in the world, after China and Italy. For Spain, rabbit meat comprised 1.5% of the overall meat production in the year 2005, 4.5% of which was exported, mostly to Portugal, France, and Italy.

The areas of the largest number of rabbit farms can be found in Cataluña (30.3%), Castilla la Mancha (22.6%), Aragón (10.4%), Communidad Valencia (7.8%) and Galicia (7%). The last National Survey of Rabbit Farming in the year 2003 showed the existence 5,644 rabbit farms throughout Spain.

The rabbit meat production originates in the 94 slaughterhouses recognized at the state level. The average live weight of the young animals that are slaughtered is 1.97 kilos, which translates to 1.14 kilos of cleaned carcass, whereas the weight of rejected animals corresponds to 3.08 kilos with a carcass weight of 1.71 kilos.

The actual consumption of rabbit meat is estimated at between 3 and 4 kilos per inhabitant, per year. Although the data of MAPA were much lower (at 1.38 kilo per person, per year), it should be considered that with this meat, there is a large degree of self-consumption. The demand for rabbit meat is more centralized in the northeast area with Levante being the region of the lowest consumption, with .53 kilos, per inhabitant, per year (MAPA 2000).

Regarding the wild rabbit, the Regional Government Department of Environment (2003) qualified as ¨optimal¨ the density levels of the wild rabbit in the Andalusian territory, following the last census in February. According to these data, the average density in Andalusia is 13.01 animals per square kilometre.

Poultry farming in Andalusia

Poultry farming in Spain is an activity of the first order, with a census of laying hens that reached 47.23 million in 2006, generating an agricultural income of 743.2 million Euros in the final production of eggs. The productivity is also significant in relation to the EU-25, where Spain is among the top positions, not only in the production of eggs (1128.7 million dozens) but in terms of the number of animals (13.2% of those in the EU), and with a commercial balance that results in higher exportation. In 2006, Spain exported 197,436 tons of shelled eggs to the EU, and imported 37,824 tons, according to the Taxes Agency of the EU (Department of Customs and Special Taxes of the EU).

The 2004 census of chickens in Andalusia numbered roughly 6.06 million laying hens, which is equivalent to 11.5% of the overall Spanish census for that same year, and a production of 118 million dozens per year, corresponding to about 230-240 eggs $year^{-1}$ hen^{-1}. 95% of these are selected hens or interlineal hybrids of the Rhode-Island and Leghorn breeds, and the remaining 5%, are those called ¨camperas¨ of the Ultreranas varieties, or of the Castellana negra, Andaluza azul, or Prat leonada varieties.

The consumption of fresh eggs in the Spanish home reflects a decline, and according to the data published by MAPA, in 2006 the average consumption was 195.5 eggs, per person, per year.

Table 14 shows breed type, number of farms, and poultry census in Andalusia, reflecting data obtained by the General Farm Register (20/04/2007).

Table 14. Breed type, Lumber of farms and poultry census in Andalusia

Farm Type	Number of Farms	Census
Organic Production	11	25845
¨Campera¨	6	8923
Free-range	3	32280
Caged	1840	4636257

In regard to the distribution among provinces, Sevilla is in first position with approximately 50% of the egg production in Andalusia, followed by

Málaga (19.2%), Córdoba (9.6%), Cádiz (9.3%), Granada (4.8%), Jaén (3.3%), Huelva (2.7%), and Almería (1.6%).

Poultry farming is one of the most important agricultural pursuits in our country, being the meat most consumed fresh, and the second most consumed overall after pork, and representing 3.9% of the overall agricultural production and 11.4% of the total production of livestock. In 2006, the production of poultry in Spain exceeded one million tons, representing a value of 1831.2 million Euros, and coming in as the second biggest producer in the EU. On the other hand, the commercial balance of poultry in Spain is usually negative, with the importation during the same year at 152,458 tons (mainly from France, Germany, Great Britain, Holland, Italy, and Portugal) and the exportation of 73,275 tons. The poultry consumption in Spain during 2006 was 30.4 kilos per inhabitant, per year, with one percent self-supply of the 94.3%. The breeding for meat in Spain numbers 4,021,000 animals, representing 13.2% within the EU-25.

The poultry sector for meat found in Andalusia is among the most outstanding, in 2004 producing 228,612 tons or 18.4% of the total poultry produced in Spain (1268317 t) and is the second largest producer after Cataluña (MAPA 2006). The number of poultry farms is shown in table 15.

Table 15. Number of poultry farms by species in Andalusia

Poultry Type	**Number of Farms**
Hen	1332
Turkey	281
Guinea fowl	10
Duck	13
Goose	9
Quail	27
Dove	33
Pheasant	22
Partridge	73
Ratite	84

Turkey production in Spain in 2005 was 21,000 tons (only 1.1% of the EU), with 3.4 million animals slaughtered, with carcasses of an average weight of 6.0 kilos, and along with that a supply of 120,000 living animals imported exported (MAPA 2006). In Andalusia along with the intensive production of commercial hybrid turkeys, a smallholder production exists with rustic bronzed or black turkeys, or white turkeys of smaller size (Fernández Cabaña and González Redondo 2007).

Table 16. Production of poultry meat of other species 2003

Poultry Type	Meat Production
Quail	9300
Partridge	470
Capon	147
¨Pularda¨	5
Pheasant	44
Duck	8000
Ostrich	187
Guinea Fowl	140
Squab	47

The 2003 tabulations of the production of other species of fowl in Spain, provided by the statistics of MAPA (2004), are shown in tons in table 16.

Apiculture Sector in Andalusia

In Spain the economic contribution of apiculture is 61.52 million Euros, which represents 0.44% of the final agricultural production (MAPA 2007). Despite of the small representation of this activity in national revenue, there is great value in the pollinating function of the bee as a species. Nowadays, this production suffers great competition from the Asian countries (China, Turkey, and Vietnam) and from South America (Argentina and Uruguay) because of the low price of their honeys, though the honeys of Spain, in their defense, are of a higher quality and greater safety.

There are roughly 3000 farms that are dedicated to the production of honey in our region, with more than 390,000 beehives and honey production of over 6 million kilos, yielding over 12 million Euros in direct sales, combined with 150,000 kilos of pollen and 405,000 kilos of wax. More than 19% of the national total in this sector is produced in Andalusia (La Besana 2008).

Aquaculture production in Andalusia

Andalusia has 912 kilometres of coastline, 2281 km^2 of inland bodies of water, and 13,935 km^2 of ocean territory, with a potential area of 35,000 hectares for aquiculture use, while at this time only 7785 hectares are being used. The great ranges of resources, that are available throughout the varied ecosystems of Andalusia, are well-suited to aquaculture. This production sector is currently concentrated in two main areas: the South Atlantic (Huelva, Sevilla, and Cádiz) where there terrestrial cultures are sited in excavated ponds and intertidal mollusc parks; and the South Mediterranean (Málaga, Almería, and Granada) with cultivation systems such as floating cages, troughs, and what are referred to as ¨long lines¨ (del Valle 2007).

Table 17. Production of fish, mollusc, crustaceans and young fish in 2005

Species	tons
Fish:	7400
¨Mahi Mahi¨	3600
Sea Bass	2140
Tuna	292
Striped Mullet	103
Others	1265
Mollusc:	1032
Mussel	952
Japanese clam	53
Other	27
Crustaceans:	153
¨Camarón¨	98
Japanese Prawn	55
Young Fish	42000000

According to the Regional Government Department of Agriculture and Fishing, the marine aquaculture production exceeded 7400 tons during 2005. This can be distributed among fish (6213 tons) mollusc (1032) and crustaceans (153), with a value of 38.4 million Euros. By species, the majority of the production was the ¨dorada¨ (¨mahi mahi¨), accounting for 65%, followed by the ¨lubina¨ (sea bass).

Of this total, 50% was produced on ¨on land¨ marine farms, 35% in troughs, with 12% in floating cages, and the remainder in the intertidal mollusc parks. Regarding the fattened fish species, the ¨dorada¨ or ¨mahi mahi¨ (3600 t) and the ¨lubina¨ or sea bass (2140 t) lead the way in production, followed by ¨atún¨ or tuna (292 t) and the ¨lisa¨ or the striped mullet (103 t). In 2005 the production of mollusc was also of note, with the mussel (952 t) and the Japanese clam (53 t); and the crustaceans such as the shrimp (98 t) and the Japanese prawn (55 t). With the cultivation of this last species, Andalusia is acting as a pioneer on the national level.

Regarding aquiculture production and the distribution among the provinces, Cádiz was the first with 2025 tons, followed by Almería (1868 t), Huelva (1696 t), Málaga (812 t), Sevilla (634 t), and Granada (363 t). In Andalusia, there are 82 businesses operating in the marine aquiculture sector, where an area of 7785 hectares is cultivated, and more than 600 jobs generated. Along with this, the activity in this area produced 42 million young fish, which translated into 11 million Euros on the market. Worldwide, Spanish aquaculture provides 3% of the production volume. And in Europe, our country provides 25% of the volume, distinguishing Spain as the most important producer for Europe in this sector (FAO 2004).

Regarding the continental aquaculture, which is based on a high quality of aquatic resources, the rainbow trout is the most cultivated species. In 2005, the Autonomous Community of Galicia was the principal producer with 7794 tons, followed by Castilla-León (6328 t), Castilla-La Mancha (3084 t), Andalusia (2225 t), Aragón (1823 t), Cataluña (1811 t), and Asturias (1573 t). To a lesser degree in Andalusia, there has been a development of the cultivation of sturgeon (102 t) and marsh crabs (5 t).

Table 18. Continental aquaculture production

Species	Tons
Rainbow Trout	2225
Sturgeon	192
Marsh Crab	1.3

Conclusion

In this review, an attempt has been made to summarize the farm patrimony of Andalusia, highlighting principle breeds that are raised here with special attention given to the indigenous breeds of the area. A comparison has also been made between the census throughout the nation, throughout Europe, and the distribution of production among the provinces. Furthermore, the locations where the higher numbers of those species and breeds are found, together with their production and resulting contribution to the total agricultural income have been presented.

Frankly, the livestock production in Andalusia is low, coming in at last place of all the Autonomous Communities because of its relative contribution to the final agriculture production, only 12.5%. However, there exists a strong difference between the production in the high versus low areas of Andalusia in favour of the western part, where the highest census in equine, bovine, swine, and fowl are found, and bear notice.

The transcendence of Andalusian farming on a national level consists principally of the reserve of indigenous breeds, especially the bovine breeds. Among the bovine, there are 23 Spanish cattle breeds, of these, 10 are original to this region and, on a national level, more than 70, and 60% of the census of the breeds ¨Retinta¨ and ¨Berrendas¨ are found in Andalusia. The same could be said for the ovine and goat species whose greatest impact is their net worth, as are the distinct lines of the ¨cerdo ibérico¨ (Iberian pig), and the diverse breeds of the free-range hens.

Andalusia contains a great quantity of underused area in the mountains and in the disadvantaged areas, the ¨dehesas¨, the grasslands, and the pasture and uncultivated areas, together with a significant reserve of indigenous breeds of the different livestock species, perfectly adapted to the environmental conditions of the Andalusian region. This combination offers a great potential for increased livestock production integrated by means of ¨ecological mechanisms¨ of low-impact, while avoiding the waste and cost of processed feed, selected animals, and dependency on technology. And instead, employment and demographic stability could be generated, most especially in the disadvantaged areas. Possibly, the new PAC through its ¨pago único¨ (single payment funding) will favour the small and family farms that are capable of sustained production in these areas which without such support, have proven over the last decades to be fields subject to degradation, erosion, fires, and abandonment.

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The Mediterranean pastures and silvopastoral systems: basic concepts

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Mediterranean pastures and silvopastoral systems. Estación Experimental del Zaidín, Spanish Council of Scientific Research (CSIC). IFAPA-CIFA. Camino de Purchil s/n E-18004 Grenade. Spain

Introduction

This chapter presents some concepts and general factors related to the evaluation and pasture management of Mediterranean silvopastoral systems. We will focus our attention on the arid and semi-arid areas of Southeast Spain.

For the last twenty years, the group of pasture and silvopastoral systems of the Estación Experimental del Zaidín (Grenade, Spanish Council of Scientific Research (CSIC)) has worked in these pastoral ecosystems. The project was initiated by Dr Julio Boza López in 1986 through the department of animal nutrition and at present, is directed by Dr. José Luis González Rebollar. This project was established in response to need for deeper understanding of the wooded pastures of Southeast Spain. Initially the research focused on:

- Evaluation of pasture: catalogue of forage species, production, and nutritional quality.

    - Evaluation of sustaining capacity.

- o Investigation regarding the proposed methodologies to evaluate the wooded pastures (shrubs and trees) and to determine the sustaining capacity of the above mentioned areas.

The methods developed have been applied and validated in the different natural environments of Andalusia, as well as in other arid and semi-arid environments of South America. Presently, the group is developing lines of investigation on the evaluation and management of agrosilvopastoral resources aimed at establishing an integrated management model and multiple land use of these systems. The following are included in the study:

- Forests: Under this, grazing as a traditional silvicultural method to prevent fire is included. In grazed fuelbreak areas, grazing and traditional silvicultural systems of fire control are combined with the objective of tree stands (timber production) and preventive silviculture of reforestation areas.
- Agricultural areas: The importance of integrating pasture and ecological management of pasture is studied in marginal and mountainous agricultural zones (marginal areas for the CAP) using grazing in orchard drylands. The objective is to develop multipurpose agripastoral models. Development of practises compatible with the sustainable development of local agropastoral systems is also being addressed.

The climate and plant ecosystems

The main characteristic that identifies the Mediterranean ecosystems is its climate, defined by marked variation of seasons, a hot and dry summer (from 3-11 months), with a period of limited rain during the relatively cold season that extends from autumn to spring (Aidoud 2001). Rain is erratic and therefore its distribution throughout the year is as important as its total value.

Along with the Mediterranean basin, other zones with this type of climate exist in California, in the Pacific coast of South America (Chile), in South Africa, and in Southeast Australia.

Table 1. Mediterranean bioclimatic areas

Climatic Zones	Mean Annual Precipitation (mm)	Ratio P/ETP (R)	Vegetation Types
Hyper-arid	100>P	0,05 > R	Steppes
Arid			Steppes
Lower	200 >P< 100	0.12 >R< 0.05	Matorrals
Medium	300 >P< 200	0.20 >R< 0.12	Garrigues
Higher	400 >P< 300	0.28 >R< 0.20	Oak sclerophyle Forest
Semiarid	600 >P< 400	0.43 >R< 0.28	Garrigues, Oak sclerophyle Forest
Sub-humid	800 >P< 600	0.60 >R< 0.43	Cork oak sclerophyle Forest
Humid	1200>P< 800	0.90 >R< 0.60	Broadleaved sclerophyle Forest
Hyper-humid	P> 1200	R< 0.90	Broadleaved forest

Based on the duration of the dry and humid seasons and the average annual rain, the Mediterranean climate has a wide range of sub-climates, from very-arid (P<100) to very-humid (P>1200). These different climates result in a large variety of plant communities, that goes from the steppe of arid environments to the deciduous forests of the humid and very-humid climates. Dry evergreen forests and different scrublands are dominant in the Mediterranean climate (Le Houérou 1993; 2000) (Table 1).

The Southeast of the Iberian Peninsula is dominated by arid (100>P< 400 mm) and semi-arid pastures (400>P< 600 mm). However, sub-humid climates (600>P< 800 mm) and humid (800>P< 1200 mm) climates appear depending on altitudinal gradient. In higher areas, water stress is produced due to low temperatures in winter and the plants' vegetative period is restricted to the summer season. The changes based on altitude in the composition and structure of the ecosystems which causes the variations in temperature and precipitation are known as "altitudinal zonation" (Rivas-Martínez 1981). Five vegetation zones are described within the Mediterranean climate. All of them are present in Southeast Spain (Rivas-Martínez 1987):

- **Thermomediterranean:** From the sea level up to 600- 800 m of altitude. It has little frost. The plant communities of note are the tall shrubs (scrubland or garriges), *Ziziphus lotus* L., *Chamaerops humilis* L., *Pistacea lentiscus* L. or *Maitenus senegalensis* (Boiss.) Rivas Mart.ex Güemes & M.B.Crespo, *Quercus coccifera* L. among others -, steppe dominated by *Stipa tenacissima* L. (alfa steppe), and halophyte plant communities (those living on saline soils) are frequent, (*Atriplex halimus* L., *A. glauca* L., *Salsola oppositifolia* Desf., *Salsola vermiculata* L., *Anabasis articulata* (Forsk.) Moq.) or in saline marsh or shallow lakes (*Sarcocornia fruticosa* (L.) A. J. Scott., *Arthrocnemum macrostachyum* (Moric.) Moris, *Salicornia ramosissima* J. Woods)
- **Mesomediterranean:** Occupies a bigger area, between 600-800 and 1200-1.400 meters altitude. With summer droughts and frequent frost. Shrublands of *Quercus coccifera,* forest of *Quercus rotundifolia* Lam., pines of *Pinus halepensis* L. are the characteristic plant communities, but shrubs such as *Retama sphaerocarpa* (L.) Boiss., *Anthyllis cytisoides* L., *Genista umbellata* (L´Her.) Poiret, *Rosmarinus officinalis* L., *Cistus clussii* Dunall., etc are quite abundant.
- **Supramediterranean.-** Mid-mountain area, it extends from 1200- 1400 m up to 1900-2000 m approximately. With low temperatures in winter and mild summer temperatures. Forest of *Quercus rotundifolia* holm oak are present and in more humid conditions, forests of *Q. pyrenaica* Willd.

and/or *Q. faginea* Lam. Shrub species such as: *Erinacea anthyllsi* Link, *Berberis hispanica* Boiss et Reut, *Adenocarpus decorticans Boiss., Genista cinerea* (Vill.) DC, etc. are common.

- **Oromediterranean** This belt is located in the highest mountains, between 1900-2000 and 2900 m. This is the limit of tree species, specifically for *Pinus sylvestris* L. Dense forest are not formed here, but open forest or scattered trees are found instead. Most frequently present are cushion-like and spiny shrubs, characterized by the species*: Genista versicolor Boiss, Cytisus galianoi Talavera and Gibbs, Hormathophylla spinosa* (L.) Küpfer., *Vella spinosa Boiss., Juniperus communis* L. subsp. *nana* Syme., *Juniperus sabina* L., etc.
- **Crioromediterranean** Appears only on the high summits of Sierra Nevada above 2900 meters of altitude. The climatic conditions are extreme, with a short vegetative period that only allows the development of pasture in high mountains, as well as perennial species with hard leaves (psicroxerophy pasture), such as grasses (matgrasses), characteristic of areas inundated with water (borregiles: matgrass pasture). The most abundant grasses are species of the genera *Festuca* (*F. indigesta* Boiss, *F. clementei* Boiss., *F. pseudoskia* Boiss., *F. tricophyllla* (Gaudin) K. Richter, *F. nevadensis* (Hackel) K. Richter, *F. frigida* (Hackel) K. Richter,etc). This area has the highest number of endemic species.

The marked seasonality in these zones conditions the variation of the forage and pasture production in each one of them as well as in each period of the year. Differences in the forage supply force the animals to travel in search of food, a practice known as “trashumance”. In summer, the animals graze in high grasslands and in winter they descend to the lower, warmer valleys.

Although the pastures that dominate the Southeast are composed of woody plants suited to goats, sheep of *segureña* breed are more abundant

(71.2 %), followed by goats (25.2 %), primarily of the *murciana-granadina and malagueña* breeds (Robles and González-Rebollar 2006).

Concepts and definitions

Pasture**:** Frequently the ecological and agricultural meaning of "pasture" has generated dispute among botanists and pastoralists. The classic studies (Rivas Goday and Rivas Martínez 1963; Braun-Blanquet 1979) defined pasture as herbaceous formations that represent an initial phase in a ecological succession, or the final stages of regression, when human intervention is noticeable and starts the colonization of shrubs and nitrophilus species.

However, from a silvopastoral point of view, the ***Sociedad Española para el Estudio de los Pastos (SEEP; Spanish Grassland Society)*** defines pasture as: any plant production *(natural or artificial) that provides feed for the domesticated and/or wild animals, either as grazing or as forage* (Ferrer et al. 2001). This definition includes both herbaceous and woody species, accepting that the pasture may be used by either domesticated or wild animals.

Following the proposal of the SEEP, it is possible to differentiate the following types of pastures:

- Natural: with trees, with shrubs, and with herbaceous plants.
- Agricultural origin: forage crops, and fallows.

The most abundant pastures in arid and semi-arid ecosystems are the shrublands, represented by chamaephytes and nanophanerophytes species of the leguminous families (*Genista* sp., *Retama* sp., *Anthyllis* sp., *Cytisus* sp.., *Ononis* sp., *Adenocarpus* sp., *Erinacea* sp., etc.), labiateae (*Rosmarinus* sp. , *Lavanda* sp., *Thymus* sp., *Sideritis* sp., etc.) and cistaceae (*Cistus* sp., *Heliantemum* sp., *Fumana* sp., etc.). The pastures that are dominated by legumes are of greater pastoral interest, because of the good nutritional value of this family as well as its forage production that in case of *Genista cinerea* and *Retama sphaerocarpa*, may reach more than 2000 kg DM (dry matter) ha^{-1} $year^{-1}$.

The most common herbaceous pasture is that of *Stipa tenacissima* (esparto: alfa), that in most cases forms communities with high ground cover, although possessing limited nutritional value (Robles and González Rebollar 2006).

Among those pastures of agricultural origin are fallows from cereal cultivation, mostly barley and oats and in more dry conditions, the species *Opuntia ficus indica* (L.) Miller, a resource of high interest in arid zones.

Stocking rate and carrying capacity The terms **“**stocking rate” and “carrying capacity” are frequently mistaken and often not clearly defined. We describe these two concepts, in accordance with American schools that study rangeland management.

Stocking rate (S.R) - Quantity of animals (number of animals or livestock units) that uses a pasture during a determined period of time. In some cases, the time scale can also be disregarded (Animals or animal Units (AU) surface $area^{-1}$unit period $^{-1}$). The Society for Range Management (1974) considers stocking rate as the number of animal units allocated to a section of land for a one year grazing period.

Carrying capacity (CCO) - Also denoted as stocking rate in equilibrium is defined as the quantity of animals (number of animals or livestock unit) that a pasture may sustain while maintaining its state or condition (Animals or Animal Units (AU) $area^{-1}$ time unit $^{-1}$). This definition implies the adequate use of the pasture and the maintainence and conservation of the vegetation. In this sense Holechek (1989) defined it as the maximum stocking rate applicable under a conservative management. Carrying capacity may vary from year to year due to the fluctuations of the forage production.

The best way to express stocking rate and carrying capacity is by energy units, since this is also how the animal requirements are estimated (Blaxter 1962). The objective is to show the inter- and intraspecific physiological variations of the herd, in the same way as the annual variations of pasture (floristic composition, quantity, and quality). The main difference between the two terms is that while the stocking rate is the quantity of energy that the animals extract from the pasture (energy demand or forage), the carrying capacity is the quantity of energy that a pasture supplies (source of energy or forage), and often is expressed as animal units by surface area and time unit. The energetic needs of the animals, or in other words, the animal units equivalent, are expressed in metabolic energy by animal unit and by year (MJ EM UA^{-1} $year^{-1}$), and represent: the sum of the energy of maintenance, production, movement, and food intake. On the other hand, the source or the supply of energy of a pasture may be expressed in metabolic energy by hectare and year (MJ ME ha^{-1} $year^{-1}$), and is estimated by multiplying plant production (kg DM ha^{-1} $year^{-1}$) by the energy output of this forage expressed metabolic energy (MJ ME kg^{-1}) (Passera 1999).

The relation between the carrying capacity and the stocking rate allows us to evaluate the impact of livestock on one specific area for a given period of time. Therefore this is a very useful tool for pasture planning in extensive areas (Passera 1999; Boza et al. 2000). According to this relationship (Gastó et al.1993), we can say that in a pasture there is:

- Adequate use or equilibrium: S.R. = C.C
- Over-grazing: S. R > C.C
- Under utilization: S.R. < C.C

Out of the three basic elements of silvopastoral systems, pasture, animals, and humans, the latter is ultimately responsible for the proper functioning of the system. The European Union provides assistance to stock-breeders based on the number of heads of livestock. This sometimes results in overgrazing and abuse and definitely results in poor resource management. Knowing how to adjust the stocking rate to the carrying capacity of the pasture is one crucial priority for owners and managers.

Silvopastoral Systems. From an integrated view, the uses of forests go beyond pure forestry. As shown by Montoya (1983), the pastoral utilization of the Mediterranean forestlands is more appropriate than forestry. Agroforestry systems are complex agrarian systems that combine the utilization of shrubs with herbaceous species and animals (Nair 1991 in San Miguel 2003).

Etienne et al. (1994) define silvopastoralism and silvopastoral systems as the combination of agroforestry and livestock activities, *to improve the conservation of natural environments and increase the efficiency of the system through product diversification.* The same authors consider the best representative of the Mediterranean silvopastoral systems to be the Spanish ***dehesa*** “La Dehesa”, or “Montado” in Portuguese (Etienne 1996).

The term “dehesa” come from the Spanish word that refers to the land in Southeast Spain set aside as free pastures for roving shepherds and herds belonging to the “mesta” (San Miguel 1994). Based on Montero et al. (1998), the *dehesa* is an agrobiosystem created by man and his animals and sustained by its continued use. It is not only characterized by diversity in species (fauna and flora), but also by structure and production. This is formed by an open tree layer (50 trees ha^{-1}) and an annual grass layer, whose composition and functioning depend largely on the former. The tree layer is composed primarily of evergreen species of *Quercus* (*Q. rotundifolia, Q. suber* L., *Q. faginea)*, although other deciduous *Quercus* are also common (*Q. pyrenaica, Q. pubescens* Willd., *Q. canariensis* Willd., etc), as well as other species (*Fraxinus, Juniperus*).

In our country the silvopastoral systems occupy sloping lands. These are classified by the Common Agricultural Policy (PAC) as marginal areas

(63.75 % of net agricultural land) where 75% of the total population of goats and sheep graze (Merino 1993). In this context, extensive grazing with livestock is one option to consider because it requires less maintenance, it has good market possibilities, and provides stable work for the population during the whole year. Furthermore, with adequate management, extensive grazing contributes to the sustainability of the system.

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Methods of analysis of pasture and silvopastoral systems at the plot and farm scale

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Mediterranean pastures and silvopastoral systems. Estación Experimental del Zaidín, Spanish Council of Scientific Research (CSIC). IFAPA-CIFA, Camino de Purchil s/n, E-18004 Granada. Spain

Introduction

The pastures of Southeast Spain (maquis, garrigues, and shrubs, perennial and annual pastures) are dominated by woody perennial and herbaceous species which make them difficult to evaluate. Our investigation group on Mediterranean pasture and silvopastoral systems of the CSIC/IFAPA focused its first research on investigating evaluation techniques for wooded pasture production and developing a methodology to determine the livestock carrying capacity of these arid and semi-arid pastures of Southeast Spain. The objective was to come up with a useful planning tool for the utilization of livestock in agro-silvopastoral and to be able to adjust the stocking rate to the carrying capacity of the pastures in protected areas. In this chapter, the evaluation methodology of these wooded pastures is summarized.

Methodological Scheme

The methodology was developed to determine the carrying capacity based on the plant component that integrates the production and the nutritional values of the species that comprises these pastures, and on the requirements of the animals. Both components, plant and animals; are expressed in energetic terms as metabolic energy: MJ ha^{-1} $year^{-1}$ for the pasture and, MJ $animal^{-1}$ $year^{-1}$ for the animals. On the other hand, this research allowed us to investigate different aspects related to the silvopastoral systems, such as: floristic composition, primary production, nutritional value of species with forage value, and the carrying capacity of these pastures.

The methodological scheme of the work (Robles 1990; González-Rebollar et al.1993; Fernández 1995; Robles and Passera 1995; Passera 1999) is summarized on Figure 1. and differentiates the following factors:

Evaluation of pastures

The evaluation of the forage resources includes:

- Qualitative aspects: territorial characterization (delimitation of the pasture units), catalogue of forage species and pasture map.
- Quantitative aspects or evaluation of forage production.

* Nutritive value of forage species

- Chemical analysis: dry matter, organic matter, protein, fiber, digestibility of dry and organic matter. The metabolic energy is calculated from the organic matter digestibility of the pasture forage species, a parameter necessary to determine carrying capacity of these pastures.

Evaluation of carrying capacity of pastures

- Calculation of the metabolic energy of pasture.

- Stocking rate (SR) and energy requirements of the animals. It consists of: livestock census (number of animals) and the calculation of the energy requirements of the animals.

- Study of carrying capacity: calculation of carrying capacity of different pasture types and map of carrying capacity.

- Analysis of the stocking rate and the carrying capacity.

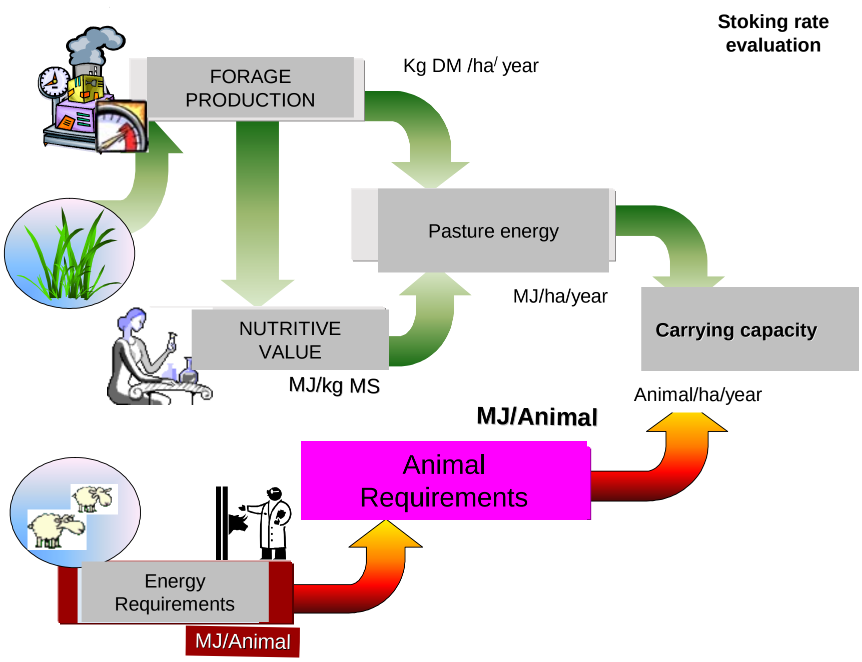

Figure 1. Methodological scheme of pasture carrying capacity evaluation

Evaluation of the pastures

The bibliography reflects the scarcity of methods to evaluate wooded pastures.

The most common is to find methods oriented to determine the dense grass pastures of humid and semi-humid environments or adaptations of these. More than 50 years ago Daubenmire (1959) emphasized the vast quantity of methods used to quantify the vegetation and showed that the selection of one over another method should adapt to the different objectives of our work, together with the search for a more robust, trustworthy, and rapid procedure.

Pasture evaluation

Territorial Characterization (Typology of pastures)

The first step in the study of pastures is to understand the distribution of homogenous cartographic units or pasture units, which would be the basis upon which to stratify the sampling later. This distribution is made up of three phases: i) Photointerpretation of homogenous units in the laboratory, using aerial photos, orthophotos, or satellite images; ii) Field visit that is understood as the field verification of the distribution of the units established in the laboratory and the gathering of data that will serve to characterize the units; ii) Finalization of information from the field data, the initial units established are corrected and the pasture map is made. Finally, the cartography with the pasture units is digitalized and linked to the database of each pasture units (GIS).

During the field visit, physical data (rockiness, altitude, slope, exposure) and vegetation were gathered. However, the vegetation has more importance from the point of view of the pasture. The methodology of a physiognomic character (Long 1974) was used, which considers two variables characteristic of the actual vegetation: i) plant formation: structure of the vegetation (layers: trees, shrubs, herbaceous) and cover, and ii) the dominant species (one or two dominant species)

Catalogue of forage species

Support from a botanist is fundamental to the study of pastures. The criteria to select the main forage plants may be diverse. In our case we have considered: i) the period of time that the species are available to be consumed by the livestock (< 3 months, 3-6 months, 7-9 months, > 10 months), and ii) acceptability or animal preference in which five categories are differentiated: preferred, good, average, deficient, and not consumed (Passera and Borsetto 1983; Robles 1990).

Pasture Map

This consists of the characterization of plant communities from a pastoral perspective. The pasture map will be used later in the field sampling to determine the forage production and the carrying capacity of the different pasture types. The limits of each unit of pasture coincide with the diagnostic units that have been differentiated during the previous stage of territorial characterization.

Evaluation of the forage production

In designing a study on the forage production of a field, there are a number of factors that must be taken into consideration such as:

Area and scale of study

The study area conditions the field work will consequently determine the sampling method. The selection of the most appropriate sampling method should be related to the objectives of the research, without neglecting other conditions that may affect its implementation, such as the available time to do the work and the desired precision level in obtaining the data.

Stratification of the sampling

The field sampling should be stratified. The stratification is done based on: i) the different types of pastures referring to the pasture map done during the stage of territorial characterization, and ii) the biological types of plants (plant life-forms): wood (shrubs and trees), herbaceous, and in other cases, succulent.

Sampling method

Various research was done on vegetation sampling methodology. The evaluation of the primary production implies the harvest of plants. From this point of view we can differentiate the sampling methods as either destructive or non-destructive. In shrub communities, both are commonly used.

$ Destructive methods

The most extended destructive method is the method with plots that delimits a concrete surface area, representative of the studied community. The sampled area may be round, rectangular, or square. The size changes according to the type of plant community and the biological types of plants (Whittaker and Niering,1965). From these plots we can get information on density, cover, and production. This method is mainly used to evaluate herbaceous communities.

In the case of shrub communities, the sampling is done by species. A determined number of individuals of different types and sizes are cut. The minimum number of samples should not be less than ten for each species (Bryant and Kothman 1979). The objective is to correlate a metrical parameter that is difficult to measure in the field such as the weight (in grams or kilograms), with other metrical parameters more easily measured (in the field) such as diameter, height, or volume (Whittaker and Woodwell 1968, Uso et al. 1997). From these data the corresponding regression equation is established for each species. The best fit is between weight and phytovolume.

The fitovolume is calculated from the volume of the geometric figure that is best suited to each species. In general, it corresponds to a cylinder (Passera 1983):

$$\text{Volume} = \pi\left(\frac{\text{medium diameter}}{2}\right)^2 \times \text{height}$$

In the case of species with biotype of chamephytes "in cushion", such as *Erinacea anthyllis,* the volume of a semisphere is used.

The forage production corresponds to the primary production of forage consumable by the livestock and is estimated by simulating the browsing of small ruminants (goats and sheep), approximately 50 % of the annual primary production (Robles and Passera 1995; Robles and Rebollar 2006).

The regression equations obtained for each species will be used in the non-destructive sampling.

$ Non-destructive methods or without plots.

Survey the area following fixed lines (transects) or though points. Different types of methods exist and are discussed in detail:

& Points method –

It consist of observation of points distributed randomly at the plot or systematically distributed along a transect. All plants found along one side of transect are recorded (Cockayne 1926; Levy 1933). Coverage and frequency data are obtained. This is mainly used in dense herbaceous community and has been widely used to determine pastoral values (Daget and Poissonet 1971).

& Line-interception method

It is more known as ”line-interception method” proposed by Canfield (1941) and measures the longitude that a plant intersects over the transect of known length. This has been widely used to measure the coverage of shrub communities.

& Distance methods

Developed by Cottan and Curtis (1949; 1956) presents multiple variants. In general, it consist of measuring the distances from fixed points, placed randomly or systematically along the transect. The density data and metric parameters (diameter and height) of the sampled plants are obtained. This has been frequently used in silviculture and forest evaluation.

The production of arid and semi-arid pastures of Southeast Spain has been evaluated using the combination of destructive and non-destructive methods. We gathered all the methods commonly used in the evaluation of these pastures of the area. We differentiate them based on plant strata or biological type:

Herbaceous layer: Cut and weighed in 50 cm by 50 cm squares. The number of plots per type of pasture is between 12 and 24. The cut plants are oven-dried until a constant weight is reached to express the data in dry mater.

Wooded layer: The destructive and non-destructive methods are combined. As non-destructive method, the distance method called “Closest Individual Method” was selected. We considered that this is the most adequate for big scale research since a bigger surface area is surveyed with the same number of observation points. Transects with 100 observation points are used. The distance between the points may vary based on the structure of the plant community, which will condition the length of the transect. In the majority of shrub pastures of Southeast Spain, the observation points are separated every meter, which implies transects of 100 m of longitude. The distance between an observation point and the one closest to it is measured, both the height and the two perpendicular diameters. From the distance data the density is calculated, and with the height and the average diameter, the fitovolume. The frequency and the coverage of each species may also be computed as well as the total coverage. The average density is determined based on the following formula:

$$\text{D (plants ha}^{-1}\text{)} = \frac{S}{(a*d)^2}$$

where "D" is the density of the plant community or pasture type, expressed in plants per ha (plants ha^{-1}), "S" is the surface area unit (1 ha = 10,000 m^2), "d" is the average distance from the plants sampled up to the sampling point; "a" is a adjustment factor that varies based on the distance method used. In this case the adjustment factor is 2. An example: from transects of 100 m and 100 observation points, the density (plant ha^{-1}) of a shrub pasture was calculated. The average transect distance resulted to 30.96 cm (0.3096 m). Applying the previous formula the total density is of 26082 individuals per hectare:

$$\text{D (plants ha}^{-1}\text{)} = \frac{10000}{(2*0.3096)^2}$$

Where "S" is the surface area unit (1 ha = 10 000 m^2)

The density of a determined species (A) is calculated by multiplying the total density of the pasture or plant community by the frequency of the said species. The frequency is calculated by dividing the number of times that a species appears in transect by the total number of plants in the transect (100 plants: number of observation points of transect) (see example in Table 1):

$$\text{D}_{\text{species A}}\text{ (plants ha}^{-1}\text{)} = D*\left(\frac{\text{number of plants of Species A}}{\text{number total of plants}}\right)$$

Table 1. Example of pastoral evaluation of shrub species *Vella spinosa*. N: Individual numbers; H: Height; D1: Diameter 1; D2: Diameter 2; C:Ground Cover plant; PV: Phytovolume

N	H cm	D1 (cm)	D2 (cm)	C cm^2	PV cm^3	Forage Production g DM $individual^{-1}$
1	16	18	15	212.06	3392.92	7.8
2	20	38	45	1343.03	26860.62	23.8
3	37	100	100	7853.98	290597.32	85.3
4	23	65	55	2807.80	64579.36	38.1
5	32	85	67	4472.84	143130.96	58.3
6	12	45	30	1060.29	12723.45	15.9
7	20	50	46	1806.42	36128.32	27.9
8	8	12	8	75.40	603.19	3.1
9	23	28	19	417.83	9610.13	13.7
10	16	23	19	343.22	5491.50	10.1
11	32	42	36	1187.52	38000.70	28.6
12	34	37	23	668.37	22724.71	21.7
13	19	35	17	467.31	8878.93	13.1
14	23	20	13	204.20	4696.68	9.3
Average Value /individual				1.637.16	47.672.77	25.49
Ground cover (%)				5.98		
Phytovolume (m^3)					174.08	
Production(kg ha^{-1} $year^{-1}$)						93.07

Continuing with the previous example (a shrub pasture with a total density of 26082 plant ha^{-1}), to calculate the density of determined shrub species (*Vella spinosa*) that appeared 14 times in the transect of 100 point (Table 1):

$$D_{V.spinosa}(\text{plants ha}^{-1}) = 26082 * \left(\frac{14}{100}\right) = 3651 \text{ plant ha}^{-1}$$

At the same time, the ground cover of each species (Table 2) is calculated from the formula of the area of a circle (in the case of species with a fitovolume of a cylinder):

$$\text{Ground cover} = \pi \left(\frac{\text{average diameter}}{2} \right)^{2}$$

The phytovolume of each individual (Table 1) is calculated as indicated in the destructive sampling, from the height and the average diameter.

The forage production by individual is determined from its phytovolume, integrating the data from the transect (phytovolume), with the regression equations calculated for each species from the data obtained from the destructive methods. In the case of *V. spinosa* the regression equation calculated is the following:

$$\text{Dry weight (kg DM)} = 0.09985725\text{x } V^{0.53659622}$$

where V is the fitovolume.

For each species, the phytovolume, the coverage, and the forage production is calculated by multiplying the specific density of each species (in the case of *V. spinosa* it will be 3651 plant ha^{-1}) by the average value of the said parameters (see the example of Table 1):

· Coverage $_{V.\ spinosa}$ ($m^2\ ha^{-1}$) = 36521 plant ha^{-1} * average coverage $_{\text{Specie A}}$ (in the transect)

ex.. Coverage $_{V.\ spinosa}$ ($m^2\ ha^{-1}$) = 36521 plant ha^{-1} * 1.637.16 = 597.80 $m^2\ ha^{-1}$,

if expressed in percentage of ground cover would be:

Ground cover (%) = 597.80 / 100 = 5.97 %

Table 2. Pastoral evaluation of a shrub pasture

Species	Density Individuals ha^{-1}	(%)	Phytovolume m^3 ha^{-1}	Production kg DM ha^{-1}
Erinacea anthyllis	16432	19.89	339.67	1.299.56
Vella spinosa	3651	5.98	174.08	93.07
Teucrium polium	3130	0.36	4.39	13.42
Sideritis incana	1043	0.37	6.38	5.20
Helianthemum apenninum	782	0.12	0.61	0.51
Juniperus sabina	782	0.91	13.01	20.93
Prunus postrata	261	0.02	0.09	0.08
Total	26082	27.65	538.23	1432.77

· Phytovolume $_{\text{Specie A}}$ (m^3ha^{-1}) = D $_{\text{Specie A}}$ * average volume $_{\text{Specie A}}$ (in the transect)

ex.: phytovolume $_{V.\ spinosa}$ (m^3 ha^{-1}) = 36521 plant ha^{-1} * 47.672.77 cm^3 =174. 8 m^3

· Forage production $_{\text{Specie A}}$ (kg ha^{-1} $year^{-1}$)= D $_{\text{Specie A}}$ * average production $_{\text{species A}}$ (in the transect)

Forage production $_{V.\ spinosa}$ (kg ha^{-1} $year^{-1}$)= 3651 plant ha^{-1} * 25.49 g $plant^{-1}$= 93.07 kg DM ha^{-1} $year^{-1}$

The total forage production of the pasture is equal to the sum of the forage production of each species that appears in the transect (Table 2).

Nutritive value

The pastoral value of a pasture depends not only on its forage production but also on its quality (chemical composition and nutritional value).There are many parameters that determine the quality of food and emphasized as more important is the crude protein (CP, %) and metabolic energy (ME, MJ kg^{-1}MS). Pastures considered to be of good quality are those that have metabolic energy of 8 to 8.4 MJ kg^{-1} of DM, equivalent to 0.70 – 0.74 UF, and a crude protein content close to 12 % (Boza et al. 2000).

Studies on the stocking rate capacity conducted in Southeast Spain evaluate the pasture in energetic terms such as metabolic energy per hectare and years (MJ ha^{-1} $year^{-1}$). This implies determination of the metabolic energy (MJ kg^{-1} DM) of the species that comprises it. The metabolic energy is a parameter difficult to calculate, and in most cases indirect methods are preferred. In our research, it was calculated from the digestibility *in vitro* of the organic matter (OMD). According to Papanastasis (1993), the digestibility *in vitro* is one of the parameters that best reflect the nutritional value of the shrubs. The method used to determine the dry matter digestibility (DDM) and organic matter digestibility (DOM) was proposed by Tilley and Terry (1963) and modified by Molina (1981). The digestive process that the food goes in the rumen of the animal is simulated *in vitro*. In our research, the ruminal liquid of a native species (sheep *segureña* or goat *murciano-granadina*) was used.

The table 3 grouped 246 autochthonous species of southeast Spain (Boza et al. 2000) by biological types according to nutritional value. It was observed that the wooded species have less variability in terms of crude protein and metabolic energy, though their average value is a little less than that of the herbaceous species. Of those analyzed 22 % are leguminous, 19 % gramineae, 18 % composite, and % labiatae. Standing out for its good nutritional value are the leguminous (CP 13.35 %, and ME 8.44 MJ kg^{-1} DM), and the chenopodiaceae (CP 18.67%, ME, 8.56 MJ kg^{-1} DM) (Robles and Rebollar 2006). Species of these two families have been widely used in the Mediterranean basin, in projects to improve pasture and to control erosion. Among the excellent species as forages are: *Adenocarpus decorticans* L., *Coronilla juncea* L., *Retama sphaerocarpa* (L.) Boiss., *Cytisus fontanesii* subsp. *fontanesii* Spach, *Cytisus scoparius* subsp.

reverchonii (Degen & Hervier) Rivas Goday & Rivas Mart., *Atriplex halimus* L., *Atriplex glauca* L., *Salsola oppositifolia* Desf., *Suaeda pruinosa* Lange (Barroso et al. 2005; Robles et al. 2006).

Table 3. Nutritive values of pastures in the SE Iberia by biological types (Boza et al. 2000)

Biotypes	Metabolic Energy MJ kg^{-1} DM	Crude Protein (%)
Tall trees and shrubs	6.0 – 12.1	4.5 – 15.9
Short bushes and shrubs	4.6 – 9.8	6.8 – 17.3
Annual and perennial grasses	5.9 – 12.3	4.8 – 22.0

Evaluation of the carrying capacity

The methodology used for the evaluation of the carrying capacity integrates the forage production of the pasture in energetic terms (MJ ME $ha^{-1}year^{-1}$) with the energy requirements of the animals (MJ ME $animal^{-1}$ $year^{-1}$) (González-Rebollar et al. 1993, Robles and Passera 1995). The metabolic energy is the type of energy commonly used in research on animal nutrition, and may be estimated for each plant independent of the type of animal that will consume it (Pulina et al. 1999).

Calculation metabolic energy of pasture

The metabolic energy of each species (ME, MJ kg^{-1} DM) was calculated from the digestibility of the organic matter ($OMD_{in\ vitro}$) using the equation described by the ARC (1990):

ME (MJ kg^{-1} DM) = OM(g kg^{-1}MS) x $OMD_{in\ vitro}$ (%) x 19 x 0.82 x 10^{-5},

where OM (g kg^{-1} DM) is organic matter.

The available metabolic energy of each species (AME_{sp}=MJ ha^{-1} $year^{-1}$) is calculated from the forage production (FP_{spi} = kg DM $ha^{-1}year^{-1}$) by the metabolic energy (ME_{spi} = MJ kg^{-1} DM) of the species, and affected by two factors: animal preference (AP_{spi}) and period of availability of the plant species in the field (PA_{spi})

Table 4. Example of a calculation of the metabolic energy of a pasture (ME = metabolic energy, PA = animal preference index, PA = period of availability)

Species	Production kg ha^{-1} year^{-1}	Index PA	Index PD	Available Production kg ha^{-1} year^{-1}	ME MJ kg^{1}DM	Available ME MJ ha^{-1} year^{-1}
Erinacea anthyllis	1299.6	0.2	1	259.9	9.33	2.425.0
Vella spinosa	93.1	0.4	1	37.2	5.67	211.1
Teucrium polium	13.4	0.2	1	2.7	6.63	17.8
Sideritis incana	5.2	0.4	1	2.1	6.33	13.2
Helianthemum apenninum	0.5	1	1	0.5	7.01	3.6
Juniperus sabina	20.9	0.2	1	4.2	5.35	22.4
Prunus postrata	0.1	0.8	1	0.1	7.29	0.5
Total	1432.8			306.7		**2693.5**

$AME_{sp.i}$ (MJ ha^{-1}year^{-1}) = $PF_{sp.i}$ (kg DM ha^{-1}year^{-1}) x ME_{spi} (MJ kg^{-1} DM) x AP_{pi} x $PA_{spi.}$ According to Barroso et al. (1995), AP(animal preference) varies on a scale of six from 0 (not preferred) to 1 (highly preferred), and PA is the period of time wherein the species may be consumed by the livestock and varies on a scale of four, from 0.3 (consumption < 3 months) to 1 (consumption > 10 months).

The total metabolic energy available in the pasture (PME = MJ ha^{-1} year^{-1}) is calculated as the sum of all the energy available from each species (i=1 a i=n) that makes up the pasture (Robles and Passera 1995).

$$PME\ (MJ\ ha^{-1}\ year^{-1}) = \sum_{1}^{n} AME_i\ (MJ\ ha^{-1} year^{-1})$$

Taking the pasture of Table 2 as an example, the metabolic energy of a shrub pasture was calculated (MJ DM ha^{-1} $year^{-1}$) (table 4), and resulted in 2693.5 MJ DM ha^{-1} $year^{-1}$.

Animal requirements

The animal requirements depends on the breed and species of the animal, the physical condition, the live weight, and the management (Martínez et al. 1986, Lachica et al. 1997, Aguilera 2002), and maybe expressed in: i) forage weight or consumed pasture (kilograms of DM, kg DM), or ii) energetic terms (kilo calories, kcal, or Mega Jules, MJ) (Pulina et al. 1999). For the calculation of the livestock carrying capacity (also of the stocking rate), the animal type or animal unit should be defined which will then be the reference for counting the remaining animals in a specified herd. From this animal unit, the corresponding equivalence among different animal species may be done (cattle, sheep, goats or horses). According to Holechek (1989) a cattle is equal to 0.15 sheep, 0.10 goats, and 1.80 horses. Cocimano et al. (1973) consider other equivalents emphasizing that sheep and goat represent 0.16 cattle unit, and that a horse is equal to 1.20 cattle units. Other aspects that should be kept in mind are whether requirements are referred to as maintenance or production requirements.

In our research, the energetic requirements for small ruminants has been mainly taken from the research done in the department of animal nutrition of the Estación Experimental del Zaidín (CSIC, Granada, Spain) and other bibliographies (INRA 1988 for sheep; Prieto et al. 1990 and Aguilera et al. 1990, 1991 for goats). From these data we have calculated the type of energetic requirement for a small ruminant, which we have called “unit for small ruminant” (UPR). This has been calculated as an average of the needs of all the animals that make up a herd type (18 animals in lactation, 2 adult males and 80 adult females). The metabolic energy calculated in maintenance and production has been:

· Maintenance: 9.06 MJ day^{-1} animal^{-1}, or in a year 3306.9 MJ year^{-1} animal^{-1}

· Production: 13.26 MJ day^{-1} animal^{-1} , or in a year 4841.36 MJ year^{-1} animal^{-1}

Calculation of the carrying capacity (CC)

The calculation of the carrying capacity consists of dividing the available metabolic energy of the pasture (expressed as metabolic energy by surface area unit, MJ ha^{-1}year^{-1}) by the energy needs of the animal unit, which in our case is calculated for small ruminants (MJ SRU^{-1} year^{-1}). Carrying capacity of pasture is expressed in animal unit by surface area unit (SRU ha^{-1}).

$$\text{CC pasture (SRU ha}^{-1}\text{)} = \frac{\text{PME}}{\text{ME SRU}} ,$$

where CC pasture = carrying capacity; PME= metabolic energy of pasture (MJ ha^{-1} year^{-1}), ME SRU = Metabolic energy of an animal type (small ruminant) or animal unit (MJ SRU^{-1} year^{-1}), calculated for a year.

The Table 5 shows an example taking the same shrub pasture of the table 3 and 4.

Table 5. Calculation of the optimum carrying capacity of a pasture considering two situations of animal requirements: production and maintenance. (SRU = Animal unit for small ruminants, ME = metabolic energy, CC = Carrying capacity)

	Animal Requirements MJ SRU^{-1} year^{-1}	Pasture EM MJ ha^{-1} year^{-1}	CC SRU ha^{-1} year^{-1}
Production	4841.36	2.682	0.55
Maintenance	3306.9	2.682	0.81

In this way, we obtain the carrying capacity by type of pasture. The map of carrying capacity is elaborated from the pasture map, assigning each pasture unit the value of carrying capacity that we have obtained. The total carrying capacity for a research area with a concrete surface area is calculated as follows:

$$\text{CC (RRU ha}^{-1}\text{) total} = \sum_{1}^{n} \text{CC}_i \times \left(\frac{\text{Area}}{\text{Total area}} \right),$$

where CC_i = carrying capacity by type of pasture in one hectare (SRU ha^{-1}); Surface area $_i$ = the area covered by a determined type of pasture in the research site (ha); Total surface area of the research site.

Stocking rate and carrying capacity analysis

As indicated above, to calculate the stocking rate it is necessary to know the number of individual animals and the composition of the herd (males, growing animals, sterile females, gestating or lactating), which presents different physical status and therefore different energy requirements. The number of the animals of the herd should be expressed in animal unit, which in our case has been defined for small ruminants as SRU.

The stocking rate (SRU ha^{-1}) is the quotient between the animal unit of our herd (SRU) and the size of the pastured area (ha).

By comparing the carrying capacity (SRU ha^{-1}) to the stocking rate (SRU ha^{-1}), we can determine whether the research site is over-grazed, under-grazed, or used adequately. Our research showed that the land management done by the stock-breeder is different depending on his relationship with the land, that is, whether he is the owner, the pastures are communal, or the pastures are owned by the state.

In general, if the stock-breeder is the land owner, he engages in more conservation and sustainable activities in the area, allowing for a balance between the stocking rate and the carrying capacity. In lands that are communal, the tendency toward over-grazing exists, the stock-breeder tends to use the resource up to the maximum, with the fear of not having enough food due to competition with other stock-breeders. Lastly, the lands owned by the state are frequently under-used due to the tendency of the state to over-protect the area. In most cases these are protected areas where resource conservation is primary and land use for pasture is penalized (González et al. 1996; Passera 1999; Robles et al. 2001).

Other aspects related to the carrying capacity

Predictive regression equations of the carrying capacity

The recommended method for determining the carrying capacity implies a lot of laboratory and field work. Different authors have developed predictive equations to estimate the primary productivity of the plant ecosystems (kg DM ha^{-1} $year^{-1}$) based on the precipitation (mm) or the availability of water. For the Mediterranean basin, the proposals described by Le Houérou and Hoste (1977): i) are the Mediterranean model: $Y= 3.89(P^{1.09})$; ii) and the Sahel-Sudan model: $Y= 2643.89(P^{1.001})$. The latter is best suited to the herbaceous pasture of the arid zones of Southeast Spain (Robles et al. 2004).

Passera (1999) and Passera et al. (2001) have concluded that the variation of ground cover of a plant community has more influence on the primary productivity than the variations in annual precipitation.

Considering the parameters of annual precipitation and the ground cover of the plant community, our research group has developed regression equations that allow the prediction of the carrying capacity of a territory, expressed as metabolic energy of the pasture (MJ ME ha^{-1} $year^{-1}$) (Passera 1999; Passera et al. 2001). These equations are calculated from different types of pastures (63 types), mainly shrubs, dominant in the southeast arid and semi-arid areas of Spain. Different equations were calculated (Table 6), considering: i) all the pastures (wooded and herbaceous), ii) only wooded pasture, iii) wooded pasture for the bio-climatic belt oromediterranean and supramediterranean and, iv) wooded pasture of the mesomediterranean belt. These equations have been used for the management of pastures in protected areas of Andalusian region.

Table 6. Regression equations: metabolic energy of the pasture (as carrying capacity) *vs* annual precipitation (x = mm) and ground cover pasture (z = %). Metabolic energy (y = MJ ME ha^{-1} $year^{-1}$), regression coeficiente (r^2aj.), confidence level (*p*) and number of samples (n)

Type of pasture	Adjusted curve	r^2aj.	*p*	n
All pastures	y = -701.036 + 0.269 x + 88.214 z	0.55	< 0.0001	63
Woody pastures	y = -2198.151 + 1.61 x + 101.22 z	0.71	< 0.0001	48
Woody pastures: oro and supramediterranean zones	y = -2253.357 + 2.916 x + 76.863 z	0.85	< 0.0001	17
Woody pasture: mesomediterranean	y = -2938.221 + 0.963 x + 129.819 z	0.80	< 0.0001	21

Land Use

The method described to calculate the carrying capacity of the pastures considers that the entire area is used by the animals with the same intensity. However, livestock monitoring shows us the existence of zones that are more visited by the animals as well as some areas that are not visited at all. Clearly, we can see different intensities in land use. To determine these different uses and the stocking rate, Passera (1999) integrated the pasture map in an area (land) (Robles 1990) with known carrying capacity for each type of pasture, with the pasture map (Barroso 1991). Using these maps, the paths taken by the herd through the area are drawn during all four seasons of the year. The study on the potential optimum carrying capacity of the farm shows that there is no over-grazing on the study site. However, when the two maps were integrated (carrying capacity and pasture) it was observed that there are zones on the site that are over-grazed. These are the areas visited by the animals three or four seasons of the year and coincide with the zones closer to sheepfolds and in shade. The areas with higher slope, like the zones farther from the sheepfolds were less used by the animals. Some areas were not visited by the animals at all. The area accessibility is a factor that most affected the land use. The cause of this behaviour is more conditioned by the stock-breeder and less so by the animals. Definitely it is humankind who is responsible for good land use and its conservation.

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The forests and rural landscapes of Andalusia

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Introduction

Andalusia is found at the edge of Europe, at both its western and sourthern borders. These two borders have marked its history and help to explain Andalusia´s present.

Andalusia is the land of the columns of Hercules, the threshold to the unknown for those reckless sailors, who travelled through those narrow columns, following the currents of the sea, to enter the shadows of the sea. This edge turns its European face toward the African dream; to dreams of Africa.

Its geographic position has been the forge of the mixed character of this land. This mix of races has forged its landscapes with the iron of the hoe and the plough, and have given form to an Andalusia that cannot be understood without opening the doors to its past and looking back toward at least, three thousand years of history.

In the past 30 years this Andalusia has progressed rapidly. In just two generations, at most three, a profound transformation of its old past has been witnessed. This evolution has involved a change in scale and coordinates of the social habits and a profound transformation of a society previously anchored in rural life to a postmodern urban society that has erased the visage of the territory converting it into a reality even more virtual than the internet.

In this introduction we hope to convey the revolution we are currently experiencing. Because we also live within this revolution, it is easier to remember or write about it, than to live it. It is something more than a simple change of customs, to move from having 50% of the population devoted to agriculture to roughly 5%, in less than a century. What is the impact of these changes on our landscapes? A transfer of rural workers to the industry and the services sectors: transfusion from the countryside to the cities, characterized by an emergence of a territory of cities and empty rural areas.

Let's look out to Andalusia, the Andalusia of today, that of the economic and social revolution and the Andalusia of the near past. The Andalusia of fields and forests: and it still is, although with the need to redefine its relationships to the land.

At least two historical Andalusia

Most travellers who have visited us have remarked upon the contrasts of such a wide territory that Andalusia is (8.75 millions of hectares), comprising one third of Spanish territory. In just 35 kilometres, or a half-day´s walk, you can go from the tranquil blue waters of the Mediterranean sea to the permanent snow of Sierra Nevada, the sugar cane fields and orange tree orchards to the wild tundra. Andalusia has plains, hills, mountains, marshes and deserts; forests of fir and wild olives; oaks and prickly oaks; and cactus and chestnuts. One must stop and think about these contrasts: are they inherent to our territory? What makes this land so diverse in landscape and singularities?

The geographic location does not warranty the heterogeneity. Especially in a region like Andalusia, that is spread along its mayor axis in the direction of the parallels. The diversity of its territories is created by the formation of the territory, by its parent rock material and by the wrinkles of the land that decisively determine the directions of the wind. Hills and valleys that have been shaped over diverse rocks and litologies such as limestone, sedimentary rocks, and Palaeozoic quartz in Sierra Morena, gneis in the central Betic mountain ranges and alluvial materials, the result of thousands of catastrophic events, the valley of Guadalquivir.

Traditionally, at least two Andalusias have been distinguished with regards to politics, history, and social events: western Andalusia and eastern Andalusia, the first one flowing towards the Atlantic Ocean through the Guadaquivir River, the Great River, and the second one that flows towards the Mediterranean Sea. A western Andalusia, of wide valleys and flat hills; the other, the eastern Andalusia with high mountains and deep depressions, and a short sea platform. The western Andalusia of the Tartesso, of the Roman Betica, of the Califa of Cordoba and the Seville emirate, and the eastern Andalusia of the Phoenician factories, Greek colonies, the kingdom of taifas, and the Nazari Granada. A western Andalusia, christianized and European after the campaigns of the Castilian king in the XIII century, and the eastern Andalusia, where the clash of two great Mediterranean civilizations delayed this process until the end of the XVI century. Andalusia is, finally, a land of the landlord in juxtaposition to a land of the smallholder, Baroque in juxtaposition to Arab architecture, and of wide horizons in counterpoint to the less wide landscapes.

Three Geographic Andalusia

There are three geographical units: Sierra Morena mountains, the Guadalquivir valley, and the Betic mountain ranges.

In the Sierra Morena mountains the central plain of Spain (meseta) falls towards the Guadalquivir valley. The mountains consist of hills and crests of quartz and plains with rock outcrops and faults. The highest elevation reaches 800 m asl. Soils are shallow: litosols and regosols, which are not appropriate for permanent agriculture. Even in the plain areas, granite rocks have formed sandy soils with low fertility. In the past, cereals were cultivated in these soils after a long fallow period, but because of low fertility, forest and dehesas are the most appropriate land use for these areas.

The Guadalquivir valley divides the region. The two sides of the streambed are not symmetric: the northern side is narrow as the Sierra Morena act as boundary and the southern side is wider with clayish soils. The soils, developed on alluvial materials, allow the development of agricultural crops and olive groves.

The orogeny forces of the Betic mountain ranges created a complex and diverse range of landforms. Although limestone is prevalent, slate outcrops are also common as a result of these forces. Humans settled in the valleys of the interior where water was abundant and temperatures lower, developing farming and livelihood systems adapted to local conditions.

Four agricultural Andalusia

With regards to agriculture, there are four different areas: the olive groves, the farm fields of the Guadalquivir valley, the coastal zone, and the mountainous areas.

Olive is the main tree crop in the region. Today there are more than 1,500,000 hectares (17% of the total land area) of olive groves, and it is increasing. The olive oil sector was greatly benefited when Spain joined the UE. It still receives large subsidies and support from the UE. Since 1998, the new plantations are not subsidized, but good market conditions make olives a very attractive crop. There are now some technological changes: new intensive plantations (some even in hedgerows with densities of 1500 trees ha^{-1}) are being established in fertile lands.

Deep clay soils in the fields on the Guadalquivir valley allow the development of forage crops. There is a specialization that allows to distinguish between the semiarid fields in the eastern part, where barley is the main crop and the western part, where wheat as the main crop. These cereal crops are cultivated in rotation with sunflower. Leguminous crops (string beans, lentils, etc) are becoming less distributed. In the irrigated lands, maize is the main cereal along with sunflower, cotton, and beet root. Market liberalization and the reduction of agricultural subsidies are spearheading a restructuring of farming, with high hopes put into the cultivation of forages and crops for biomass (thistle or beet root).

The coastal area is represented by the Doñana National Park at the mouth of the Guadalquivir River. Towards Portugal, strawberries are cultivated in the coastal fringe of Huelva; towards the south, in Cadiz, intensive agriculture is practised in greenhouses.

The coastal mountains have been shaped by terraces with wine grapes which was the main export of the region for many centuries. Now, many grape plants have been substituted by almond trees or tropical trees like avocado or mango. Many terraces have been abandoned and others will be soon. In wider coastal zones, agriculture in plastic greenhouses is practiced, forming an extensive and special man-made landscape.

In mountain areas, agriculture is not extensive in the marginal areas of Sierra Morena and the interior depressions of Granada, Antequera, Guadix and Baza. But beyond, these agricultural lands that depend on irrigation, the mountains have become in an area of marginal agriculture. Thousand of hectares of slopes with almond, grapes, olives and cereals have been recently abandoned. Reforestation has occurred in response to the massive rural migration. These reforestations have transformed the landscapes into extensive monocultures of Mediterranean pines. Current alternatives to rural abandonment are ecotourism and recreational activities related to environmental conservation.

The five livestock of Andalusia

There are four main livestock raised in Andalusia: sheep, goats, cows and pigs and two models of cattle production, both intensive and extensive.

Extensive livestock grazing is decreasing in Andalusia. There are few shepherds today, though recently there is growing renewal of interest in this new form of livestock grazing. Extensive livestock grazing is undergoing a transformation due to the lack of labour: on the one hand, sheep and goats are being substituted by cows as the latter are easier to manage. On the other, trashumant herds are disappearing.

However, sheep grazing on crop stubble and in dehesas can still be seen in Andalusia (as an example, the Segureña sheep in the northeast and the Merina sheep in the dehesa). Goats are also important in some parts of the Mediterranean environment of Andalusia. Extensive cattle raising, practiced until recent times only in the more humid pastures of Cadiz and Sierra Morena, is now being practiced in other environments as a result of subsidies and support from the UE in the 1990s. Finally, extensive pig raising has been one of the symbols of Andalusia. The Iberian pig eats the acorns of the holm oak dehesas and yields valued meat products.

With regards to intensive cattle raising, milking cows are worth noting. They are found in the valleys of Granada, Los Pedroches, or northern Cordoba. The production of white pigs in northeastern Almeria, Antequera, and Carmona is also worth mention.

Six Forest Types in Andalusia

Six forest types should be noted in Andalusia: the holm oak forest, the cork oak forest, the pine forest, the fir forest, and other forms such as steppe, garrigue, and eucalypts, among other timber species.

Holm oak covers the largest area in Andalusia. Most of its forests have been transformed into dehesas by shrub and tree clearing, leaving an average of 40 to 60 trees per hectare so that pastures will grow. In those dense holm oak forests which remain, game hunting (deer and wild beard) is the most important use. Holm oak is replaced by cork oak in the more temperate and humid areas. It too can form dehesas or dense forests. Cork is harvested every nine years, with the region of Andalusia being the main cork producer of Spain. The other four species of Mediterranean oaks, present in areas with higher rainfall are: the Portuguese oak or quejigo (*Quercus faginea*), African or Algerian oak (*Quercus canariensis*), the Pirenean oak or rebollo (*Quercus pyrenaica),* and the quejigo rastrero (*Quercus lusitanica*).

There are five species of native pines in Andalusia. Their distribution area has been expanding as a result of the reforestation carried out in the XX century: Mediterranean pine (*Pinus halepensis*), stone pine (*Pinus pinea*), resin pine (*Pinus pinaster*), European black pine or laricio pine (*Pinus nigra*) and Scots pine (*Pinus sylvestris*). Mediterranean pines grow in rock outcrops and clay soils of semiarid regions; stone pine in the coastal sandy soils; resin pine grows in the dolomitic and Triassic clays; laricio pine grows in the mountains at mid-altitude; and Scots pine grows in the higher altitudes of Baza and Sierra Nevada. Pines are hardier than broadleaves and thus have been used extensively for reforestation and forest landscape restoration. These forests require silvicultural management so they can be transformed into mixed forests of pine and holm and cork oaks.

There are some unique forest formations in Andalusia, such as the fir forests of Grazalema, Ronda, and Sierra Bermeja (close to those found in the

Morocco Atlas Mountain), relict tree stands with *Taxus baccata* and *Ilex aquifolium,* riparian forests with *Alnus glutinosa,* or the "corridors" with laurisilva in Cadiz as the last forests of the Tertiary on the European continent.

Shrublands and steppe are the main forest forms when trees cannot grow due to poor or shallow soils or low rainfall (or high evapotranspiration). Shrublands and steppe have been traditionally managed to obtain charcoal, fuelwood, and essential oils. Today, these lands are used only for honey production, hunting, or occasional grazing.

Finally, we should indicate that although most forests in Andalusia are protected (landscape, biodiversity, etc), there are also some productive forests with timber species (pine trees and *Populus* sp.) and for paper pulp (eucalypts).

Conclusion: rapid transformation of Andalusia

Agriculture and forestry have shaped the current landscapes of Andalusia. Our territory cannot be understood without considering deforestation for agricultural production, fuelwood, and charcoal. Mountain slopes are stil terraced, though they have not been ploughed for a long time. Vegetation has been adapted to grazing. Holm oak forests have been transformed into dehesas, a sustainable land use system that needs to be continuously managed in order to be conserved.

Some of our landscapes (natural and human-made) are threatened by economic development. Others are not functional anymore or are being transformed as there are no longer farmers to manage them. This is also happening in other parts of the Mediterranean basin.

Even if money is available, it will not be possible to bring back the landscapes that were created under different socio-economic and climatic conditions. We can only replicate or conserve the landscapes and management practices as part of our cultural heritage or for educational purposes.

These landscapes will be replaced by others: nature is always evolving. As a prosperous society, we keep on transforming nature for our betterment. Today, we have a more modern agriculture as a result of a more competitive world and globalization. At the same time, we still have other agricultural systems that are more environmental-friendly. We manage forests with limited resources with the objective of enjoying them, protecting their biodiversity and avoiding rapid change. New challenges lie ahead, such as climate change, which we have to confront in the best way we can.

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ANEXES: MAIN FORESTRY AND AGRICULTURAL STATISTICS IN ANDALUSIA

1. Land use in Andalusia (2001)

	Total area	Crop land		Pasture		Forests		Others	
	province	ha	% over total	ha	% over total	ha	% over total	ha	% Over total
Almería	**818598**	210239	25.7%	53527	6.5%	184023	22.5%	370809	45.3%
Cádiz	**739299**	330889	44.8%	101426	13.7%	222600	30.1%	84374	11.4%
Córdoba	**1376940**	730470	53.1%	126293	9.2%	440587	32.0%	79590	5.8%
Granada	**1250415**	596815	47.7%	160600	12.8%	291500	23.3%	201500	16.1%
Huelva	**1007769**	228487	22.7%	87536	8.7%	580058	59.6%	111688	11.1%
Jaén	**1349435**	676997	50.2%	157642	11.7%	402252	29.8%	112544	8.3%
Málaga	**727611**	325127	44.7%	0		210035	28.9%	192449	26.4%
Sevilla	**1403433**	936981	66.8%	85919	6.1%	243675	17.4%	136858	9.8%
TOTAL	**8673500**	**4036015**	**46.5%**	**772943**	**8.9%**	**2574730**	**29.7%**	**1289812**	**14.9%**

Source: Anuario de Estadísticas Agrarias y Pesqueras de Andalusia 2001

2. Crops (2001)

Crop Group	Total ha	Non-irrigated ha	Irrigated ha
Olive	1503276	1217258	286018
Cereals	86462	707150	157312
Industrial crops	442062	276318	165744
Fruit trees (except citrus)	233398	189809	43589
Forages	142050	125675	16375
Vegetables	134293	5748	128545
Leguminous	53658	49019	4639
Citrics	62385	9	62376
Grape	46160	42895	3265
Tuber	22261	1109	21152
Other woody crops	6873	6528	345
Flower	1693	0	1693
TOTAL	**4036015**	**3111075**	**924940**

3. Livestock

	Total Cattle Provincial	Total sheep Provincial	Total goat Provincial	Total pig Provincial
Sevilla	180617	677906	480606	669516
Cádiz	136241	454200	225660	328121
Córdoba	60106	432713	198342	302867
Huelva	53726	309554	190021	296592
Jaén	35797	273856	132764	229285
Granada	20348	268060	66458	176538
Málaga	15031	167760	62617	132365
Almería	2514	8270	14315	113832
TOTAL	**504380**	**2666419**	**1370783**	**2249116**

The Tunisian cork oak forests: environmental, economic and social importance

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Introduction

The Tunisian cork oak forests have undergone extreme human and animal pressure since the Roman period, which has caused their alarming diminishment. These forests have been subjected, simultaneously to social pressure due to overgrazing, clearing, and ploughing and to pressure from the tourist trade due to the expansion of tourist areas. In the past, cork oak forests occupied large areas of Tunisia (more than 100,000 ha). At present, the inventory is comprised of 70,000 ha (DGF 2005). Moreover, since 1988, a new problem has arisen: the "decay" of cork oak forests, which causes defoliation, mortality, and loss of vigour. This factor has become even more harmful in conjunction with the removal of the first layer of cork by inexpert workers, which causes injuries that can weaken or even kill the mother trees. This lack of expertise among workers is one of the main causes for the increase in vulnerability to disease and in cork quality degradation.

Some cork oak stands are old: in 1893 cork exploitation was initiated in harvest sites, using twelve-year rotations; which means that in 2007, the ninth cork harvest was conducted (Abid 2007). The coefficients of cork extraction applied since that time, rather arbitrarily, were 1.5 and 2.0 times the tree perimeter at 1.30 m height.

In order to determine the impact of human and animal pressure on cork oak forests in Tunisia, we have undertaken a series of analyses on the evolution of the human population, the number and composition of domestic livestock, and the distribution of farmlands. Furthermore, within the context of a programme for the increase in cork production, we have applied a multi-site assay in the Tunisian cork oak forests since 1996-1997.

Material and methods

Plant material

Cork oak is an endemic species of the occidental mediterranean basin, occupying large areas, mainly in Spain, Portugal, Algeria, Morocco, Tunisia, France, and Italy. In the Arabic Maghreb, it covers 896,000 ha, distributed as follows: Algeria, 429,000 ha; Morocco, 397,000 ha, and Tunisia, 70,000 ha (DGF 2005).

In Tunisia, cork oak is concentrated in the northwest region. In addition, it grows at certain summits of the Tunisian "Dorsale", mainly at Jbel serj, Jbel Zghouan, Jbel Zid, and Jbel Abderrahmane, under humid and sub-humid bioclimatic conditions, with mild or hot winters.

Cork oak forests belong to the following classes:

- Class of Quercetea ilicis (Br.Bl. 1947)
- Class of Cisto-Lavanduletea (Br.Bl. 1952)

Two associations are to be distinguished in the Tunisian cork oak forests:

- Cytiso-Quercetum suberis (Barbero et al. 1981)
- Myrto-Quercetum suberis (Barbero et al. 1981)

The use of cork in industry is extensive, with plenty of uses. The first is linoleum production from "male cork". The thick "reproduction cork" is used for cork (cap) production. Cork is also used in refrigeration and the acclimatisation industry. In the building trade, it is used for isothermal and acoustic coating in ceilings and walls, and to make granulated chipboards. In the automobile industry, it is used for engine gaskets and for anti-vibration blocks. In cabinetwork, cork can be used to make bath mats, clip frames, table mats, or gaming tables.

Statistical analysis

Correlation analyses have been carried out taking into account human population, number of heads of cattle, distribution of farmlands and forestlands, and reforestation rate per governorate.

Regarding intensification of cork production in Tunisia (as a result of a multi-plot assay), a two-way analysis of variance of the annual measurements per assay has been carried out, followed by multiple comparisons of means. Furthermore, a partially hierarchical three-way analysis of variance of data of annual increase of cork thickness has also been conducted.

Results

Variation of human population

An important change in the human population has been observed in Northwest Tunisia, mainly within the three governorates where cork oak is found. For example, in Jendouba's governorate, where the most important Tunisian cork oak forests are located, the population increased from 404,000 inhabitants in 1994 to 430,000 inhabitants in 2002 (INS 2004). However, as it can be observed in Figure 1, the population decreased between 2002 and 2004 (417,000 inhabitants). In Béja's governorate the population was 306,000 inhabitants in 1994, 320,000 in 2002 and 305,000 in 2004. On the contrary, in Bizerte's governorate, the population increased from 484,000 inhabitants in 1994 to 525,000 in 2004.

According to Figure 1, 41% of the total population belongs to Bizerte. The population of Jendouba and Béja represent 34% and 25% respectively, of the total.

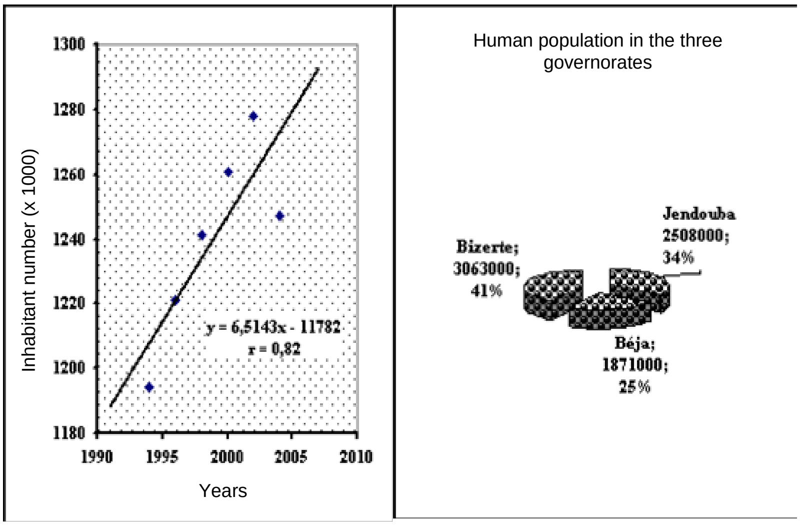

Figure 1. Changes of human population (1994-2004)

Size and composition of domestic livestock

The study of the size and composition of domestic livestock in the three governorates where cork oak (*Quercus suber*) grows reveals that the number of bovines exceeds 80,000 heads in each of the governorates considered (86,620 in Jendouba, 84,000 in Béja, and 84,660 in Bizerte (DGPDIA 2004). On the contrary, the number of sheep is 395,600 heads in Béja, 251,890 in Bizerte, and 185,870 in Jendouba. Concerning goats, the number of heads is similar in all three areas (51,000 in Béja, 52,000 in Jendouba and 55,000 in Bizerte).

According to Figure 2, ovines are the most frequent livestock in the three governorates, representing 74%, 64 % and 57% of the total livestock in Béja, Bizerte, and Jendouba, respectively. Bovines are in second place, representing 16%, 22%, and 27% of the total livestock in Béja, Bizerte, and

Jendouba, respectively. Goat livestock is the least important, with goats comprising 10%, 14%, and 16% of the total in Béja, Bizerte, and Jendouba, respectively.

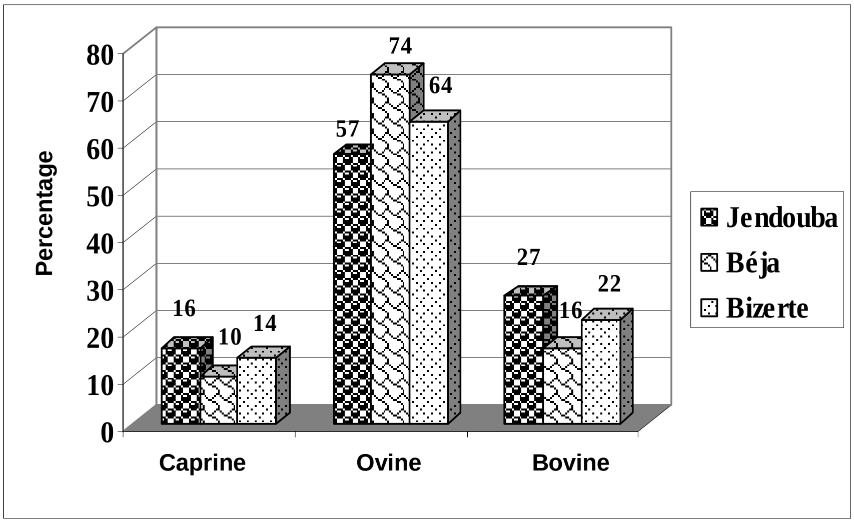

Figure 2. Percentage of domestic livestock in Jendouba, Béja, and Bizerte governorates

Importance of farmland in the governorates

Jendouba's governorate occupies the first place in terms of forest surface (114000 ha), followed by Béja (94000 ha), and Bizerte (30000 ha). Regarding pastureland, there are 38,000 ha in Bizerte, 13,110 ha in Béja, and 4,570 ha in Jendouba. Finally, Béja has the greatest area of farmland (251,000 ha), followed by Bizerte (206,430 ha) and Jendouba (170,000 ha).

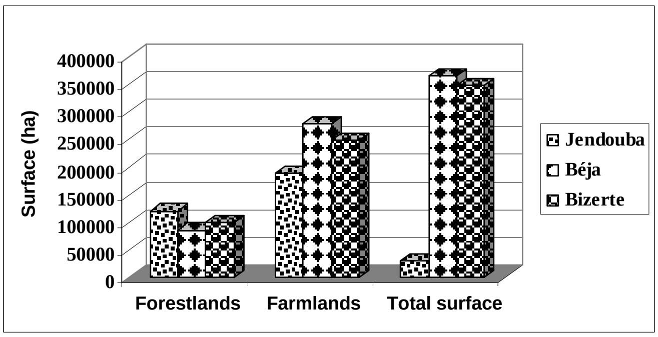

Figure 3. Distribution of forest and farmland surfaces in the governorates

Reforestation rate per governorate

The greatest forest surface is in Jendouba (120,992 ha), while in Bizerte and Béja it represents just 99,135 ha and 86,340 ha, respectively. On the contrary, Béja has 278,000 ha of farmland, followed by Bizerte (248,965 ha), and Jendouba (188,717 ha). The total surface of the three governorates is 1,022,149 ha.

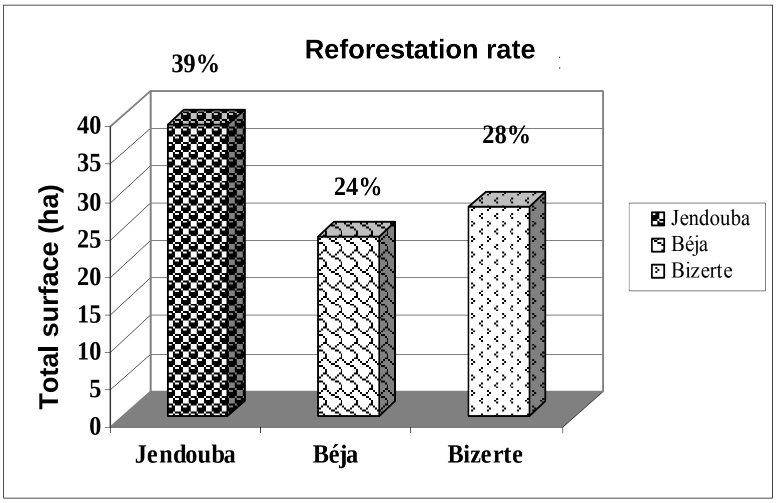

Figure 4. Reforestation rate per governorate.

Figure 4 shows that the reforestation rate is higher in Jendouba (39%). In Bizerte and Béja, the rates are 28% and 24%, respectively. The three governorates considered together represent the most important forest and agricultural area in Tunisia.

Importance of cork oak forests in Tunisia

Thirteen percent of Tunisian forests are cork oak forest, which is the main natural resource in the country. The cork oak forests are placed close to the main water resources of the country, counting 15 dams. The average volume of wood in cork oak and zéen oak (*Q. canariensis*) stands is also important (Figure 5). In Jendouba, cork oak yields an average volume of 76

m^3 ha^{-1} and an average annual volume increase of 1.5 m^3 ha^{-1} $year^{-1}$. The second forest species in this region is zéen oak, which yields an average volume of 126 m^3 ha^{-1} and an average annual volume increase of 1.031m^3 ha^{-1} $year^{-1}$. In Bizerte, the northern limit of the cork oak area, this species yields an average volume of 22 m^3 ha^{-1} and an average annual volume increase of 0.847 m^3 ha^{-1} an^{-1}. On the other hand, the zéen oak is characterized by a low average wood volume (9.7 m^3 ha^{-1}). In Béja, in the middle of the cork oak area in Tunisia, cork oak forests yield an average volume of 25.015 m^3 ha^{-1} and an average annual volume increase of 1.14 m^3 ha^{-1} $year^{-1}$. Zéen oak yields an average volume of 32.59 m^3 ha^{-1} and an average annual volume increase of 1.4 m^3 ha^{-1} $year^{-1}$.

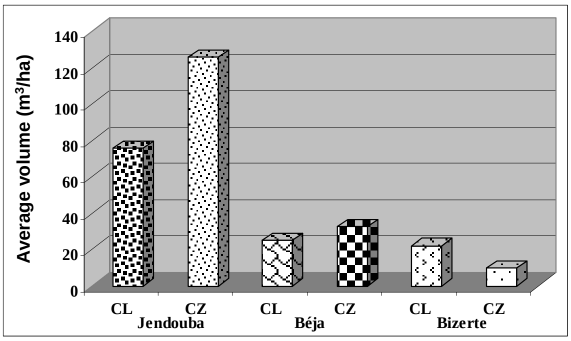

Figure 5. Average volume of wood from cork and zéen oak (CL= cork oak; CZ= zéen oak)

The highest volumes of wood from cork and zéen oak are obtained in the Jendouba area (Figure 5). On the contrary, the lowest volumes for both species, are obtained in Bizerte.

Changes in production of reproduction cork

The average annual production of reproduction cork is about 50,000 quintals. In Jendouba, the average annual production is about 44,592 quintals. Béja produces just 3,264 quintals, and Bizerte, 584 quintals. Most reproduction cork (92%) is obtained in Jendouba (Figure 6). In the other two regions, production is very low (about 7% in Béja and 1% in Bizerte).

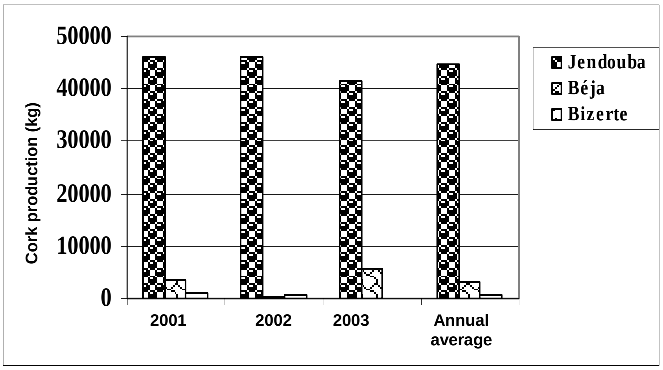

Figure 6. Reproduction cork production from 2001 to 2003

Intensification of reproduction cork production

As part of a programme for intensification of cork production, an assay concerning the removal of the first layer of cork was carried out, in July 1996 and July 1997, in four representative plots of cork oak stands in the northwest of the country. Three removal coefficients (2, 2.5, and 3 times the perimeter at 1.30 m height) were applied per plot on three groups of stem thickness.

The experimental plots were set up across the cork oak forest under similar soil and climatic conditions. Individual measurements of thickness of cork formed after the removal process were recorded from the first year of growth until 2006. Additionally, the collected data were used to carry out annual and global analyses.

The results obtained (Sghaier and Garchi 2005) show that the evolution of cork thickness, according to age, during ten years of growth after the first removal of the cork layer, is lineal during the whole period in all the experimental plots. The synthetic variable (β), which represents the annual increase of thickness of the cork layer, is a linear regression in all the experimental plots. With an annual increase of thickness of 3.64 mm $year^{-1}$, Béllif's plot shows the highest values, followed by Thébénia's, Ain

Draham's, and Chihia's plot, where increases of 3.25, 3.09, and 2.80 mm $year^{-1}$ were recorded, respectively.

Multiple comparison of means (Newman-Keuls method) shows that there are no significant differences between the three removal coefficients, classified from the lowest to the highest intensity (1, 2 and 3), in all experimental plots.

The global analysis of variance of annual increase shows that perimeter class factor is significant to highly significant in all analyses and plots. Furthermore, no interaction effect has been recorded for removal coefficient or for perimeter classes.

Discussion and conclusions

The Tunisian cork oak forests have undergone extreme human and animal pressure since the Roman period, which has resulted in an alarming decrease in cork oaks. In fact, they have been simultaneously subjected to a social pressure linked to overgrazing, clearing, and ploughing as well as to tourism pressure, due to the enlargement of tourist areas. On the other hand, the decay of cork oak forests, which has been spreading since 1988, has caused defoliation, mortality, and loss of vigour. This factor becomes even more harmful when combined with cork layer removal operations being carried out by non-qualified workers, causing injuries that induce weakening and mortality of the mother trees.

The Tunisian cork oak forests are impacted by a strong human pressure; in 2004, Jendouba, Béja, and Bizerte had 364,000, 325,000 and 525,000 inhabitants, respectively.

The calculation of the number of heads and the distribution of domestic livestock in those governorates (cork oak areas) studied, show that bovines exceed 80,000 heads in each of the three governorates. The number of ovines is much higher (395,600 heads in Béja, 251,890 in Bizerte, and 185,870 in

Jendouba). When considering goats, the number of heads is the lowest, and is similar in all cases (51,000 heads in Béja, 52,000 in Jendouba, and 55,000 in Bizerte).

The reforestation rate is 39% in Jendouba, 28% in Bizerte, and 24% in Béja. These three governorates combined represent the most important agricultural and forest area in Tunisia.

The study of dendrometric characteristics of natural forest stands in the northwest of Tunisia shows that cork oak is characterized by an average annual volume increase of 1.5 m^3 ha^{-1} $year^{-1}$ in Jendouba, 1.141 m^3 ha^{-1} $year^{-1}$ in Béja, and 0.847 m^3 ha^{-1} $year^{-1}$ in Bizerte.

The average annual production of reproduction cork is about 50,000 quintals, 92% of which are produced in Jendouba.

The results of the multi-plot assay show that the three removal coefficients studied have the same effect on the thickening of the cork layer. The thickness of the stem positively affects the cork growth, and there is no interaction between removal coefficients and stem thickness. Nowadays, cork is removed every twelve years. The increase of cork thickness after ten years of growth in the different experimental plots allows us to estimate the optimal length of rotations in the Tunisian cork oak forests in order to get high quality natural corks (thickness > 38 mm). In our case, the rotation can be 9 years in Béllif, 10 in Ain Draham, 11 in Thébénia, and 13 in Chihia.

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Importance of sylvopastoralism to the income of populations that exploit Ordha cork oak forests (NW Tunisia)

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Introduction

The people of the "khroumirie" cork oak forests exploit both the meager openings of the private forests with subsistence farming as well as the nearby state forests as collective pastoral areas within the context of the free exercise of their rights of use. Given this, we will present the socioeconomic conditions of two human groups, "Ordha" and "Khaddouma", who inhabit the clearings of the Mekna cork oak forests, which are part of the Tabarka forests. Furthermore, we will attempt to estimate the relative influence of agroforestry on the income of the local populations.

Material and methods

Physical and human environment

Ordha is located in Jandouba governorate, Tabarka delegation, Nadhour sector. This area is mainly devoted to forestry and depends on the forestry division of Ain Draham, a subdivision of Tabarka, within the district of Tabarka and the area of Nadhour. The Oligocene flysch are the main substrates of its forest and farming soils. The climate is mediterranean-like (humid bioclimatic stage, temperate variety) and the natural flora is composed of cork oak forests with mastic trees, occupying 2300 ha of forest surface, and by substitution species such as stone pine, maritime pine, and *Eucalyptus*.

The population is comprised of 443 people, established in four settlements: Khadouma, Dar el hadj, Adher Syoud, and Dar Tria, with 40, 47, 38, and 19 households respectively. Sixty-five percent of the heads of household are occasional workers, 16% are farmers of small farms and 3% are civil servants. The rate of unemployment is estimated at 13%. The surface devoted to farming is estimated at 138 ha. The households hold a combined herd composed of 92 bovine heads, 51 ovine heads, and 295 caprine heads.

Methods

The population analysis was made using two different approaches: a participative analysis of the community and an analysis of the community per household. The first analysis was carried out in the presence of four representatives of the settlements during a single meeting. The questionnaire covered the topics of land and property, water resources, main crop and animal production, occupations of households, schooling and literacy, and the previous and current projects in the region. The open questions permitted the four representatives to express themselves and give their opinion about the different topics. The prior analysis of this survey allowed for the forming of a first, general impression of the current conditions of the region and facilitated the drawing up of the questionnaire to be used for the analysis per household.

The classical analysis per household is established based on a survey of a representative sample of all the households. The survey is done based on a pre-established questionnaire concerning the characteristics of the head of the household and the rest of its members, the characteristics of the habitat of the households, the characteristics of land exploitation, the relationship with current projects in the region, the relationship with forest services, and the different suggestions for local development. The sample used for the survey represents 30% of the households of each settlement. A previous stratification was established based on the farming surface belonging to the household, divided in seven groups of property: 0 ha, 0.5 ha, 1 ha, 1.5 ha, 2 ha, 4 ha and 5 ha. For every stratum concerning a given settlement and a given category of property, a draw was made from a pre-established list. For each category, the substitution of heads of household which were absent at the moment of the interview was defined previously. The income of every household was divided into two categories: farming and non-farming income. The farming income was estimated from the sum of the gross margins of land exploitation. The gross margin of certain exploitation (plantation/crop or livestock farming) is the difference between the value of the production and the sum total of variable costs. The gross margins of farming exploitations are calculated based on technical cards/forms/sheets from official sources (MAHR 1999) and prices published by the MAHR (MAHR 2000). The non-farming income is comprised of public aid, the non-farming work of the head of the household, and the contribution of the other family members.

Results

General socioeconomic characteristics

The public forests occupy 2300 ha. The occupations strictly related to farming occupy 138 ha. The average surface of a farming exploitation is 1.6 ha. The farming exploitations are small: 98% of them in Ordha, and 90% in Khaddouma have less than 2 ha.

Non-irrigated farming is characterized by the predominance of food-producing crops, mainly cereals and legumes for self-consumption.

Irrigated crops, represented by fruit tree plantations, locally associated with market gardens, are partially used for commercial purposes.

The main livestock is goat, that primarily use the forest lands. Bovines, mainly represented by the local breed, occupy second place. Apiculture is negligible. Poultry is used for self-consumption.

Both non-irrigated and irrigated forage crops are scarce. This fact confirms the low degree of integration of livestock into farming exploitations. The feeding of livestock is primarily based on the maquis during nine months of the year (autumn, winter and spring) and sometimes throughout the whole year. The farmers tend to diversify feeding by introducing more and more hay-based forage, by creating straw stocks, and purchasing barley and concentrates**.** The meadows are exploited during the spring and sometimes in winter, but the surfaces are small.

Sources of income in the households

The average annual income of households is 5888 DT (Tunisian dinars), i.e. 4710 US $. Forty-seven percent of this income comes from farming activities, (i.e. 2870 DT or 2296 US $). Livestock production represents, on average, 1947 DT (1557 US $), or 33% of the total annual income, while plant production provides on average 952 DT (761 US $), 15% of the total annual income.

Table 1 shows that, in the case of livestock farming, income does not depend essentially on land property type. This activity, mainly carried out in forests lands, is not linked to privately-owned land. In addition, this activity, which provides on average 33% of household income, is not subjected to any charge, as the farmer uses the natural meadows without paying any fee.

Table 1. Average annual income according to land surface (in Tunisian dinars: 1.25 TD= 1.00 $ USA)

Land surface	Total annual income (TD)	Annual agricultural income		Annual income from plant production		Annual income from animal production	
		TD	%	TD	%	TD	%
0 ha	5217	1713	32.8	0	0	1713	32.8
0.5 ha	4975	1813	39.6	382	7.6	1431	28.7
1 ha	5376	2413	47.5	553	10.2	1972	39.6
1.5 ha	7732	4695	49.6	1466	18.9	3228	41.7
2 ha	7153	4088	57.1	1879	26.2	2208	30.8
4 ha	5870	3992	68	2136	36.3	1856	31.6
5 ha	4737	2935	61	2915	61	20	0.4

Conclusions and discussion

The analysis of livestock farming activity, which is supposed to be the main source of income, shows that all the resources cannot currently provide more than 220,000 FU (fodder units) per year (DGF 1995), 90% of which come from forest resources (200000 FU per year).

The current needs of the livestock held by local populations of the settlements studied are estimated at 300,000 FU per year.

In view of this, it is not possible to propose any sustainable development based on livestock farming under the conditions of current practises.

The cork oak forests, which represent the main source of income to the population, cannot continue to withstanding this situation. Natural regeneration of the cork oak forest, historically hindered by human pressure, has been provisionally and partially substituted by conifer plantations, which could even cause a progressive degradation of the environment and reduce the pastoral productivity of the natural cork oak forests.

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Silvopastoral systems for forest fire prevention in Andalusia

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Introduction

Forest fires are one of the main problems faced by forestlands in Europe. Development has produced a series of socio-economic changes leading to the devaluation and abandonment of the forestlands; that has been particularly intense in the less productive areas of the Mediterranean, which have become highly vulnerable to fire. The frequency, intensity, and impact of this perturbation are such that forest fires have become the first environmental concern for the Andalusian society (IESA/CSIC 2006). In accordance with this fact, it is the issue that receives the most attention and investment among forest management activities.

As a consequence of the increased budget provided during these last twenty (20) years, the tasks of detection, control, and extinction have achieved a spectacular improvement in Spain and, except for some particularly difficult years, the results have consistently improved. The average annual percentage of burnt forest area in Spain is close to 0.54%, a successful figure in Europe, but still far from the objective of 0.3% marked by the current Spanish National Forest Plan. When these figures are compared with those of the countries on the south coast of the Mediterranean sea, which are below 0.2%, though they hardly have any means for detection and extinction. These figures represent large differences in the status of Mediterranean forests despite the dissimilar socio-economic contexts. On the one hand, in less developed countries, rural activities that reduce fire incidence are still practised: gathering of wood and firewood, intense domestic livestock use, agroforestry mosaics, etc. On the other hand, in the countries of the European Union, rural abandonment enhances shrub encroachment and the loss of heterogeneity in forestlands.

High vulnerability of forestlands areas in combination with long dry periods and strong winds, create the conditions for the occurrence of wild forest fires that generate extensive and costly damage, for which, the abundance and efficacy of detection and extinction methods may prove insufficient. For this reason, and with the objective of reducing the impact of forest fires, the reinforcement of preventive measures to reduce the vulnerability of the forestlands is put forward.

The silvopastoral system for fire prevention

Among many other available techniques, controlled grazing has been proposed in various national and international fora as a tool for fire prevention (González-Rebollar et al. 1999; Rigueiro et al. 2005). The establishment of “pastures on fuelbreaks”, defined as fuelbreaks with scattered trees and pasture maintained by grazing, may be an effective and efficient way to put this idea into practice. This is a silvopastoral system whose more immediate objective is to create an adequate zone to facilitate the control and extinction of fire that may occur in forestlands (Ruiz-Mirazo et al. 2005).

Logically, livestock use reduces the fuel load and lessens the maintenance costs of the fuelbreaks. Furthermore, this system is a way of making the local cattle ranchers co-responsible for the management of their own environment. Many managers, having to face the consequences of the rural abandonment and the abandonment of the forestlands, demand collaboration in the development of sustainable and efficient alternatives for area management. In the context of the insecurity generated by the Common Agricultural Policy (PAC), the cattle owners need to join the programmes that recognize the environmental role of their activity; that is, they must participate in activities that will allow them to have access to new subsidies and means of assistance. In this context, the pasture-fuelbreak areas constitute a response of understanding and collaboration attractive to both agents. In this way they share responsibility for the management of the forest resources.

In addition, extensive livestock use is a key to achieving the multi-functionality of the forestlands. There is no doubt as to the relation between the abandonment and the proliferation of forest fires. Therefore, the promotion of activities like livestock grazing are important in that they renew that value of a declining activity and provide new agriculture and rural jobs.

From the ecological point of view, intense pasture is considered in itself an element of the Mediterranean ecosystems (Perevolotsky and Seligman 1998). The impact of big herbivores has been present in the evolution of this environment since time immemorial, provoking a multitude of adaptations in the plant species, and generating mutual relationships between the plants and animals (Ramos et al. 2006). For this, the livestock fulfill a very relevant ecological function. The pasture-fuelbreak areas constitute open spaces within the forests, forming part of a mosaic of vegetation that maximizes biodiversity values (Fernández 1995).

For all of these reasons, the pasture-fuelbreak areas are seen as a silvopastoral system useful in fire prevention and a valuable system of forest land management that provides, at the same time, socio-economic and environmental functions.

Current situation in Andalusia

Since 2003, the “Junta de Andalusia”, the administration responsible for the management and protection of the forestlands of the region, has financed scientific studies to understand the potential and the limitations of cattle grazing in pasture-fuelbreak areas. In 2005, the working group “Pastores por el monte mediterráneo” (“Shepherds in support of Mediterranean forests”) was formed with the goal of promoting this management system in Andalusia based on the experience gained.

This group is formed by diverse professionals that will develop this proposal. Among them, there are shepherds and livestock owners, forest managers and forest rangers, technicians specialized in fire prevention and scientists from the Spanish Council for Scientific Research (CSIC). The group has pursued the creation of the network of Pasture-Fuelbreak areas of Andalusia (RAPCA), which is described next.

The RAPCA is composed of the group of fuelbreaks and fuelbreak areas that are maintained with the controlled use of livestock and whose results are subject to scientific and technical monitoring. This network extends to the provinces of Cádiz, Málaga, Granada, and Almería, located preferably in protected areas. The programme includes a total of 12 municipalities and 16 forestlands owned by the municipalities or by the regional government. The area covered by the RAPCA is around 791.4 ha and there are 16 shepherds with their herds, grazing in these areas and participating in the programme. There are livestock other than cattle, with a total of approximately 3,260 sheep and 1,940 goats distributed among 15 forestlands, while cows are practically nonexistent, with only 6 individuals grazing in one of the forestlands.

After a detailed assessment of the current forest status, grazing areas are delineated for each shepherd and cattle owner. These grazing areas are only a fraction of the total fuelbreak areas existing in the forest. Grazing in these areas is intensive, since these are *strategic zones* in which the reduction of the fuel load is the priority. However, the grazing activities are not limited to these spaces. In order to make the integration of livestock grazing in fire prevention activities feasible and viable, it is necessary to have additional, supplementary grazing areas. These additional areas are grazed less intensively, with stocking rates adjusted to the sustaining capacity of the forestlands, and considering the protection of natural tree regeneration. The use of forestlands by livestock creates a gradient in grazing intensity that configures the following mosaic: i) Areas under regeneration or protected due to the presence of endangered plant species with restricted or zero-grazing; ii) Areas with intermediate grazing rate (*Supporting Zones)*; and iii) *Strategic Zones*, with high grazing rates, necessary to reduce the fuel load. This way of managing livestock in the preventive and integrated management of the forestlands, makes the presence of a shepherd or the use of fencing necessary in order to concentrate the animals in strategic zones. The RAPCA has specifically opted for the first option, due to the advantage of having vocational shepherds in the area committed to the mission of preventing forest fires.

In any case, the maintenance of the fuelbreaks with livestock does not mean that the mechanical shrub clearing on them will be stopped. The increased stocking rate limits, though does not completely prevent, the growth of vegetation and thus the accumulation of wood fuels. This does allow for less mechanical shrub clearing interventions however, and therefore a great savings in cost. For improved performance of the system, it is advisable to provide incentives, such as the placement of water points and pasture improvement, to graze in the fuelbreak areas. Also, payments to shepherds have been considered necessary in order to obtain an adequate control of the vegetation. This economic compensation was designed like an award /prize for those fuelbreak areas maintained free of vegetation, and not as a subsidy *a priori*. Thus, the work done by each shepherd is under technical monitoring, focused on measuring the effect of grazing on the vegetation at the start of summer which coincides with the start of the fire season. A negative evaluation will result in the cancellation of the payment for the grazing services, while a positive evaluation, demonstrating an effective control of vegetation, results in a payment. The amount of this remuneration will be determined according to the level of vegetation control in the pasture-fuelbreak areas as a result of grazing, considering the slope, the remoteness, and the existing vegetation.

Aside from this technical monitoring, various scientific investigations are being done to rigorously study some of the key factors that influence the functioning of the system. Current on-going research includes:

- The use of less flammable forage shrubs in pasture-fuelbreaks
- The effects of fuelbreak creation and its maintenance on biodiversity
- A detailed measurement of the accumulation of the fuels in distinct scenarios with livestock pressure and type of vegetation.
- The efficacy of using SALT or improved pasture to stimulate the presence of herbivores (wild and domestic) in the fuelbreaks.
- The economic evaluation of this management system, including all its externalities, and the alternatives.

The monitoring and assessment of pasture-fuelbreaks in Andalusia is a pioneering line of research of great importance and relevance. The results that will be generated in the next two years will allow the adjustment of the development possibilities of this preventive system within the Andalusian context.

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Non trade amenities for sustainable management of Mediterranean Rural Areas: The environmental goods of traditional mountainous agrarian system in South-eastern of Spain

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Introduction

Farming systems that are not financially competitive are being abandoned as the environmental externalities of agriculture are not taken into account in policy making and in the design of rural development. Today, migration and farm abandonment, particularly in the marginal uplands, is widespread (Calatrava and Sayadi 1997; Calatrava and Sayadi 2004). The abandonment of rural activities results in a reduction of *environmental services* (biodiversity, landscape, agroecosystems, etc) and *social services* (rural population, cultural heritage, etc.) more and more demanded by a society that is increasingly aware of environmental issues and intergeneration equality. Thus, conservation and recreation, options, legacy, and values derived from the non-use of environmental resources are becoming more important, competing with the production and direct consumption of goods. Environmental sustainability is now a criterion to be considered in all productive systems.

In this paper, we briefly discuss the concept of externality as a key concept of environmental economics and identify the different externalities of upland farming systems of Southeast Spain. Then, we try to assess the aesthetic value of agroecosystems in the Alpujarras, a typical mountainous area in the Southern Mediterranean.

Externality as a key concept of environmental economics

In the basic model of general equilibrium, the interactions among market agents are manifested by their effect on prices. We say that an *externality* (external economy) exists when the actions of an agent affect the environment of another agent by any means except the market. In this regard, an externality exist when farmers provide environmental goods and services since the effects of agriculture have an impact on the utility function and productive functions of other agents (the society) without any market compensation, as markets do not take into account these goods and services. These externalities can be positive or negative. An externality is positive (landscape improvement, erosion control, food for fauna) when the impact is favourable and therefore, there is an increase in the utility of any agent not involved in farming although this is not reflected in an increase in the price of goods. The externality is negative (pollution, excessive exploitation of aquifers, landscape degradation, etc.) if there is a reduction in welfare, but the producing agents are not penalized nor the affected people compensated.

Today society increasingly demands positive externalities and penalizes the negative externalities derived from farming. However, farmers allocate their resources according to market goods (inputs and food), thus reaching their private optimum and marginal private benefits. Consequently, there is market failure as prices do not reflect those externalities (i.e., the producers do not *internalize* the negative externalities). This situation presents the potential risks of overproduction or underproduction of public goods needed by the society (social optimum), as farmers do not pay for them (negative externalities) or do not receive any incentive for producing them (positive externalities) (Ortiz 2001).

In this context, the valuation of the environmental externalities of farming systems emerges as a discipline with a growing importance, particularly since the mid-1980s. This discipline proposes to include environmental objectives in a new model of sustainable agriculture, responding to environmental demands.

To internalize the effects of the externalities in the functioning of the farming systems and to foresee the expected costs and benefits, a valuation is necessary (Pretty et al. 2003). The value of the externality can be estimated through the mechanism of "internalization".

Two aspects are important when valuing environmental externalities: the *value* of what is estimated and the *method* of estimating (Calatrava 1996a). The Value of something (the externality in this case) is determined by what people are willing to pay for it, to enjoy and maintain it. To properly internalize the externalities, environmental economics have developed several general methods with the objective of valuing, not just the negative environmental impacts, but also the benefits derived from activities that enhance environmental quality. Those values are good indicators for environmental policy-making (subsidies, taxes, etc).

The classification of methods of valuing natural resources and environmental impact is diverse and can be done in different ways. Calatrava (1996b) has a simple and practical classification based on the demand curves. Contingent Valuation methods, Choise Experiment Travel Cost Conjoint Analisis, Recovery Cost, etc are the most used among those methods. The basic characteristics, limitations, and advantages can be found for example, in Pearce and Turner (1990), Azqueta and Pérez (1996), Calatrava (1996a and 1996b) and Navrud (2000). In this paper we describe our application of the method of Analysis to evaluate the social preferences of several landscapes of the Alpujarras (South-eastern Spain).

Environmental externalities of the farming systems in the Alta Alpujarra region: the potencial of the landscape

The Alpujarras is a good example of the transformation of the rural areas of the Southern Mediterranean: most cultivated land has been abandoned with only a few cultivated plots near the villages. The landscapes in this region have been described in detail by Navarro (1981), Mignon (1982), Calatrava and Molero (1983), Jiménez (1991), Sayadi and Calatrava (1995 and 2002), among others.

The farming systems in this area are environmental friendly, with positive environmental externalities. In this paper, we will focus on the landscape, although other environmental aspects as a result of farming will be described. The environmental externalities have been grouped as follows:

- Pollution from agrochemicals
- Externalities derived from management practices and terraces, etc.
- Externalities related to water management
- Externalities related to forest fires
- Externalities related to development
- Externalities derived from the landscape

Use of agrochemicals

Until the massive abandonment of agriculture in the area, farming was based on traditional, environmental-friendly practices: the use of agrochemicals and pesticides was restricted. The relationships between livestock, agriculture, and crop diversity were the foundation of this ecological agriculture. From the 1970s, the use of agrochemicals increased, although less than in conventional agriculture. Towards the mid-80s, the decrease in irrigated land accelerated (a reduction in the number of species, of management practices, introduction of the almond tree, abandonment of vegetable gardens, etc.) together with a massive migration towards urban areas. This process reduces the negative externalities from farming. The process could be accelerated if ecological agriculture is further adopted.

Management practices, terraces, etc.

Agriculture usually implies a loss of stability of the ecosystem and can result in a degradation of the natural capital which is necessary for environmental equilibrium.

In the Alpujarras, particularly since Arab times (VIII century), human influence in nature began during the Neolithic period (Sayadi Calatrava 1995; Sayadi 1998)[1] and the ecosystem was progressively replaced by an agro-ecosystem which was environmentally-friendly although transforming the original ecosystems. In Arab times, irrigated agriculture particularly on sloping lands was practiced, and was adapted to the local topography and landscape. Irrigated agriculture has been the motor of economic development and of the rational management of natural resources.

The first impact on the local agro-ecosystems began with the re-population plans by Philipp II in the XVI century. The natural balance between farming practices and the natural ecosystem was seriously threatened after the arrival of the first migrants with their cereal cultivation and sheep grazing practices along with a total disregard for horticulture.

[1] The authors studied the transformation of agricultural systems in the Alpujarras since the expulsion of the moriscos in the XVI century to date. The factors influencing this transformation (political, economic, demographic) and how they shaped the functioning of the current agrarian system in the area were also determined.

Later in the Alpujarra Alta, population pressure between the XVII and XIX century, the introduction of a multi cropping system based on cereal grains, as well as changes in the socio-economic system forced the expansion and clearing of forested sloping lands far away from the villages.

The massive migration experienced in the second half of the XX centuryhas produced the opposite results: the total cultivated area has been reduced with only those lands next to the village being cultivated.

The current decline of farming has led to a series of processes which threaten the balance of sloping lands. These processes are the destruction of terraces due to small-scale landslides, changes in the soils, and reactivation of vegetation dynamics (Jiménez 1991; Douglas 1997). These consequences are different in irrigated land than in dry land.

Firstly, the maintenance of terraces and irrigation channels is key to the equilibrium of the local farming systems and for the environment, as terracing reduces considerably the steepness of the slopes. Similarly, continuous land cultivation of the terraces allows a redistribution of the soil deposited due to erosion in the lower part of the terrace.

The effect of dryland crops, both forages and ligneous crops, on erosion should be noted, although those crops, with the exception of the almond, are not abundant in the area. Dryland agriculture on sloping lands creates an erosion problem since the soil remains bare for a large part of the year unless mounds are established or planting done on contour lines (Martínez and Francia 1997; Martínez et al. 2006).

The irrigation channels allow a better distribution of water, reaching the furthest corners of the field. The channels also distribute water by infiltration, resulting in higher and more diverse plant cover. Therefore soils are better protected, and more stable, with higher levels of fauna.

Massive abandonment of farming activities in the Alpujarras results in the elimination of all these benefits. The abandonment of farms and irrigation practices and the maintenance of terraces, is a fundamental change of the functioning of a system based upon a strong relationship between humans and the environment. The abandoned lands are subject to deterioration processes such as soil erosion. This process is more serious if we consider the high percentage of sloping lands which have not been improved by terracing. Additional factors include extreme climatic conditions such as seasonal and erratic rains, etc., which contribute to erosion (Goicoechea 1981). Due to the change in the management system and the reduction in human control over sloping farms, a big proportion of mountain sides are evolving by natural processes. From the landscape point of view, according to Jiménez (1989), Ruiz (1993), Blanca and Martínez Lirola (1998) and Camacho Olmeda et al. (2002), the most immediate impact of abandonment is the re-vegetation of sloping lands, resulting in a heterogeneous landscape with a great density of vegetation. Typically, terraces will be colonized first by annual grasses, then by perennials, and later by woody vegetation. But since these soils are of medium to low quality, the abandoned fields deteriorate and remain without plant cover. Eventually, in the best areas, the fields will be colonized by low density woody vegetation etc. Pérez and Vabre (1987) indicate that unproductive farms are considered an ecological manifestation of rural abandonment… "and it is the result of the interaction between socio-economic and ecological processes".

Water management and use

In addition to the advantages of water distribution through irrigation channels, (Calatrava and Sayadi (2007) demonstrate the relative importance of the attribute "water" in the aesthetic preferences of "landscape consumers"), it is important to note that the abandonment of irrigation and the lack of maintenance of the irrigation channels causes the water to flow through new channels which cause erosion. In recent years, torrential rains have caused landslides, which are common in the Alpujarras and that damage roads. This problem is exacerbated by the abandonment of agriculture upstream and consequent changes in the flow of water. Upland agriculture had been producing a positive externality which had never been valued, and its negative effects are being manifested as agriculture is abandoned.

A minimum value of that externality would be the costs of repair and the reconstruction of roads and other damaged property.

Risk of forest fires

As terraces are being re-vegetated with woody vegetation, the risk of forest fire increases. Forest fires have obvious ecological and economic effects and the abandonment of agriculture combined with increasing tourism and urbanization increase the risk of fire. The effects of forest fires in the region have been increased by the abandonment of farming activities.

The economic and environmental balance of development

Agriculture has a productive and environmental function and therefore is the best activity to ensure rural development. The balance between economic and environmental systems is a characteristic of sustainable development models (Calatrava 1988).

In the Alpujarras, the practice of irrigated agriculture in the uplands supports the environmental balance as a result of the positive externalities it produces. It also supports the balance of the economic system for several reasons: it supports diversification of activities, it generates income and employment which complements tourism, it adds value to products thereby enhancing the local tourism industry, and it helps the development of agrotourism (Sayadi and Calatrava 2001 and 2002).

Valuing agrarian landscapes

In this section the externalities resulting from the agrarian landscape are analyzed. Calatrava (1996a and 1996b) and Calatrava and Sayadi (2007) developed a typology of landscapes in rural areas as well as some considerations on their value and the methods of valuation.

Table 1. Results of the Conjoint Analisis of agricultural landscapes

Attribute	Relative Importance (%)	Levels	Partial Value (Part-Worth)
VEGETATION LAYER	55.77	**Virgin land**	-0.6358
		Irrigated land	**1.2843**
		Dry farm land	0.1997
		Abandoned farm land	-0.8482
BUILDING LEVELS	28.09	**High**	**0.4849**
		Little	0.1044
		Without	-0.5893
LEVEL OF INCLINE	16.1	High	-0.2706
		Medium	**0.3466**
		Low	-0.0760

Source: Sayadi and Calatrava (2002)

In Spain, there are few studies on the value of agrarian landscapes. The first study was done by Calatrava (1994 and 1996b) using Contingent Valuation techniques to estimate, in monetary terms, the value of the landscape of the sugar cane plantations in the subtropical coastal area of Grenade. Other studies include that of Real et al. (2000) which presents an interesting quantitative classification of landscapes using multivariant methods, as well of those of Pérez (2002), Sayadi and Calatrava (2002), Arriaza et al. (2004), Sayadi et al. (2005), although none of these carries out a monetary valuation of the aesthetic value of landscapes. Sayadi et al. (2004) compared the results of

Contigent valuation methods with conjoint Analysis methods in the estimation of tourists´ willingness to pay for the conservation of irrigated farming landscapes in the Alpujarras.

Conjoint Analysis method[2] concluded that tourists assign the higher value of the landscape to the vegetation layer cover of the Alpujarra (55.77% of the aesthetic value given to the landscape), followed by the existence of traditional villages (28.09%), and the sloping lands (16.14%) (see Table 1).

With regards to the vegetative cover, the vegetation associated with irrigated lands was given the highest value as compared to dryland agriculture and "Virgen lands". Those abandoned farms had the lowest value. Specifically, in the mentioned study, the results in terms of aggregated partial utility aesthetic value (Part-Worth) of the visitors surveyed, standardized with the restriction of zero sum, were (Table 1): for the irrigated lands: 1284, 0.1997 for drylands, -0.636 for virgen land and -0.848 for cultivated but later abandoned land. That provides an idea of the extent to which the irrigated fields are key to an attractive the landscape.

Therefore, the irrigated agricultural land is the most valued aesthetic element of the landscape in the Alpujarra.

From the previous results (table 1) we can conclude that the most valued landscape for the people interviewed corresponded to those irrigated agricultural lands of average slope, where there was a village well-integrated into the landscape. On the other hand, the less preferred landscape was that of abandoned agricultural land, without a village and with steep slopes.

Conclusions

▪ There is a need to consider in the sustainable rural development design process the environmental service functions of rural landscapes and in particular those of sloping agricultural lands.

[2] For a classification of preferred landscapes see the work of Sayadi and Calatrava (2002) and Sayadi et al. (2004).

- The farming systems on sloping lands of the southern Mediterranean present positive externalities that provide a utility to society.
- One of the main methodological problems of these systems is the valuation of their environmental externalities and how to provide feedback based on the results to policy-makers.
- Valuation allows the internalization of those externalities and therefore the design of intervention strategies. Similarly, valuation allows a Cost-Benefit Analysis introducing environmental valuation parameters.
- The environmental externalities of the agricultural systems identified in the area are derived from the use of agrochemicals, management practices, terraces, etc. in relation to water management and forest fires; in relation to the influence of the balance of the development process with the landscape.
- The irrigated agricultural land is the most valued aesthetic element of the landscape in the Alpujarras.
- Rural development policies should support some farming systems and activities as a relevant part of the landscape, specially the irrigated lands. Farming contributes to the prevention of migration from rural areas and thus the conservation of the villages, which are another valued element of the landscape in the Alpujarras.

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Social demand for the aesthetic externality of rural landscape: Monetary and non-monetary valuation for sustainable agri-environmental policy design in Mediterranean rural areas

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Introduction

In response to social environmental concern and demand, and as a result of the growing consideration of environmental objectives in the new paradigm of sustainable agriculture, evaluation of environmental externalities of agricultural systems has become increasingly important, particularly since the mid-eighties. Among the externalities caused by agriculture, we should consider how this activity has shaped the landscape, analysing the aesthetic function of agro-ecosystems (Deffontaines 1985; Thenail and Baudy 1994). Different agro-ecosystems have different capabilities of shaping the landscape, and rural landscapes will display a different degree of the agricultural component, depending on the composition of the agricultural systems.

Agricultural landscapes in mountain areas constitute an important component of society's aesthetic utility function. Therefore, the current abandonment of farming activities, particularly irrigated farming in these areas, would indirectly have a negative impact on rural tourism by reducing demand, which is sufficient to justify a policy aimed at maintaining this kind of rural landscape, particularly in the Mediterranean regions of Europe. Policy makers need information on public preferences for intervention that efficiently enhances the aesthetic externality of agriculture in such areas (Dearden 1980, UE 2000).

In this paper we attempt to identify the value of agricultural landscape amenities by comparing estimates of this obtained value using Conjoint Analysis (CA), which is a non-monetary approach, and Contingent Valuation (CV), a monetary approach. This evaluation has subsequently been complemented with the estimation of a landscape agrarian component preference model.

Landscape change in the Alpujarran mountain of southeastern Spain: The study area

Since the 1950s, as a consequence of the rural exodus, many rural Spanish regions have undergone changes in their landscape structure due to the abandonment of agricultural activities and, in some cases to the proliferation of other economic activities, such as tourism.

The Alpujarras of Granada (see Figure 1), situated in the south of the massif of Sierra Nevada (Southeastern Spain), exemplifies this transformation, typifying the Mediterranean high-mountain regions of Europe.

The Alpujarras district, with a series of mountain valleys and gorges, has abrupt altitude gradients (almost sea level to 3500 m), and steep inclines which impede traditional farming systems. Irrigation systems, many dating from the 15th century or earlier, are fed by streams and snowmelt from the

Sierra Nevada summits and have permitted an intricate system of terraced agricultural land, which typifies the landscape around the mountain villages from 800 to 1800 m a.s.l. This traditional agricultural landscape is at risk due to agricultural abandonment. The irrigated terraces are labour-intensive and thus support a multi-cropping system which includes field crops, vegetables, trees, and, at lower elevations, vines and olives.

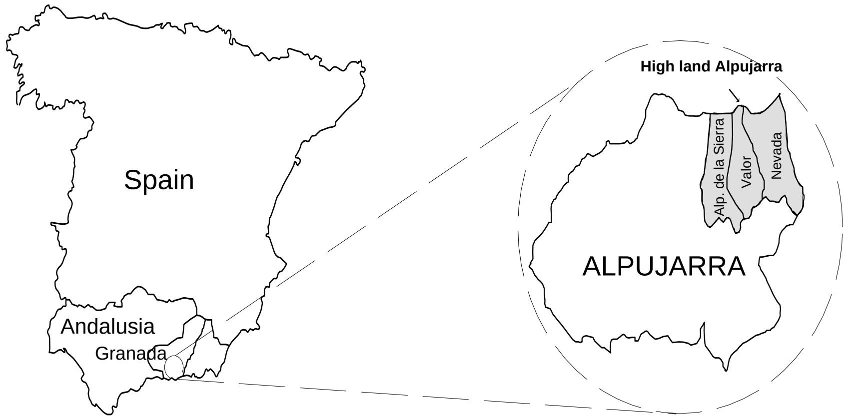

Figure 1. The study region; the High Lands of the Alpujarras area in Southeastern Spain

Local farming has gradually been abandoned since the beginning of the rural exodus in the fifties, and demographic changes in the second half of this century were dramatic. Most of the Alpujarran villages recorded population highs in 1950 and an exodus since then. The population declined by roughly 50% since 1950, with rates approaching 4% per year between 1960 and 1975, migrating towards other parts of Spain (especially Barcelona and Madrid) seeking employment in industry, in coastal tourism (e.g. Costa del Sol, Malaga), and also in intensive agriculture (particularly that of greenhouse horticulture along the Spanish Mediterranean coast).

The abandonment will affect not only the landscape structure, but also the habitat suitability of many species (Scozzafava and De Sanctis 2006). The autochthonous landscape in these mountain areas and their ecological equilibrium are consequently menaced.

The evaluation of public landscape preferences of these areas and the estimation of their Willingness To Pay (WTP) is particularly valuable in helping policy makers redesign sustainable rural development programmes in order to take fuller advantage of the aesthetic potential and to increase social welfare.

Methodology

Non monetary valuation: The Conjoint Analysis of rural landscapes

In order to apply the Conjoint Analysis method (Sayadi et al. 2005 and 2008), the Alpujarra's landscapes features were identified by analysing the answers given by visitors in previous work (Sayadi 1998) to some scale-rating questions involving the main attributes of the landscape in the area. Three landscape attributes were finally selected (Table 1).

Table 1. Features and levels of the landscapes used in the experiment

Features	Levels	Description
Vegetation Layer (feature 1)	Abandoned fields	Abandoned farmlands
	Dryland farming	Almond orchard, vineyard, fig, olive tree
	Irrigated farming	
	Irrigated-orchard	
	Natural lands	Lands that never were used in agriculture
Level of slope (feature 2)	Gentle slope	Less that 10 %
	Intermediate slope	From 10 – 20 %
	Steep slope	More than 20 %
Level of Building (feature 3)	No building	Without architectonic components
	Little building	Some typical houses, isolated houses
	Intense building	Population centre

Table 2. Orthogonal fractional factorial design of landscape profiles

Landscapes	Vegetation Layer	Level of slope	Building
Landscape 1	Irrigated farming	Gentle	No building
Landscape 2	Irrigated farming	Intermediate	Little building
Landscape 3	Irrigated farming	Gentle	Intense building
Landscape 4	Abandoned farming	Gentle	No building
Landscape 5	Natural lands	Steep	Little building
Landscape 6	Irrigated farming	Gentle	Little building
Landscape 7	Dryland farming	Intermediate	Little building
Landscape 8	Dryland farming	Gentle	No building
Landscape 9	Abandoned farming	Intermediate	Little building
Landscape 10	Abandoned farming	Gentle	Little building
Landscape 11	Dryland farming	Gentle	Little building
Landscape 12	Dryland farming	Steep	Intense building
Landscape 13	Abandoned farming	Steep	Little building
Landscape 14	Natural lands	Gentle	Little building
Landscape 15	Natural lands	Intermediate	No building
Landscape 16	Natural lands	Gentle	Intense building

A full profile design was used (by including all the possible combinations of levels and attributes), but an excessive number of possible landscapes (36 profiles) would have been generated for a respondent to be evaluated, some of which would not even be present in real life. Each combination of attribute levels represents a specific landscape alternative (profile). For this to be narrowed down to a reasonable number of testable combinations, an orthogonal fractional factorial design was used (Louviere et al. 2000), allowing assessment of the relative importance of the different landscape attributes through a reduced sampling of the profiles. Since none of the attributes in an orthogonal array are related, the intercorrelations, or of-diagonal elements are 0.0 (Papoulis and Pillai 2002). Thus, the orthogonal array permits the measurement of the main effects of attributes on an uncorrelated basis. This design assumes that all interactions are negligible. The Conjoint Designer program (Bretton-Clarck 1987b) provided 16 hypothetical landscapes or index cards, which comprise the total number of final stimuli which the respondents were shown (Table 2).

The additive composition model was also adopted as applied by Steekamp (1987). This model, the simplest and by far the most frequently used, assumes that the overall evaluations are formed by the sum of the separate part-worth (partial standardised utility) of the attributes.

The stimuli (attribute-level combinations) presented to the interviewees were photographs of real landscapes taken in the area, following the orthogonal fractional-array design shown in Table 2.

Each photo represents a specific combination of attribute levels or specific landscape alternative. Several studies have attempted to assess the scenic preferences of observers using photographs of rural landscapes (Shafer and Brush 1977; Wherrett 2000; Arriaza et al. 2004). Descriptions of the use of pictures in public-preference models and other methods (field observation, written description, etc.), can be found in Shelby and Harris (1985), Bernaldez et al. (1988), among others.

The landscapes (stimuli) in the photographs shown to the individuals were selected according to the same orthogonal design used for the Conjoint Analysis.

The landscape preferences were measured on an ordinal scale from 1 to 16, by ranking the landscape cards or stimuli from most (1) to least (16) preferred. Thus, after examining each photograph, the interviewees were asked to rank each landscape according to their preferences. Sayadi et al. (2005) show that this ranking approach represents public preferences better than does a rating technique in the Conjoint Analysis of rural landscapes and reveals more clearly the differences between levels of attributes than does the rating method.

Monetary valuation: The Contingent Valuation of rural landscapes

In order to apply the Contingent Valuation (CV) method to estimate the willingness to pay (WTP) for landscape views, an artificial market was created. Each interviewee was asked: "Please imagine in the Alpujarras area a hypothetical rural hotel of standard category with rooms offering different landscape views for which the only differentiating criterion in the room price is the view to be enjoyed from the terrace of room. With all the other lodging conditions the same (category of the hotel, services, type of the room, etc.), please indicate, after carefully examining the following landscape photographs, your maximum willingness to pay (WTP) for a day of lodging to enjoy the different views represented in the photographs". The people interviewed were asked only once to state their maximum WTP for the room including the view to enjoy each of the landscapes; in this case, the payment vehicle was the price of lodging. The most useful information in the CV was the difference in WTP that the same individual expressed for rooms with different landscape views.

For the expression of the WTP, an open-ended question format was used because the market was private (room price) and the persons polled were familiar with the prices of the hotels and country houses of the zone (Sayadi 1998). Also, given that the number of landscapes shown to each individual was rather high, the use of another type of format (dichotomous, auction, etc.) would have excessively prolonged the test. For subjects who expressed some difficulty in understanding the kind of "medium category hotel" in the area, prices, etc., a brochure was used to explain the type of accommodation existing in the area. These subjects, representing less than 5% of the sample, were less familiar with the area and showed some difficulty in comprehending the objective of the Contingent Valuation exercise.

Rural landscapes preference assessment: A multiple regression model

In order to analyse the relationship between interviewees' agrarian landscape preferences and their socio-economic characteristics, a multiple regression model was set up, and the following independent variables were considered in the model specification: province (PR), sex (SEX), monthly income per capita (PCI), age (AGE), education (ED), and professional occupation (O). Two co-variables obtained from the conjoint analysis were also taken into account: the relative importance that each individual assigned to the Vegetation Layer attribute (RIVL), and the individual's utility function constant (U_0). Table 3 shows the different levels taken by each of the initially selected variables

Table 3. Definition of variables in the landscape preference model

Independent variables	Description
Constant	Constant term
PR	1 if the province is Granada, 0 if not
SEX	1 if a man, 0 if a woman
PCI	Per capita available monthly income
AGE1	1 if age is below 25, 0 if not
AGE2	1 if age is between 26 and 44, 0 if not
AGE3	1 if age is between 45 and 59, 0 if not
AGE4	1 if age is over 60, 0 if not
ED1-2	1 if without studies / Primary /, 0 if not
ED3	1 if Secondary, 0 if not
ED4	1 if Intermediate University degree, 0 if not
ED5	1 if Higher University degree, 0 if not
O	1 if interviewee is working, 0 if not
RIVL	Relative importance of vegetation layer
U_0	Individual utility function constant

Regarding the dependent variable of the model, the following variable was used:

$$\mathbf{UA_i = UI_i + UD_i}$$

where UA_i is the utility (worth) associated in the individual *i* with the agrarian components of the landscape feature "Vegetation Layer", representing the sum value given to agrarian components (irrigated and dry land) by the respondent i.

UI_i is the partial utility (part-worth) for the individual *i* associated with the level “Irrigation Lands”.

UD_i is the partial utility for the individual *i* associated with the level “Dry Lands”.

Data collection and analysis

The questionnaire was divided into three parts. The first part contained the Conjoint Analysis (CA) exercise and was aimed at quantifying the individual landscape preferences of the interviewees. The second part included the Contingent Valuation (CV) exercise and attempted to find out the maximum daily WTP of interviewees for room in a medium Cottage/Rural Hotel with views of any of these different landscapes from the bedroom window. The third part of the questionnaire included socio-economic characteristics of the respondents (age, sex, income, education, etc.). The CA and CV exercises were administered by the same researcher but surveys were separated in time.

Data were collected from June to August 2006 in 203 personal interviews to citizens from Granada and Almeria, who lived close to the area. These two provinces were the most likely origins for potential visitors (Sayadi 1998, Sayadi and Calatrava 2001). The sample size was acceptable, considering the standard deviation resulting for the WTP means giving a sample error of less than 2 Euros.

The individuals were randomly selected. However, sample characteristics were compared to visitor characteristics on the basis of the distribution of age, gender, and level of study, and were found to be representative of tourists in the area. Both the CA and CV were administered to the same subjects, but separately in time and without any connection between the two tests.

Persons were contacted in different places (some on the street, others in bars, workplaces, parks, etc.), but always where they were able to examine the photos (presence of tables, benches, etc.). The respondent was asked to observe all the photographs carefully in order to fill out the questionnaire. It was explained that the questionnaire consisted of two parts: the first part to be conducted immediately and the second afterwards on the date that the person preferred (after one day, two days, etc.) in a place that the person specified. Persons that did not agree to participate in the second part (less than 10% of the subjects), were excluded from the survey. The refusal to participate did not appear to be a response to the content of the questionnaire, as the individuals were first asked for their willingness to cooperate before beginning the work. Only 9% of respondents that participate in the first part of the survey (CA) failed to fulfill their commitment to continue with the second exercise (CV), resulting in 203 valid questionnaires.

After the survey, the data of the CA and CV were analysed by calculating: (i) the average ranking (AR) assigned by respondents to each landscape (input of CA), (ii) the average utilities (AU) obtained from the assessed utility model (output of CA), and (iii) the average of the WTP (AWTP) for each landscape stimuli used in the experimental design (input CV).

Results

The main characteristics of the citizens surveyed were as follows: 69% were 25-45 years old; most (62.35%) were male; about half (52.47%) were married; the most frequent household size (77.85%) was 2-4 people; the average monthly household income was about 1,200 € month^{-1}; and more than 40% had a university degree.

According to the Conjoint Analysis of rural landscapes results, table 4 shows the group utility function (part-worth) and relative importance (%) of the different attributes.

The aggregate utility function for landscape aesthetic valuation for all the sample is the following:

U = [- 0.383 Natural Lands + 2.255 Irrigated Lands + 0.044 Dray Farming Lands – 1.916 Abandoned Farming] + [1.630 Intense Building + 0.050 Little Building – 1.679 None Building] + [- 0.765 Steep Slope + 1.034 Intermediate Slope - 0.247 Gentle Slope] + 8.622

Table 4. Preference test results for the total group

Features	Relative importance (%)	Levels	Utility value (Part-Worth)
		Irrigated Farming	2.255
VEGETATION LAYER	44.95	Dryland Farming Lands	0.044
		Abandoned Farming	-1.916
		Natural Lands	-0.383
		Intense	1.630
BUILDING LEVEL	35.66	Little	0.050
		None	-1.679
		Intermediate	1.034
SLOPE LEVEL	19.39	Gentle	-0.270
		Steep	-0.765

It can be stated that the nature of the vegetation layer proved the most relevant attribute (44.95%) in forming public landscape preferences. This was followed by the level of existing building or construction (35.66%). The level of slope occupied the third place in importance (19.39%).

The most highly valued landscape had an agricultural component of irrigated farming on an intermediate slope with a village visible in the landscape. On the other hand, the least preferred landscape involved old abandoned farmlands, with no villages and a steep slope (Table 4).

As for the Contingent Valuation results, the interviewees' WTP for a room to stay in a standard hotel to enjoy the views of the landscapes, the average daily price expressed was 27.07 € day^{-1}, the absolute maximum price being 54.09 €/day and the absolute minimum of 18.03 € day^{-1}. Most respondents (60.5%) were willing to pay between 24.04 € day^{-1} and 36.06 € day^{-1}. Taking into account that the WTP estimated here is the price for the room including the view and the WTP score was from 21.48 € day^{-1} to 31.60 € day^{-1}, the only difference (between 0 € and 10.12 €) was due to the landscape views.

No protest bids were identified (protest bids are zero answers from subjects deriving positive utility from the good subject to valuation). Although protest bids in contingent valuation are quite common (Mitchell and Carson 1989), they refer to a normal protest rate percentage of around 30%. In our case the absence of protest bids can be explained by the valuation context. Firstly, the payment vehicle was not focused on public policy (i.e. taxes), which is related to most protest bids in Spain (Barreiro and Pérez and Pérez 1999). Secondly, the landscape in Spain is not supported through specific public programmes and the payment vehicle is related to private benefits derived from accommodation, and thus incentives for free enjoyment and/or strategic behaviour, expressed as protest bids, are also minimised.

Table 5 also lists the average prices (AWTP) expressed by respondents for the different landscape stimuli shown in the photographs. The last column of Table 5 shows the results of Duncan's multiple-range test to determine which WTP means were significantly different from others. The landscapes with the same letters imply homogeneous groups ($p \leq 0.05$) of WTP means. Different letters imply significance of the difference between WTP means of the corresponding landscapes.

Table 5. Ordinal Scoring Average values, Average Utility and Average Willingness to Pay (AWTP)

Landscapes (Photos)	Average Ranking (AR)	Average Utility (AU)	Average WTP (**) (AWTP) (€)	Average WTP (AWTP) Difference Significance ($p \leq 0.05$)(*)
13	13.03	5.99	21.48	a
8	12.01	6.72	23.29	b
4	11.70	4.76	23.56	b
10	10.59	6.49	24.36	b c
15	9.66	7.59	25.40	c d
14	9.05	8.02	26.18	d e
11	8.86	8.45	26.71	d e f
16	8.10	9.60	26.76	d e f
5	8.46	7.52	26.78	d e f
9	7.65	7.79	27.70	e f g
2	7.38	11.96	28.49	f g h
1	6.63	8.93	28.97	g h
12	6.47	9.53	29.03	g h
7	6.21	9.75	30.24	h i
6	5.14	10.66	31.52	i
3	5.07	12.23	31.60	i

(*) Same letter implies no significant difference between groups of landscapes (homogeneous groups) (**) Taking into account that the WTP estimated here is the price for the room including the view and the willingness to pay score was from 21.48 € day^{-1} to 31.60 € day^{-1}, the only difference (between 0 € and 10.12 €) was due to the landscape characteristics.

Table 5 shows an overlap in the central preference valuation section, and two clearly differentiated groups: that of the most highly valued landscapes, and that of the least valued ones.

In terms of the preference model for the agricultural component of the landscape, the results of the assessment may be seen in tables 6 where only the final models with the variables, which have proved significant, have been included.

It can be seen that apart from the work situation and the co-variables, the effect of which in the preferences for the agricultural components of the landscape is direct and very significant, other variables such as age, level of studies, and income per capita do have a clearly significant influence in the panel lists landscape aesthetic valuation. The province and the sex of the individuals do not have a relationship with the agricultural component preference of landscapes (P ≥0.005).

Table 6: Results of the multiple regression model: Ranking

Variables	***Coefficients***	***t***	***Significance***
Constant	8.69450	4.33988	***
PCI	0.00054	2.19457	*
AGE2	-2.26627	-3.42807	***
AGE3	-2.94596	-4.10702	***
AGE4	-2.83128	-3.20253	**
ED3	1.19375	2.13729	*
ED4	2.27365	4.09532	***
ED5	1.75886	2.83057	**
0	1.66791	4.03660	***
RIVL	0.09303	7.41845	***
U_0	-1.30629	-6.24364	***

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	874.741	10	87.4741	21.34	0.0000
Residual	590.25	144	4.09896		
Total (Corr.)	1464.99	154			

R-squared = 59.7096 percent
R-squared (adjusted for d.f.) = 56.9117 percent
Standard Error of Est. = 2.02459
Mean absolute error = 1.6245
Durbin-Watson statistic = 1.97953

Regarding the multinomial explanatory variables, age and level of studies, it can be stated that the youngest group of people (18 - 25 years) appreciate the agricultural component more than those older than 25, and university graduates appreciate the agricultural component more than those with secondary studies, who in turn appreciate it more than those with a lower level of studies.

Conclusions

The Conjoint Analysis and the Contingent Valuation results match in the ordinal preference structure and willingness to pay (WTP) of interviewees, both in relation to the attributes that make up the landscape profile and their respective levels. The attributes of vegetation layer, level of building, and level of slope were, in this order, the ones presenting the highest to lowest relative importance in the expression of preferences and WTP by respondents.

Within the attribute vegetation layer, the agricultural component (first, irrigated, followed by dryland farming) was the most highly esteemed vegetation layer aesthetically, and the one that most strongly stimulated respondents' WTP for views that include it. Natural lands and abandoned fields were the least appreciated and the ones which inspired the lowest WTP of citizens. Thus, in general, the higher the appreciation of the landscape, the higher the individual's WTP to enjoy its aesthetic qualities.

The average WTP for accommodations with views of the most highly appreciated landscape (landscapes with an irrigation agricultural component on an intermediate slope with a village or traditional houses visible in the landscape) was 31.60 € day^{-1}, and the least valued (landscapes of abandoned agricultural lands without any village in view and with a steep slope) was 21.48 € day^{-1}.

Paradoxically, current rural development policies in the area do not encourage the growth (nor even the maintenance) of the most highly valued vegetation-layer component in the area. The opposite is occurring: the abandonment of agriculture is sharply increasing the surface area of the least valued vegetation layer.

The age, the level of the studies, income, and also the occupation of the respondents have a significant and direct influence upon their agricultural preference component of landscape.

Notwithstanding these findings and the suitability of stated preferences methods to estimate the social value of non-market agricultural output and environmental amenities “the landscape externality in this study”, we should not ignore some limitations and weaknesses related to the nature of the methods used and the robustness of parameters and values estimated. Limitations are linked to methodological biases which are both instrumental and non-instrumental. These methods cannot alone provide the definitive answer to any significant political decision (Carson et al. 2002).

Regarding the value concepts estimated in this study, the values of rural landscape found (utilities and WTP) should be interpreted as a lower boundary of the use value of the agricultural landscape in the region, as it measures only part of use value, the aesthetic value, based on data from citizens located in neighbouring provinces. Agricultural landscape amenities certainly also have other use value (recreational, cultural, etc.) and non-use value (e.g. conservation, existence, option, legacy, etc.) which have not been considered in our research.

Based on our findings concerning the aesthetic potential of the agricultural systems of the area, some recommendations can be drawn for designing agri-environmental policies and sustainable rural development strategies:

- Local agricultural activities should be maintained and, whenever possible, those involving irrigation. Future migration from agricultural lands must be prevented and previously abandoned fields recovered.
- Rural landscape observation and appreciation should be included in existing recreational activity programmes for rural tourism in the zone (hiking, etc.).

- Agriculture should be maintained close to population centres, since there seems to be a positive impact, in landscape preferences, on the architecture-agriculture combination.
- Further research will be needed to analyse preferences using other aesthetic criteria (biological, ecological, etc.), in order to gain other perspectives for sustainable development in the area.

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Creation of Dehesas: A History

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Human impact and the landscapes of the Mediterranean Iberia

In the Mediterranean basin, there is evidence of natural resource management by humans since the beginning of the post-glacial era, particularly in the last 10.000 years (Holocene) (Le Houérou 1981). Most studies show a history of degradation as a result of an expanding agriculture Thirgood (1981). But other authors present a different view, in which human intervention has maintained high biodiversity, emphasizing the creation of a heterogenous mosaic of land uses that supports different plant and animal species (Blondel and Aronson 1998). In addition, paleocological studies increasingly show the importance of non-linear dynamics in which there appear to be thresholds and unpredictable responses of the vegetation to perturbation (Arroyo et al. 2004). This less deterministic approach has been gaining popularity as more paleoecological and botanical studies are conducted in the Iberian Levant. Unfortunately, there is not yet similar data for the western Iberian Peninsula, where the silvopastoral system known as, "dehesa" is found.

The definition of "dehesa" is far from clear and in many instances it depends on the context in which it is used. From a legal and semantic perspective, a dehesa is a wide pasture area with or without trees, where the arrangement impones some restrictions to grazing by outside livestock (DOE 1986, García Martín 1992). A more widely accepted definition stresses the co-existence of pastoral, forestry, and agricultural uses in flat lands in a Mediterranean climate and a dry period in summer (Montero et al. 1998). Lastly, a definition based on the landforms and the biological components of the landscape emphasizes the savanna with scattered trees and crops, which was created by forest and shrub clearing (Pulido et al. 2002). In any case, the dehesa landscapes have the following characteristics: (1) open pastures as a result of clearing the woody vegetation, (2) grazing is a requirement so as to maintain dehesas as open landscapes (3) the potencial vegetation in the dehesa areas is forests. Therefore, treeless dehesas are only found in those cases of extreme degradation. . Consequently, when studying the origin of dehesas we should ask ourselves about the creation by humans of open landscapes with trees, crops, and pastures for livestock production and human sustenance.

Paleoecology of pasture with trees of the Southwestern Iberian Peninsula

Paleocological studies of the pre-Holocene period in the Southwestern Iberian Peninsula, characterized at that time by a dry and cold climate and the absence of humans, indicates the existence of natural pastures with trees. The dehesas, therefore, were artificially created in a later period, when climate conditions were not so extreme and when human density and skills and a social organization allowed the permanent opening of the forest. It can be concluded, therefore, that there is not just one origin of the dehesas as the mechanisms, objectives, and level of planning for the transformation of closed forest, as well as the landscapes created, varied throughout history. In our opinion, the key variable to understanding landscape change is population density, as most of the area currently under dehesa has been transformed in the modern age as a result of increasing demand for grain by a growing population (Linares and Zapata 2002).

Records of prehistorical times show the use flash and burn agriculture since the Neolitic period (7000 years ago). Specifically, the oldest archaeological evidence found in areas of dehesas (Los Barruecos amd Cerro de La Horca en Cáceres) present a 40% of pollen of holm oak, Juniperus sp, and Olea sp., indicating the presence of dense forests. This seems to indicate that slash and burn agriculture was unplanned in space and time so that we cannot talk about dehesas per se (López Sáez et al. 2006). Later in the mid-neolithic period, 4,000 years B.C. pollen analysis shows an increase in grazing and slash and burn agriculture in landscapes with low tree density and low presence of shrubs. The existence of this type of landscapes has led some researchers to establish the "origin of the dehesas" in this period (López-Sáez et al. 2007). However, even though pollen analyses indicate the existence of man-made savannas, the landscape could also have been a changing mosaic of tree stands and pasture which cannot be called "dehesa".

Data from archaeological sites in the coastal fringe of Huelva also indicate the origin of "dehesa systems" in the third millennium B.C. as humans introduced pigs and sheep (Lewthwaite 1982; Stevensson and Harrison 1992 and Harrison 1995). As in other sites, the consumption of acorns by humans as well as farming and cattle grazing is evident, but the information obtained is insufficient to indicate the extent to which or the length of time the dehesa system was maintained. Therefore we still do not know whether the dehesa was planned or just the result of unplanned farming activities. Finally, during the Roman times, the establishment of large farms in marginal areas with low population density is one the most important signs of the systematic use of agroforestry. This seems to have lasted until the Visigothic period, although evidence is still scarce (Gutiérrez 1992).

Repopulation programs and dehesas in the Middle Ages

During the early Middle Ages, the Southwestern Iberian Peninsula, particularly Extremadura, was unsettled land and the establishment of a human population was seen as necessary (Clemente Ramos 2001). The political and economic circumstances at that time favoured the raising of itinerant livestock to supply the European markets with wool. The interest of the Castilian king in promoting this enterprise network led him to establish the “Mesta” in the XIII century as an institution representing the interests of the shepherds and ranchers. During the next five centuries the growing stock of itinerant livestock became the main modelling agent of the Iberian dehesa landscape (Klein 1920). Basically, it is known that these medieval dehesas were similar to the present dehesas, namely, enclosed land (private or public land) used for agrosilviculture in areas with poor soils and Mediterranean climate. These and similar systems could have existed before the Middle Ages but if so, they would not have been so stable throughout the years, nor so extensive.

The demand for cereal grain promotes the present dehesas

During the XVIII century, the agrarian reform and the privatization of large areas of public land dramatically changed the land tenure systems in Spain and led to the establishment of an elite of landlords whose only objective was to farm on those lands purchased from the Spanish crown. They had an abundance of cheap, labour available that they used to produce cereal crops needed to satisfy the increasing demand from a growing population (Linares and Zapata 2002). In the late XIX century and in the first decades of the XX century, farm and grazing land expanded substantially as farming techniques improved. Therefore, in spite of the evidence from early times of the existence of man-made open grazing land, there is only solid evidence of the systematic creation and use of dehesas since the XII century and its rapid expansion since the XVIII century.

Stages in the creation of dehesas

The process of creating dehesas is slow (even in modern times) and requires constant activity by a large number of rural labourers working for the landowner, something that did not happen until the beginning of the XX century (Plieninger 2006). During land clearing, the labourers acquired the rights to plant crops and the landowner would benefit from putting his land to productive use. Land clearing practices consisted of: (1) shrub clearing, (2) protection of young holm oak trees with productive potential and (3) pruning of productive holm oak trees. For the maintenance of open land (without shrubs) crops were planted on those areas where tree branches from the pruning operation and the woody residues from shrub clearing were burnt. After harvest, livestock was allowed to graze. Since the mid XXth century, the area with dense Mediterranean forests has been shrinking whereas the open forest has been expanding. However, this process occurs in both directions. When farms are abandoned, the land reverts to closed forest due to shrub encroachment and the vigorous re-sprouting of trees. In fact, it is likely that some of the most recent dehesas may have been created from re-sprouts of trees that were cut long ago.

The receding traditional dehesa and new trends

The stages described above mark the history of the creation of those so-called traditional dehesas, that is, those with abundant labour, without use of farm machinery, where cereal crops are planted, and trees regularly pruned. Nonetheless, profound socio-economic changes of the past four decades has changed the way dehesas have been managed. On the one hand, many dehesas have been abandoned or converted to hunting reserves, particularly in those areas legally protected by environmental laws and regulations with difficult terrain. On the other hand, European farm subsidies have resulted in the intensification of livestock production, with an important reduction of farm labour, and a large increase in the stocking rate.

The current intensification also implies the reduction of the cultivated area or the use of cultivated land to produce forages, the lack of interest in forestry practices, excessive tree pruning, and the change from a diverse mosaic of land uses to a more uniform landscape. There is no doubt that the trees are the victims of these processes, as in the past decades tree management practices have no longer been profitable. Consequently, the appearance of pests and diseases, which seems to have been more intense in recent years, threatens the permanence of the tree component of the dehesas (Pulido et al. 2002).

The lack of tree regeneration is a consequence of ecological constraints such as low seed production or the production of non-viable seed, and the lack of areas where seedlings can be established and grow. These problems may have been enhanced in recent times, but also they should be seen as something inherent to the traditional management practices of dehesas which do not promote tree regeneration except on few occasions (Montero et al. 1998). The existence of large areas of former dehesas without trees shows the consequences of this lack of tree regeneration. Therefore, any action to maintain the ecological integrity and productivity of the dehesas should consider the regeneration mechanisms of trees, including artificial reforestation and the protection of natural regeneration.

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The Dehesa: The most extensive agroforestry system in Europe

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The Concept of dehesa

Agroforestry systems are widely used in the tropics (García-Barrios and Ong 2004) whereas in Europe the majority of the traditional agroforestry systems have drastically disappeared during the last century (Eichhorn et al. 2006). However, in the Mediterranean basin, a traditional agroforestry system still survives covering more that 3 million hectares of the Southeast of the Iberian Peninsula, the dehesa.

The dehesa is an agrosilvopastoral system of savanna aspect, multiple-use in an extensive regime and where wild animals, trees and livestock have important roles (Montero et al. 1998). The dispersed trees are combined with crops, pasture and shrubs as a result of the different management practices: agriculture, livestock, forestry and game; similar systems but without extensive pasture maybe found in northern Greece, Crete and Corsica (Eichhorn et al. 2006).

Table 1. Main characteristics of the dehesas (adapted from Miguel et al. 2000)

- Productivity: Low
  500-3000 foraging unit year^{-1}. 1-4 sheep ha^{-1}
  Complement forest production or associated crops
- Efficiency (production / resources used): High
- Variability: High, both spatial and temporal
- Stability (productivity variation along the time): High
  Strong dependency on the variability of the annual Mediterranean climate
- Elasticity: High
  The system is able to recover after moderate human interventions.
- Diversity: High, biological as well as economic.
- Direct Products: Cereals, Fodder/Forage, Meat (bovine, sheep, goat), Cheese, Hunting (partridge, rabbit, turtledove, deer, roe deer, wild boar), cork, fuelwood, charcoal, Mushrooms, Honey.
- Environmental Goods: High value landscape, Erosion control, Genetic Resources (habitat of protected species), Carbon sink.

An average size of a dehesa is around 500 ha, reaching in some cases up to 5000 ha. It needs a relatively large area so that it doesn’t run out of the pasture and the land use is rotational, a key management aspect in order to be able to be competitive. The population density in dehesa areas is low, with around 4 people per square kilometer. However, the dehesa is considered as a highly humanized agroecosystem, with important livelihood functions and producing high quality animal products without generating residues (Miguel et al. 2000). It is a model of land-use that comes close to what is called “sustainable development”, although technical and socio-economic changes in these last years may compromise its sustainability. Some of these changes result in soil degradation (compaction and erosion; Schnabel et al. 2006), the absence of tree regeneration, which is almost generalized (Pulido and Díaz 2005) and the sudden death of many of adult trees (“die back” or “seca”; Tuset and Sanchez 2004). All these shall be discussed in the following chapters.

Biophysical caractheristics

The dehesa is mainly distributed in the southeast quadrant of the Iberian Peninsula where the climate is typically Mediterranean, with high climatic intra- and inter-annual variability. Rainfall is concentrated during the cooler months of the year and there is a long period of summer drought, with high temperatures and without significant rainfall. The average rainfall in the areas where dehesas are found varies from 400 to 800 mm and its average annual temperature ranges from 14 to 17 ºC. Typical climate of the dehesa is characterized in Figure 1, showing a four-month water deficit.

The dehesas are basically in areas with an undulating topography, with moderate slopes and commonly, the plain areas are cultivated and the more mountainous or steep areas are forested (or with shrubs). The majority of the dehesas are between 350 and 550 m asl, although in the provinces in the North they are also frequently found at 800 and 900 m altitude and in the South at less than 100 m of altitude. Dehesas are usually found on acid soils (originating from slate, granites, quartz rocks), poor in nutrients, and with shallow soils that easily erode. This low fertility has limited the utilization for crops thereby devoting most of the area to natural pasture.

Figure 1. The dehesas are in areas of undulating relief, since the plain areas are cultivated (above) and the areas with slopes are forested (below).

Soil variability is high in the dehesas as a result of erosion, transportation, and sedimentation processes from hillsides and seasonal streams. Within a small area one can find red deep soils with a thick clay soil layer (e.g. Luvisoles) shallow, stony soils (e.g. Leptosoles), and Cambisoles with different depths and development. Management practices of nutritional resources take into consideration this high variability of soils.

Components of the system

Domestic livestock is the main product of the dehesa. For this reason the plant components of the system are conditioned by the nutritional needs of the livestock. In a simple way the dehesa is structured in two plant layers, the herbaceous and the trees. The first generally consist of natural pasture, although crops and improved pasture also appear (see López-Díaz, this volume). The trees are dispersed in low density, typically between 20 and 40 trees per hectare (10-50% canopy ground cover). Trees are maintained not only to protect the soil and the herbaceous layer, but also to provide diverse products to the system (fruits, fuel wood, cork, fodder).

The most frequent tree species are the Holm oak (*Quercus rotundifolia*) and the cork oak (*Quercus suber*), both xerofitic evergreens. The holm oaks are found in the interior regions and the cork oaks are present in the more temperate and humid regions, with more Atlantic influence. The first are very good producers of fruits (sweet acorn) while the second are very much appreciated for their cork production. Other species present in the more humid dehesas are other oaks (*Quercus faginea* and *Q. pyrenaica*) and ash (*Fraxinus agustifolia*). These tree species are valued for fodder since branches can be pruned for food in periods of pasture scarcity. Also present, although marginally, are various species such as chestnut (*Catanea sativa*), junipers (*Juniperus* sp.), and pines (*Pinus* sp.). Conifers are generally only used for purposed of protection (Miguel *et al*. 2000).

A shrub layer is also common in dehesas and usually has high diversity. It is common to find half a dozen of shrub species together, such as *Cistus* sp., *Retama* sp., *Erica* sp., *Arbutus unedo*, *Viburnum tinus* and others). These shrub species may have high nutritional interest (Hajer et al. 2004) both for the domestic livestock as well as for the game species. Recurrent shrub encroachment in the dehesas may be needed to ensure the natural regeneration of the trees (Pulido and Díaz 2005).

Formation and management

The dehesa is a man-made system created by clearing the dense forest and eliminating a large proportion of the woody vegetation with the objective of favouring the development of an herbaceous layer. The result is a system more productive than the forest, but also less stable. It needs management and utilization for its permanence.

The process of formation of dehesas is not well-defined given that the point of departure, the available elements, the objectives pursued, and the historical origin vary widely. The transformation of forestlands to dehesas is a slow, gradual process which may be cyclical or not. It always starts with the clearing of trees and the removal of shrub layer. Generally annual crops are planted on the first year followed by grazing in the subsequent years to enhance and improve the herbaceous layer. However, the regeneration of shrubs and the loss of productivity of the created herbaceous layer require a regular removal of shrubs and periodic sowing. When land clearing is accompanied with adequate management of grazing, the pasture will gradually be richer and the removal of shrubs will not be necessary. Soil cultivation will also become increasingly unnecessary and done only in cycles of 10 years or more in order to reduce soil compaction generated by the continuous trampling of the livestock. However, the optimization of pasture and grazing usually brings the absence of tree regeneration and the "fossilization" of the system. The abandonment (or the reduction) of grazing should allow tree regeneration. Below are some details of each one of the processes identified in the formation and maintenance of the dehesas.

Clearing

The trees, that may initially cover up to 100% of the soil, are cleared leaving a tree density not larger than 40% of crown cover (often it is reduced to less than 20%). The clearing of the tree layer is done with the objective of favouring the growth of the herbaceous layer, but at the same time represents significant benefits for the tree layer itself in terms of functioning/performance (Moreno and Cubera 2008) and productivity (Pulido et al. 2001). These benefits result from reduced interspecific (tree-tree) competition. Moreno and Cubera (2008) showed how reducing tree density is more important when available water is limited. In the same way, Joffre et al. (1999) showed at the regional scale that the average tree density in dehesas decreases with the average annual precipitation. The maintenance of high tree densities (e.g. with the objective of maximizing cork production in the case of cork oaks) may be a risk if it doesn't comply to a proper assessment of tree density in relation to the availability of water that allows the maintenance of the functioning of the trees and the multi-functionality of the system.

Although there is very little information for the determination of the optimum density of different ages of trees in the dehesa, Montero et al. (2003) propose a norm for clearing in the case of cork oak (Figure 1) that could serve us as a guide. These recommended densities may vary from one environment to another and according to the objective. Undoubtedly this is one of the aspects that would require further research in the future, with the objective of establishing the much needed management plans of trees in the dehesas.

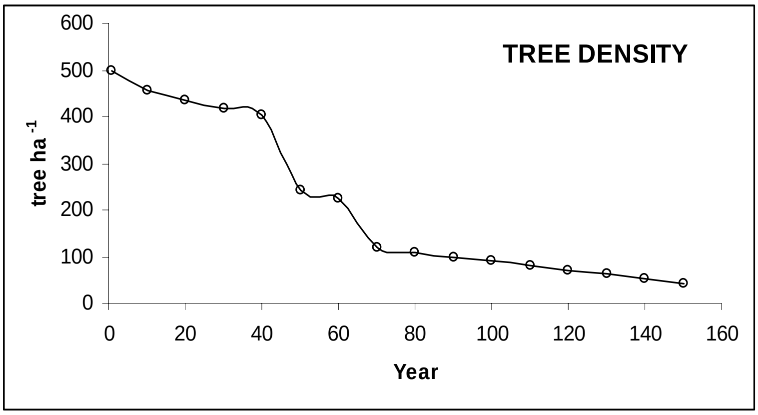

Figure 1. Optimum density of trees in dehesas of cork oak at different ages (Adapted from Montero et al.2003))

Aside from the selection of the trees through the initial clearing of the forestland, the planting of trees in the dehesas has also been a traditional practice (Llorente Pino 2003; Martín-Vicente and Fernández-Alés 2006), although it is difficult to determine exactly the relative importance of tree planting in the maintenance or creation of the dehesas. The predominance of *Quercus ilex* subsp. *ballota*, which produces a sweeter acorn than other oaks, is usually attributed to the active role of humans in the planted tree stands in the dehesa. At least through the 20th century, a number of regular plantations of *Quercus suber* were established in dehesas. In the last decades, as a consequence of the application of the Reforestation Plan of Agricultural land, thousands of hectares of dehesas have been reforested with different *Quercus species*. These reforestations should allow the creation of new dehesas through the successive clearing of the trees.

Pruning

Tree pruning should be done right after clearing. The term “apostado” refers to pruning to achieve a clear bole up to a third of the tree height. Pruning operations may have to be performed several times until reaching the browsing height of bare bole.

Form pruning is implemented after the recommended bare bole has been achieved. Form pruning is done to develop a wide crown, with almost-horizontal branches, and to limit the growth in height. In this way, trees develop crowns which are wide but small in height. This crown shape is also favoured by the lack of apical dominance of most *Quercus* species and the open structure of the dehesa.

In addition to “apostado” and form pruning, trees are periodically pruned with the objective of obtaining fodder for the livestock in winter, for firewood and charcoal, to increase the available light for the herbaceous layer, and probably to increase acorn production (San Miguel 2005). (Although the latter has not yet been demonstrated as recent studies have found that the larger size of the acorn as a result of pruning does not compensate for the loss in branche production.) (Cañellas et al. 2007).

In the recent past, the viability of the trees has been compromised as a result of changes in the way pruning has been performed. The more intense pruning (although in rotations of 20 years) and the cutting of large branches with the main objective of producing fuelwood, reduce tree vigour. Consequently, in some areas, the cutting of branches larger than 20 cm in diameter has been prohibited. Furthermore, no more than 1/3 of the tree´s foliage should be removed in any pruning in order to avoid excessive damage to the tree. Excessive pruning results in the overproduction of shoots, large wounds (which may result in infections), and unbalanced crowns.

Shrubs Clearing

At the time of tree clearing, all the shrub vegetation is eliminated as well. However, shrubs will regenerate later, either vegetatively (e.g. *Erica*), by germination from the soil seed bank (e.g. *Cistus*), or through both mechanisms (e.g. *Cytisus* and *Genista*). In Mediterranean environments, the importance of the soil seed bank for plant regeneration is well-known

(Vallejo et al. 1999).

The traditional practice of manual pulling of shrub vegetation has been replaced by mechanical shrub clearing. In some cases it is done with a disk plough, resulting in soil erosion. The cleared shrubs are piled up and generally burned, with the consequent lost of organic matter and nutrients. Mechanical shrub clearing is now commonly used, although its efficiency is sometimes limited and should always be accompanied by pasture improvement practices (fertilization, direct sowing, etc.) (San Miguel 2005).

The regularity of shrub clearing is variable as it depends on a multitude of factors. Some of these are the shrub species, the soil fertility, and the stocking rate and its management. Normally, the need for shrub removal decreases with time as shrubs become increasingly controlled by grazing.

Crops and the development of pasture

The reason for crop planting in the dehesas has changed through time and the cultivation practices also vary between zones. Today, commercial grain production is not as important as it once was, since yields in the poor soils of the dehesas are normally low. Nowadays, the dehesa is mostly cultivated to obtain supplemental food for livestock, especially for the winter and summer periods of low pasture production, to regenerate the soil (reduce soil compaction) for better pasture development, and as a method for controlling shrub encroachment.

Cereal cultivation, and less frequently legumes or sunflower, is done every year in a different portion of the land. Frequently, the area that will be cultivated in the dehesa is divided into four parts (called “cuartos de labor”), and each quarter of the area is cultivated only once every four years. In some cases the number of portions into which the cropping area is divided varies from three to ten portions, depending on the supplementary food needed, and on the vigour of shrub regeneration. In this way, only a small portion of the land is cultivated in a given year, between 10.3% (MAPYA 2004) and 16% (Escribano and Pulido 1998).

The “*cuartos de labor*” are managed following the sequence of activities described below (Miguel et al. 2000):

1). Fallow: intended to prepare the land for the next year’s crop. It consists on ploughing during winter or at the end of winter, when the soils are cold, and sometimes a second ploughing in April or May. This practice involves leaving the soil bare during one cycle which allows: (i) soil water conservation so that it will be available for the crops; (ii) accumulation of mineral N by enhancing mineralization of the organic matter and plant residues; (iii) interruption of the reproductive cycle of many annual weeds that may compete with the future crops.

2). Sowing: Sowing is done in October, generally with grains (oats, wheat, barley) and occasionally sunflower, leguminous or veza-oats. Harvesting is done between May and June when the grain has formed and dried. Only 30% of the crops are harvested for selling, the rest are used for direct pasture or harvested green to serve as food supplement (Escribano and Pulido 1998).

3). Stalks and crop residues: Once harvested, the livestock graze on the stalks and crop residues during Summer and all the following year. It is estimated that with a production of 1.000 kg ha^{-1} of grain it is possible to obtain between 1, 5 and 2 t of stalk. Furthermore, the stalks may cover 30% of the land and reduce the runoff up to 70%, which facilitates the water infiltration and lessens erosion.

4) “*Posío*”: This is the pasture that grows after grazing the stalk. The pasture is usually poor but improves in successive years. This cycle is repeated when the invasion of pasture by the woody vegetation starts to reduce the grass/pasture production.

5) Permanent Pasture/Grazing: If properly done, grazing improves

pasture by enhancing species richness (annual and biannual species) and development. In most cases, livestock prevents shrub development (though unfortunately tree regeneration as well) and makes ploughing and cropping unnecessary. This is the situation with most dehesas at present.

5) "Majadal": In some cases, soil fertility improvement and adequate livestock management results in a pasture with a balanced presence of annuals and perennials, and of gramineous and leguminous, free of shrubs and with a high yield of nutritional quality. "Redileo" or the enclosing of livestock every evening with small mobile fences is the traditional practice to develop a "majadal". For several nights, the livestock fertilizes the "majadal" with their manure.

In most dehesas the pasture is composed of native herbaceous species. In other cases, fertilization with calcium superphosphate and the introduction of subterranean clover-type species (*Trifoliun subterraneum*), ray grass, or another mix of leguminous grass (commonly called "tremosilla") is done with the objective of improving productivity and the nutritional value of the pasture.

Livestock species

In the dehesas, different types of livestock (native or hybrids) or animal species are used to take advantage of the wide variety of nutritional resources. The raising of porcine, bovine, sheep, and goats are combined, in addition to other animals important for household consumption: rabbits, doves, turkeys, etc. Nowadays the number of species present in the dehesas has been reduced. The dehesas are mostly devoted to cattle or sheep production, with the possibility of maintaining some pigs during the period of acorn production in Autumn and Winter. Few dehesas are specialized in porcine livestock, although their number is increasing given the increasing demand for and price of Iberian pig products. Goats have been relegated to the marginal dehesas and to the mountainous areas.

Many other dehesas are now involved in game hunting, which before was only a complementary activity. In many areas the “openness” of the dehesa is disappearing as they are being transformed into closed shrub areas where deer, wild boar, red deer, and other game species are bred.

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Nutritional resources in the dehesa: Improved pastures

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Introduction

In general a dehesa is a forestland with trees and in most cases its main product is livestock. As such, the dehesa provides the nourishment needed by the livestock or at least most of it. The dietary resources that are provided by the dehesa are herbaceous, fodder, and fruits. These resources are influenced by a series of environmental characteristics of the dehesas´ location. On one hand this type of system´s vegetation develops in areas with a Mediterranean climate, characterized by the presence of dry summers and more or less cool winters, whose potential limiting factor is drought. These are areas with annual precipitation reaching between 450 and 800 mm. On the other hand, there are dehesas that developed in poor soils, poor in P and Ca, where for the most part, the practice of conventional agriculture will not be viable. Finally, there are dehesas situated in plain or rolling areas that are not too steep that allows the mechanization of the operations (Ceresuela 1998; Hernández 1998; Montero et al. 2000; Olea and San Miguel 2006).

Herbaceous pasture

The dehesa has pastures with a high diversity of plant species, with a large number of leguminous species (Hernández 1998; Olea and Viguera 1998), that play an important role because of their ability to fix atmospheric nitrogen, which improves the quality of the soil and therefore the productivity and the quality of the pastures. Aside from this, herbaceous pasture is made up of high quality pasture due to its high protein content and diverse essential nutrients important to the animals like the Ca and Mg (Whitehead 1995). It is important to remember the strong influence of trees in the dehesas. These trees cause important environmental modifications under their canopy that gives way to the floristic variations and functioning of the pasture. Under the canopy, the vegetative period is longer, the abundance of the bi-annual species is generally higher and of better quality and with a distinct floristic composition that includes the presence of good quality species that otherwise could not tolerate the conditions outside (the canopy) except in the most favorable years. The pasture situated under the canopy increases the diversity of the general grazing area (Escribano and Pulido 1998; Olea and San Miguel 2006).

Herbaceous pastures have high variations both at the temporal and spatial levels. The maximum production of the herbaceous pasture is obtained in spring (around 70%) with no summer production and with winter production occurring only sometimes. Production in autumn is low. Along with winter production it is at most, 30% of the total annual production. It varies according to the area and the type of pasture (Escribano and Pulido 1998; Olea and Viguera 1998).

The herbaceous pastures in the dehesas may be classified based on there origin; either pasture of natural origin or cultivated forages (San Miguel 1994; Escribano and Pulido 1998; Montero et al. 2000; Olea and San Miguel 2006).

Pasture of natural origin

The natural pastures are the main source of nourishment of the livestock while in periods of scarcity it is provided by browsing; consumption of fruits (especially acorn), cultivated forage, and food supplements. The most important natural pastures of the dehesa may be divided functionally into four groups. The first will be the more degraded part which usually covers most part of the dehesa. This is composed almost exclusively of annual and short species that have been stabilized by grazing and/or by cultivation. Drying is produced prematurely at the end of spring. Autumn production depends greatly on the degree and the temporal distribution of rain, while production is usually very low or null in winter due to cold weather. These are pastures with annual production of between 1000 and 2700 kg DM ha^{-1} $year^{-1}$ depending on the type of management practiced which is usually focused on maintaining an adequate content of legumes in the pasture. Legumes are important due to their protein content and also because after drying, their nutritional quality is still highly sufficient to maintain the livestock. This would also reduce the critical period in terms of food and would represent a savings in supplementary food. The management techniques used are based on the adequate stocking rate followed and the application of phosphorous. The recommended doses of phosphorous are between 25 and 35 kg P_2O_5 ha^{-1} during the first year and between 18 and 25 kg P_2O_5 ha^{-1} for successive years. Phosphorous is applied on the pasture in autumn after the first rains with the objective of reaching a phosphorous soil content available (Olsen-P) of between 8 and 12 mg kg^{-1}. This facilitates the growth of legumes always and when sufficient percentage is reached (Olea et al. 1991). If not, it will be necessary to sow. The fertilizer calcium superphosphate is usually applied at 18 %(Escribano and Pulido 1998; Olea and Viguera 1998).

The second type of natural pasture is known as *majadal*. This is a pasture composed of annual and very dense bi-annual species that are small in size and usually of good nutritional quality, created by the intense and continuous action of the livestock, where the presence of poaceae *Poa bulbosa* and the legume *Trifolium subterraneum* is noticeable. Its creation is due partly to intense and continued grazing and the soil improvement produced by the livestock manure fertilizing the area. The *majadales* are situated in frequently grazed areas: on hills where the animals usually climb to rest, near the water points (for drinking), refuge (the place the shepherds take the livestock for protection and shelter) and at the spots where food supplements are provided. For this, its creation may be induced or it area may be augmented through the practice of *redileo*. This consists of concentrating the presence of the animals in one area for 2-3 consecutive nights so that the animals may fertilize it with their manure/dung at the rate of 1 sheep per 1,5-2 ha, then complemented or not with phosphorous fertilizer and the contribution of food supplements given at concrete plots.

The production of DM of the *majadal* (around 3000 kg ha^{-1} $year^{-1}$) is generally higher than the first type because it has a higher capacity of re-sprouting. Its palatability is superior as is its nutritional quality, because the subterranean clover contributes to the increase in the protein content through the pasture. However, the *majadales* are not only important due to their productive qualities but above all, to their strategic value, which is determined by two circumstances: in spring the subterranean clover dries slowly and provides an important quantity of digestible nitrogen matter at the moment when the animals' need for proteins is higher because of lactation. In autumn, *Poa bulbosa* is the species that readily resprouts after the first rains and consequently determines the start of the autumn grazing period and the end of the artificial supplementation.

In the depressions of the dehesas located in poor substrate bases and where the phenomenon of an abnormal seasonal presence of water or humidity in the soil or subsoil (not very prolonged and ceases in summer) occur, a third type of natural pasture develops known as *vallicares*. These are mostly made up of bi-annuals that flower at the end of the spring and dry in the middle of summer with abundant tall gramineous and few legumes. Their pastoral value is average because although productivity is high, their palatability and nutritional quality are not, due to the scarcity of legumes. However they are the only grazing areas that remain green during the long period of summer. That is why they may make an important contribution to the reduction of summer food scarcity and thus reduce the cost to the owner and thus increasing the likelihood of the dehesa´s self-sufficiency.

If the water log is prolonged and is maintained during the spring, as often happens in some depressions of the dehesas, the pastures are characterized by being composed almost exclusively of Therophyta (annual species that completes the cycle during the growth season) short lived, although of late phenology (they can only develop when the water level is low). These communities usually are called *bonales.* Their pastoral value is low due to their low nutritive value and production, poor extension, and being short-lived. The annual production of *vallicares* and *bonales* fodder are usually between 1500 and 2500 kg DM ha^{-1}.

Forages

The presence of periods with low or scarce production in the dehesa (summer and winter) frequently compels owners to plant artificial pastures or cultivate herbaceous forages that may be used during these periods. These are planted in the best soils of the farms with a topography that would allow mechanization and irrigation without difficulty. The widely used cultivated forage in the dehesas are various types of cereals like barley, oats, and wheat, for the consumption of their dried grains in summer, or the rye that is sown to be consumed green at the end of winter and spring. The productions obtained from these are usually between 1000 and 3000 kg ha^{-1} of grains and between 2000 and 5000 kg ha^{-1} of straw.

A mix of species of the genus *Vicia* (*Vicia sativa* or *Vicia villosa*) and *Avena sativa* are also sown, from which between 3000 and 6000 kg ha^{-1} of hay per year is obtained, and cultivated forages of annual gramineous, like *Lolium multiflorum* for its hay.

Lastly, the regular planting of artificial pasture is frequently composed of diverse legumes that regenerate naturally, like in the case of the subterranean clover (*Trifolium subterraneum*), and a low content of gramineous and are grazed or harvested, and with which reaches a production of around 3000 kg ha^{-1} and $year^{-1}$. These pastures are only sown in cases when the percentage of the legumes of the original pasture is very low. If not, the fertilization with phosphorous would be sufficient (San Miguel 1994; Olea and Viguera 1998; Olea and San Miguel 2006).

The introduction of cultivated forages starts with land preparation towards the end of winter before the sowing at the end of spring, and at the beginning of autumn. Sowing is also done at the beginning of autumn. In the case of cereals, cultivated annual forages and *Vicia-Avena* application of fertilizer is usually recommended at 200-300 kg ha^{-1} de 8:24:8, while in pastures rich in legumes it is usually treated with 35-40 kg P_2O_5 ha^{-1} a few days after sowing and 25-30 P_2O_5 ha^{-1} in successive years (Escribano and Pulido 1998; Olea and San Miguel 2006).

Browsing

Browsing occurs in woody pasture usually made up of tree branches and shrubs and other products such as fruits, flowers, and tree bark. The tree fodder of the dehesa may be obtained by the livestock directly (browsing) or indirectly through the fallen branches due to pruning or cutting. The production of DM in these two cases may reach up to 300-500 kg DM ha^{-1} $year^{-1}$ and 60-90 kg DM ha^{-1} $year^{-1}$, respectively. At the periods of pruning and harvesting *(vireo),* the periods of scarcity of grass and food preferences of the livestock, typically these are consumed in the end of summer and especially in winter. The animals most suited to the consumption of tree fodder within the dehesa are goats, followed by cattle, horses, and sheep. Moreover, this food is also commonly consumed in high proportions by animals associated with big hunting (San Miguel 1994; Montero et al. 2000).

Fruits

The typical fruit of the dehesa is the acorn. Acorn consumption is important in areas with mild winters where there are abundant harvests and with less irregular production of seed, which affects the trees in the dehesa differently (possibly due to genetic reasons). On the contrary, in areas with cold winters, the acorn production is low and very irregular and its use is only a complement to pasture and fodder (Hernández 1998).

The acorn with higher quality is that of the holm oak, followed by that of *Quercus faginea*, cork oak (*Quercus suber*), and prickly oak (*Quercus pyrenaica*). As food, acorn is low in protein and rich in carbohydrates that are easily transformed into fat. This is why acorns are given to animals for fattening once they have already reached the limit of their physical development (Escribano and Pulido 1998). The animal of the dehesa that consumes acorns most widely, is the pig, specifically the Iberian breed, with an extensive system of exploitation and generally without supplements. For all the rest of the livestock species, the acorn provides only a supplement to their diet. Despite the high variability of acorn production in the dehesa, the average fruiting holm oak produces around 500 kg ha^{-1} $year^{-1}$, and in some cases may reach up to 800 kg ha^{-1} $year^{-1}$.

It is the fallen acorns that are eaten, with falling occurring naturally or by beating *(vareos),* which happens in October to January. The first fallen acorn are usually green (with a high content of tannin that may affect the livestock) or bitten by *Balaninus* sp (borer insect). The maturity of the acorn occurs earlier in *Quercus faginea* than in the holm oak and occurs earlier in the holm oak than in the cork oak (San Miguel 1994; Montero et al. 2000).

Other forage resources

The marked seasonality in the dehesa, with a period of summer drought and no production in winter, determines the existence of a period of food scarcity. Sometimes, the winter problem may be resolved partly with fruits (acorn) and tree fodder, but generally the dehesas cannot be auto- sufficient in summer at the very least and depend on adjacent systems or the importation of food for the animals. The solutions most often applied in these cases are (San Miguel 1994; Montero et al. 2000):

- Transhumance or transterminance: the animals are taken out of the dehesa to make use of the valley pastures that have a summer vegetative period or other pastures that are irrigated. If the distances covered are long, they are called “transhumance”, and if shorter, are called “transterminance” (Escribano and Pulido 1998; Hernández 1998).
- Making use of the residues of the cultivated crops: this is usually done by the direct grazing on the areas where diverse crops were harvested.
- Importation of food: the option widely chosen is the acquisition of conserved forages (hay, silage, straw) and concentrates (feeds) to cover the food requirement of the livestock in the period of scarcity. This is the easiest

option, but also the most expensive.

Livestock in the dehesa

The dehesa is characterized by big extensions of areas dedicated to the grazing of animals that are well adapted to its conditions. Livestock is the main final product of the dehesa as well as its source of stabilization and improvement.

The sheep is the animal most appropriate to good use of the dehesa´s pasture: a walker, selective, consumes low growing grass, and browses very little. The typical breeds are rustic, like the *merina* that are mainly raised for milk and meat production (cheese). The stocking rate fluctuates between 1-4 sheep ha^{-1}. It is usually necessary to supplement the sheep with concentrates during the period of maximum nutritional requirements (lactation and the last month of gestation) (San Miguel 1994; Daza 1998a; Escribano and Pulido 1998; Montero et al. 2000; Olea and San Miguel 2006).

The less dry dehesas are adequate for cattle raised for meat production, with stock of 1 LU (livestock unit = female dry of 500 kg of live weight) per 3-4 ha. In recent years, cattle production has increased notably due to the herds not requiring shepherding, which requires less time and causes less inconveniences in management. The breeds used are local (like *Retinta*, *Morucha*, *Avileña negra ibérica*) (San Miguel 1994; Escribano and Pulido 1998; Montero et al. 2000; Olea and San Miguel 2006).

The pigs, that have good market potential in the future, make good use of acorns in those dehesas with moderate winters, although pasture and bulbs are also used if the snouts are not ringed. The typical breed is the Iberian pig and is commonly found in the dehesas from October to November at around 8 to 12 months of age and at a weight of 60-80 kg. The pigs are removed in January with 120-160 kg, normally without having required any supplement. The stocking rate is usually of 0.4-0.6 pigs ha^{-1}. Before this, piglets are given feed once weaned. Another method is that during the fattening period they are fed with acorn and feeds, which is called "*de recebo*" (San Miguel 1994; Daza 1998a; Escribano and Pulido 1998; Montero et al. 2000; Olea and San Miguel 2006).

Goats are usually used as a complement with other animals to make better use of the woody fodder. The breed may include goats for meat or milk production or mixed, with stocking rate of 2-3 goats ha^{-1}, if there are a lot of shrubs, supplemented with concentrates in the last period of gestation and during the whole period of lactation. Lastly, horses are used as a complement to other types of animals or, concretely, in horse raising with pure breed. In addition to livestock, the presence of animals associated with big game hunting is common, as with the deer or small game as with the rabbit, whose exploitation increases the profitability of the dehesa (San Miguel 1994; Escribano and Pulido 1998; Montero et al. 2000; Olea and San Miguel 2006).

Optimizing the forage resources

The livestock management system in the dehesas is determined by the quantity and the seasonal distribution of the nutritional resources together with the market situation. Thus, the high production of green grass in the grazing land are optimized during spring and when it has dried, the livestock consumes the green grass provided by the *majadales* and the *vallicares* and complete its diet with dried grass still standing whose quality and weight has dramatically decreased. In summer the animals are usually out of the dehesas or they consume imported products: agricultural sub-products, hay, feeds, etc. The livestock are taken back to the dehesa after the first autumn rains and once the early re-sprouting of *Poa bulbosa* has started. Before this, the autumn pasture and the acorn is consumed**.** During winter, when there is scarcity of pasture production, the acorn and the fodder with some supplement, allows the maintenance of the livestock up to the following spring (Montero et al. 2000).

The system of regulating sufficient grazing for the majority of the dehesa is with continued grazing, where the livestock may be found covering the total grazing area continuously due to the low quantity and the high seasonal variability of its production. At times however, it is most efficientto divide the dehesa into small plots where the livestock will be rotated for grazing (Olea and Viguera 1998).

With respect to optimization, in clear pastures or those with problems of dissemination, it may be convenient to use deferred grazing which involves delaying consumption to optimize the quantity and quality of the pasture, always avoiding extreme stress in spring. This way, the flowering, fruition, and dissemination of annual species is facilitated, mainly in the grazing land of the dehesa. Sometimes it is convenient to reserve the grazing in the pastureland in spring or in autumn, for a certain number of years, with the objective of achieving better seed production for establishment (Escribano and Pulido 1998; Olea and Viguera 1998). However, with the rest of the dehesa, the reduction of the competition of the less valued with the more valued species should be done early on and intensely (without being excessive), to support the species with the best grazing quality. This not only supports better grazing tolerance, but are also favored by it; diversifying in livestock species and in systems, to optimally make use of the productive diversity of the environment; and integrated with the forestry systems (forest, shrubs) and agriculture (cultivated cereals and forages, agricultural sub-products) to counteract as much as possible the shortage/absence of the dehesa´s self-sufficiency (Montero et al. 2000).

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Roles and Functioning of Agroforestry Systems

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Agroforestry systems: optimizing the use of resources

Agroforestry systems (SAFs) are multi-function systems with the presence of a layer of trees (long-term cycle) in combination with crops or pasture (short-term cycle). In comparison with crop monocultures, agroforestry systems are structurally more diverse and make better use of light, water, and soil nutrients in space and time. The improved use of environmental resources generally results in higher economic and environmental benefits (Gordon and Newman 1997). Some of the peculiarities of the SAFs (especially of the dehesa) with regards to their efficient utilization of environmental resources will be mentioned below.

In agroforestry systems, light is a fundamental factor in the growth of plants and the microclimate. The trees allow the penetration of a high percentage of light towards the lower layer which enables the pasture to cover 99% of the area. The trees reduce the effects of winter frosts and of the sun exposure in summer, for example, the presence of vegetative cover mitigates the maximum and minimum temperatures under the crown of the holm oak (Moreno et al. 2007).

Water is the main limiting factor of productivity in the Mediterranean ecosystems. Precipitation during the long summer periods is absent or constitutes only 10% of the total annual rainfall and when it occurs, the torrential characteristic makes it ineffective.

In the dehesas, annual grass species extracts 90% of the water necessary within the first 40 cm of soil. The perennial grass species can reach down to 60 cm, whereas the shrubs (*Retama* sp.or *Cistus* sp.) probably can reach down to one meter. Trees are able to use water from the deeper soil profile (Moreno et al. 2005).

In agroforestry soil fertility increases as a result of the pumping of nutrients by the trees from the deep soil layers and the recycling of leaves (Brandle et al. 2004; Dahlgren et al. 1997; Escudero 1985; Halvorson et al. 1995; Menenzes et al. 2002). The deep root system of the trees takes nutrients from the deeper soil layers, reducing the loss of these through lixiviation. These nutrients are recycled through the decomposition of leaves, returning to the roots and increasing the efficiency of resource use in the system (Jose et al. 2004; van Noordwijk et al. 1996). Trees also attract birds, since the shade allows them to rest and refresh, leaving their excrements which increase the fertility under the canopy (Grove and Rackham 2001). The trees also protect the soil from the effects of erosive agents such as wind and water. The tree canopy intercepts rain drops, lessening the intensity of its impact on the soil and the tree root system, improves the physical properties of the soil, and also facilitates infiltration and increases the capacity of water retention (Joffre and Rambal 1988; Cubera and Moreno 2008). The tree litter may act as a shock absorberfor water and wind erosion, whereas in traditional agriculture the upper soil layers are unprotected against these agents of erosion.

Tree-Crop Interactions

As a consequence of the positive effects that trees have, a number of studies have described an improvement in the production and quality of pasture and crops in association with trees in dehesas (Puerto 1992; Moreno et al. 2007; Moreno 2008). Trees also contribute to the prolongation of the vegetative period of the pasture showing an increased early growth in the cold season (autumn and winter) and later in the dry season (start of summer) (Puerto et al. 1987). This has very positive implications in the nutrition of the domestic livestock and wild herbivores of the dehesa.

However in all the AFS, there are trade-offs between positive and negative effects of trees on the herbaceous layer and vice-versa. The possible negative effects are related to the competition for light, water, and nutrients (Ong 1996; Bayala 2002).

Many examples from the temperate zone exist of the increase in crop production when trees are associated with crops (Jose et al. 2004), although these studies also show that the competition for resources among species of agroforestry systems represents the rule rather than the exception. Because of their size, trees often have a clear competitive advantage, reducing the yield of crops within the systems mentioned, once they have reached a certain size. Some situations have also been described where the trees in the dehesas reduce pasture production (Puerto 1992).

Often the reduction of crop production in association with trees has been attributed to the effects of the shade. These effects depend on the crop species under the trees and their physiological changes (Brandle et al. 2004). Shading imposes more restrictions in the productivity of the tree-crop systems in the north of Europe than in tropical or Mediterranean systems.

Less sunlight in high altitudes reduces the growth of crops under the tree canopy. However, in lower latitudes there is a benefit to the reduction of sunlight (and thus of transpiration), especially in environments with water shortage, thus in some cases extending some benefit of the shade over the pasture or crop production (Lin et al. 1999; Moreno 2008).

When the competition for soil resources are eliminated (with root barriers) Bayala et al. (2002) showed that the sunlight has a minor or no effect in the reduction in crop production. Therefore, while in high altitudes the limiting factor is often the sunlight, in southern areas, water and nutrients are more relevant.

Trees may also intercept rain coming from dew or mists, helping in the conservation of water (Grove and Rackham 2001). They may act as windbreaks, lessening the movement of air, thus reducing the evaporation stress on the crops (Jose et al. 2004). The root systems of the trees are able to absorb water deep in the soil, store, and make it available to the upper soil layers (a phenomenon known as “hydraulic lift”), where the plants with short or shallow root systems benefit (Dawson 1993; van Noordwijk et al. 1996). But aside from these possible effects in the water balance of the system, trees usually intercept large quantities of water (up to 30% of rain) (Mateos and Schnabel 2002), and use large volumes of water by transpiration (Moreno and Cubera 2008; David et al. 2004). In arid environments, this results in a negative effect for the pasture /crop (Cubera and Moreno 2007).

Other aspects of agroforestry systems that have been less studied are the effects of the practice of silvoagriculture on the functioning, growth, and production of trees. On Spanish dehesas, a positive effect on the productivity of acorn of the holm oaks of thinning has been published by Pulido and Díaz (2005), and a positive effect on the physiological state of the trees has been demonstrated by Moreno and Cubera (2008). Other authors have reported higher growth values of trees in agroforestry in comparison with those that grow in tree monocultures (Garrett et al. 2004), as a result of better spacing (better availability of resources for the tree), and a benefit of cultural practices such as fertilization and deepening of its roots (Chiffot et al. 2005).

In order to minimize the negative interactions between trees and crops, it is necessary to select combinations of herbaceous and tree species and their spatial and temporal arrangement that result in positive interactions. The most efficient and sustainable systems are those which are able to optimize the use of space and time by minimizing overlapping layers of vegetation and using soil and light resources at different points in time (Jose et al. 2004).

Some investigation has shown that a tree-crop combination may, in some cases, be more productive than monocultures, especially if trees benefit from some resources that may not be available to the crops (Cannell et al. 1996), as well as from reducing the needs for chemical inputs (Vandermeer 1989). A better appreciation of the functioning of the traditional agroforestry systems and its management may help in the future adoption of silvoagriculture techniques with adequate designs and sustainable management plans such as: optimum densities, space-season design, fertilization, pruning, thinning, etc. Designs based on this information may help reduce the competition and/or improve the facilitation effects (García-Barrios and Ong 2004).

Functions of agroforestry systems

In Europe, initial interest in new AFSs came about from the environmental benefits attributed to these mixed systems as opposed to monoculture. The AFSs are diverse and have a more complex structure in comparison to monoculture agriculture. Therefore, in AFS trees and crops use resources such as light, water, and nutrients more effectively and efficiently. In these systems, the complementation of plant layers are specifically managed to reduce chemical inputs to the system (Vandermeer

1989), improve the cost-efficiency of crop yields, and thus lessen the dependency on subsidies. Aside from this, the AFSs may contribute to the improvement of the landscape, fire prevention, erosion control, improved micro-climate, improved soil fertility, control of widespread pollution and enhanced biodiversity and CO_2 sequestration (Jose et al. 2004; Thevathasan and Gordon 2004). These aspects are discussed below in detail.

Benefits for the environment

a. Improvement of the landscape: this is one of the arguments that has been used by many European countries and regions to be able to get various subsidies to maintain trees in agriculture lands as windbreaks, hedgerows, scattered trees, etc.,

b. Fire control in forests: there are very interesting studies in southern France (Etienne 2001), Italy (Pardini et al. 2007), Grece (Papanastasis 2001), Spain (Rigueiro-Rodríguez et al. 2006), on the role of AFS in fire control. All of them resulting from the exploration of the possibilities of transforming natural forests (mainly of *Quercus*) or forest plantations of *Eucalyptus globulus, Pinus pinaster, P. sylvestris* and *P. radiata* to silvopastoral systems through the use of native goats, horses, and sheep. So far the results are encouraging from the point of view of increased production of pasture resources and the reduction of fire risk.

c. Control of erosion: the use of strips or hedgerows of wooded vegetation in association with crops or riparian vegetation has been shown to be an efficient mechanism in erosion control (Young 1997).

d. Improvement of the micro-climate: the windbreak effect of rows of trees planted between crops has been widely studied and described by different authors (Brandle et al. 2004). The effect of trees in the regulation of climatic oscillation (temperature, humidity, etc) has also been demonstrated by different authors (Williams and Gordon 1995).

e. Improvement of soil fertility: trees contribute to the improvement of soil fertility through the pumping of nutrients, biological fixation of N, capture of aerosols, etc. (Young 1997), which allows the reduction of fertilizer use on crops or improves the production and quality of pasture (Puerto 1992).

f. Control of non-point pollution: AFS have a shallow root system of the herbaceous plants and a deeper one of the woody vegetation (Ehleringer et al. 1991; Moreno et al. 2005; Smith et al. 1999). Thus a large proportion of the nutrients that may not be reached by the roots of the herbaceous plants because of lixiviation (e.g. nitrates) are more efficiently used by the trees, contributing to their development and to the control of the pollution of aquifers and water streams (Nair and Graetz 2004). This is of great importance in the irrigated lands of the Mediterranean basin. The woody vegetation also contributes to the control of the erosion as mentioned above.

g. Increased biodiversity: biodiversity conservation is a current concept difficult to define and to value economically. Many studies have shown the positive role of the introduction of trees in agricultural plots. Thevathasan and Gordon (2001, cited in Thevathasan and Gordon 2004) found a spectacular increase in the diversity of arthropod and detritivore parasites, and a slight increase in the predators and pollinating animals in agroforestry systems in comparison to monocultures, while the presence of those herbivore arthropods detrimental to crops lessened. Similarly, Price (1999) found a spectacular increase in the density of earthworms in agroforestry plots of corn with poplar, maple, and ash tree as compared to corn monoculture. The unique high diversity of different taxa that may be found in the dehesas of the Iberian Peninsula is also known (Díaz et al. 1997).

h. CO_2 sequestration: in the last 3 to 4 years AFS have gained increasing recognition as carbon sinks, especially with the ratification of the Kyoto Protocol. Several investigations have been carried out on the potential of AFS as carbon sinks. Thevathasan and Gordon (2004) estimated a carbon fixation rate of 1 t ha^{-1} $year^{-1}$ for grasslands and 2.7 t ha^{-1} $year^{-1}$ for agroforestry plots (100 poplar ha^{-1}). Besides, it should be considered that the fixation of carbon in the soil as the result of root turnover is 1.5 to 3 times higher than in the above-ground biomass and of longer duration.

On the other hand, care should be taken in claiming great environmental benefits from silvoagricultural systems, especially in the context of sustainable agriculture. Many experiments done in the tropics have demonstrated that the management of mixed systems is often intensive and not as sustainable as one may think.

Benefits for the farmer

a. Increase and diversify productivity: AFSs are multi-function systems that contribute to the diversification of the agrarian income and create new employment opportunities for planting, managing, and processing tree products.

b. Allow annual income and the capitalization/investment in trees (e.g., wood) within a short period.

c. Shorten the amortization period of tree plantations.

d. Promote self-sufficiency (of special interest in less developed areas).

e. Improve marginal lands: ensures maintenance of soil fertility and an optimum use of water. This is most relevant in arid environments.

f. Pump nutrients and fix N_2, reducing use of fertilizers and consequently the cost of production.

g. Contribute to the biological control of pests and diseases.

h. Reduce risks associated with plantations.

There have been interesting advances toward incorporating environmental parameters in the economic evaluation of different systems, but it is still far from the day when the owners may receive subsidies for these services. Alavalapati et al. (2004) reviewed the perspective of incorporating payment for the environmental benefits and levies for the environmental damages that are yielded in agricultural production, showing promising possibilities for agroforestry systems, in terms of land values.

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Biodiversity in the dehesa

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Introduction

The Mediterranean Basin is one of the 25 biodiversity spots of the world (Myers et al. 2000). The presence in the Basin of more than 2500 species of plants and 770 of vertebrate animals, most of them endemic, is closely associated with the high heterogeneity in ecology, climate, and human use of the region. This heterogeneity has allowed the arrival and settlement of species of extremely varied origins, as well as *in situ* speciation, and the development of different biological systems, both natural and man-made, closely condensed in space (Blondel and Aronson 1999). Wooded dehesas are outstanding among man-made systems because of the high levels of biodiversity they maintain. In fact, this unique system of forest utilization has been included in the list of habitats to be protected under the EU Habitat Directive, together with the natural systems from which they are derived (Díaz et al. 1997 and 2003).

Biological diversity has commonly been used to assess the ecological integrity of natural systems. High diversity would be associated with a high functional redundancy of species within trophic levels in the case of simple systems such as plakton or pastures. This redundancy ensures that some species from each trophic level will survive the natural disturbances suffered by the system, thus maintaining its functionality (Yachi and Loreau 1999). However, more complex systems such as benthic or forest tend to include a few species, that are closely associated with or even responsible for the functioning of the processes key to the functionality of the whole system, while others are associated in a more or less passive way with habitat features derived from these key processes (see Díaz 2002 for a review). Therefore, it could be possible that high diversity does not imply ecological integrity in complex systems, since its functioning depends on a few keystone species and ecological engineers not necessarily associated with situations of high biological diversity (see Manning et al. 2006 for systems characterized by having scattered tree populations, such as savannas and dehesas). On the other hand, the sustainable use of biological diversity is increasingly relevant to the development of land-use policies both in the Mediterranean and worldwide (Mattison and Norris 2005). In fact, a growing proportion of the budget of the European Common Agricultural Policy (CAP) is aimed at financing types of land-uses less productive from the commercial point of view but that would maintain and increase the biological diversity and its associated values (Tscharntke et al. 2005; Kleijn et al. 2006). This trend incorporates economic and social values into the levels of biological diversity maintained by man-made systems such as dehesas, that may be key for its biological diversity survival in the long term (Díaz et al. 1997 and 2003).

Patterns of biological diversity in dehesas

Dehesas in comparison to other types of habitat

The richness of species tends to be higher in dehesas than in other types of habitat either natural (including Mediterranean forests) or man-made. This tendency is observed especially in the most abundant groups of species, such as herbaceous plants and diurnal butterflies and birds, and is found in a wide range of spatial scales, from regions where dehesas co-exists with other land-uses and with scarcely managed forests (Figure 1a and 1b), to worldwide scales (Figure 1c). For example, the presence of more than 100 species of herbaceous plants in 0.1 ha is common in dehesa farm systems (179 in the Monte Gilboa, Israel -Naveh and Whittaker 1979-, 151 in La Motilla, Cádiz -Díaz-Villa et al. 1999- o 135 in Sierra Morena -Marañón 1985), while in the Mediterranean, mature forests plant species richness is around 60-100 per 0.1 ha (Iberian cork oak forests; Ojeda et al. 2000) and in forests or scrublands in Californian, it rarely reaches more than 40 species (Westman 1988). Richness of passerine birds in Iberian dehesas is around 11 species per 10 minute spot-sampling, and 29 species per farm on average, significantly higher than the 8 species per sample and 25 species per mature conifer or broadleaved forest stand (Tellería 2001). This tendency however, is the opposite for species-poor groups such as shrubs (Figure 1d), that are directly and negatively affected by the management of the dehesas. Overall however, the total richness of species is still higher in the dehesa systems (Figure 4c). Finally, it is worth mention that a great number of species found in the dehesas are protected by European legislation. Specifically, 44 species of birds, 31 mammals, 8 freshwater fish, 6 reptiles, 10 amphibians, 10 invertebrates, and 33 plants found in the dehesas are covered under protective directives (Díaz et al. 2006).

Diversity within dehesa farms: a mix of habitats at various spatial scales

Co-existence of trees and grasslands at various scales

The reason that has been traditionally given to explain the richness of species maintained by the dehesas or savannas is that these systems can be viewed as a close mix of two different habitat types at scales of a few square meters: forests represented by the scattered trees, and open habitats represented by the grazed or cultivated matrix over which croplands and trees are distributed (Díaz et al. 1997; 2003; Manning et al. 2006).

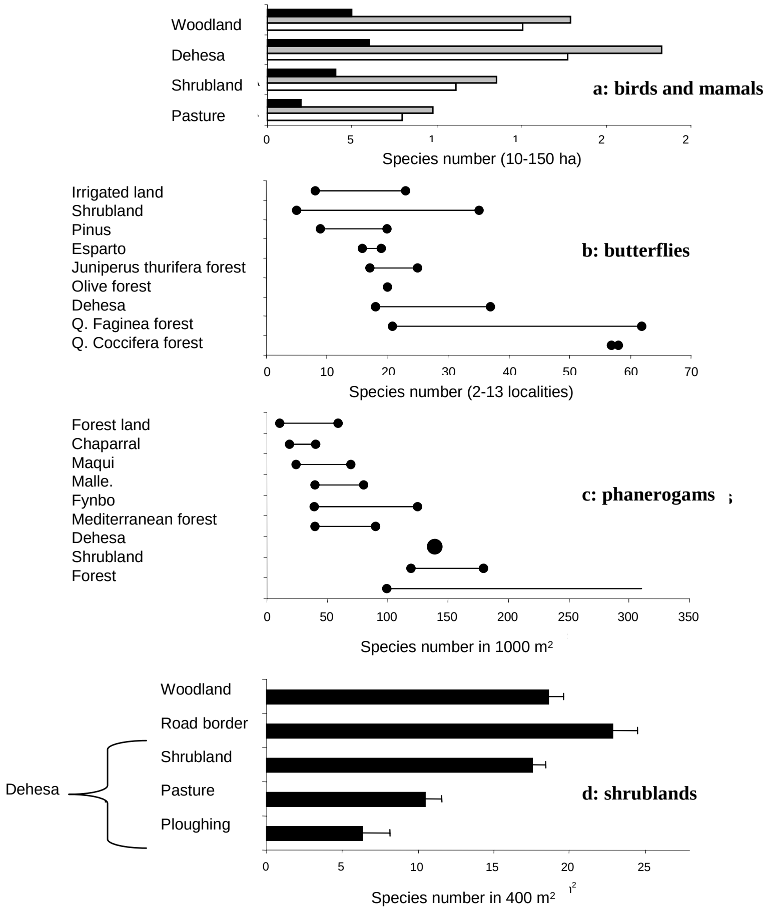

Figure 1. Comparison of the richness of species in dehesas and other types of habitat for various groups of organisms and spatial scales. a: birds (winter light gray; spring: dark gray) and mammals (black) in the valley of the Tiétar River, Avila-Toledo, Central Spain (Tellería et al. 1992); b: dirunal butterflies in the center of Spain (Viejo et al. 1989); c: phanerogram plants in forests and shrublands worldwide of the planet (Marañón 1986); d: shrubs in cork oak *Quercus suber* forests and dehesas of Central and Western Spain (Domínguez et al. 2007)

This mix would allow the coexistence of forest organisms and organisms typical of an open environment within the same type of "hybrid" habitat. This coexistence has been demonstrated in the case of herbaceous plants and nesting birds. Thus, although the richness of the herbaceous species is on average lower under the tree canopy, the specific composition of grasslands differ between these places and in areas far from the canopy, which results in an increase in the richness of species at a scale of few square meters (Marañón 1986; Fernández and Pérez 2004). The richness of nesting bird species increases with an increase of tree cover in dehesas of holm oak without shrubs (Pulido and Díaz 1992; Díaz et al. 2001). This increase follow a pattern, in such a way that species are not substituted by others as the tree cover increases, but that the community in plots with less species is a subgroup of those that occupy the plots with more species (Figure 2). Considering the habitat requirements of the species, what can be observed is that the species of open environments typical of open dehesas are not substituted by forest species as the tree cover increases, but they are added to them (Figure 2), supporting the hypothesis that the close mix of forest organisms associated with trees, with organism of open areas associated with grasslands, is responsible for the high local richness of dehesas. In fact, the nested increase of species richness with the increase in tree cover is found only in dehesas with low shrub cover. This relation disappears in dehesas encroached by shrubs (Díaz et al. 2001), that therefore cannot be colonized by species of open habitats.

Coexistence of different types of understorey vegetation in the dehesa farms

The traditional management of dehesa farms generated a mosaic of grasslands, small cultivated plots, and plots encroached with shrubs under scattered tree cover, at typical scales of hundred hectares, which is the average size of dehesa farms (Díaz et al. 1997). The diversity of different groups of organisms responds to the structure of the understorey vegetation in a manner independent of the tree cover (Pulido and Díaz 1992).

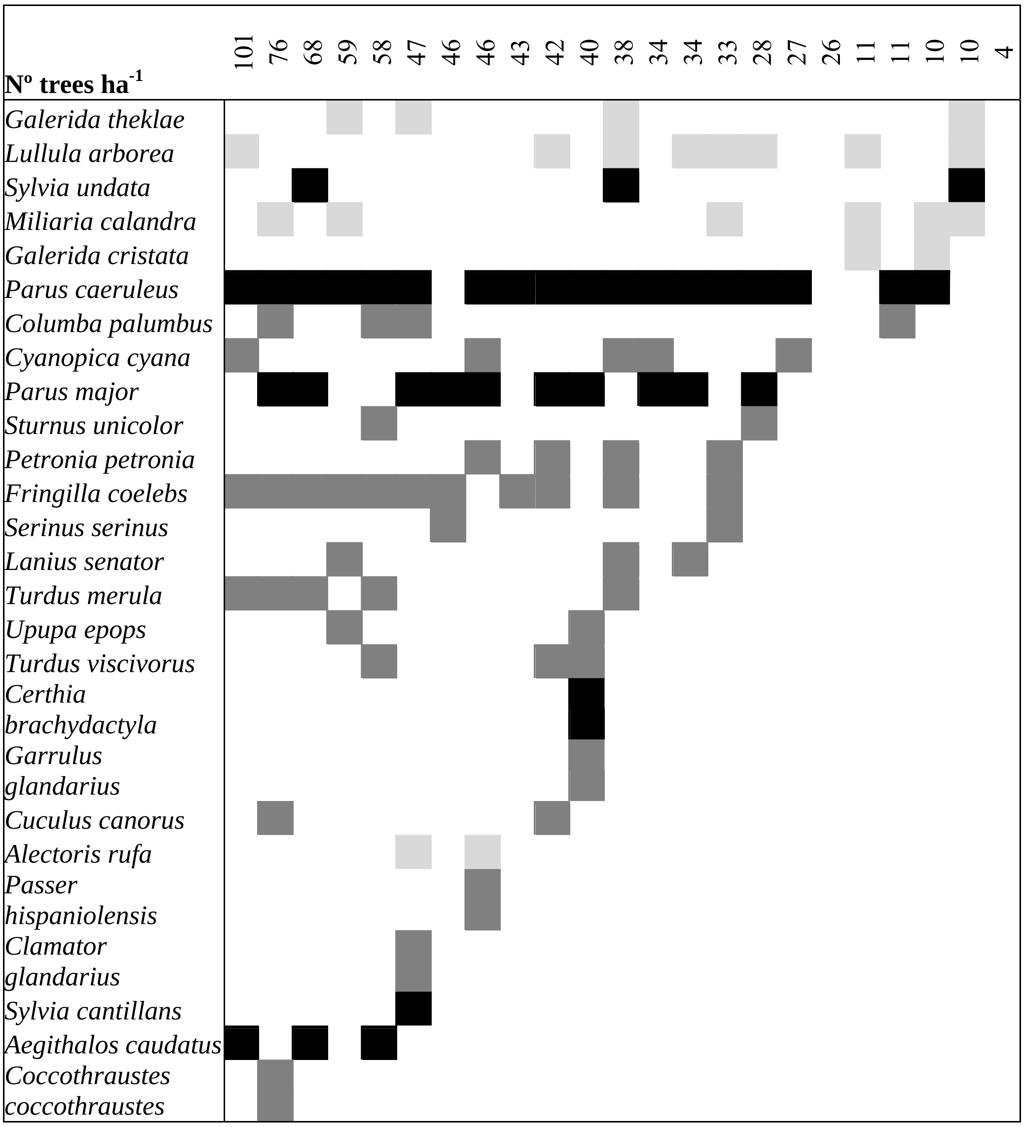

Figure 2. Species composition of nesting passerine bird communities in relation to tree density (upper line) in 23 plots of 50 x 500 m of dehesa with pasture (shrubs cover of less than 10%) situated around the Monfragüe Park (Cáceres) and sampled in the spring of 1987. The habitat requirements of each species are also shown. Light gray: open areas (breeding and foraging on the ground); dark gray: generalist forest birds (breeding on trees or shrubs and foraging on the ground); black: specialist forest birds (breeding and foraging on trees and shrubs; Pulido and Díaz 1992 and unpublished). The degree of nestedness of the data matrix is 8.22, marginally significant (P=0.08; Lomolino 1996)

The number of species of nesting birds and earthworms tends to be higher in the areas with pasture under trees than in zones with shrubs or crops, while the number of species of mammals and shrubs tends to be higher in dehesas encroached by shrubs (Figure 3).

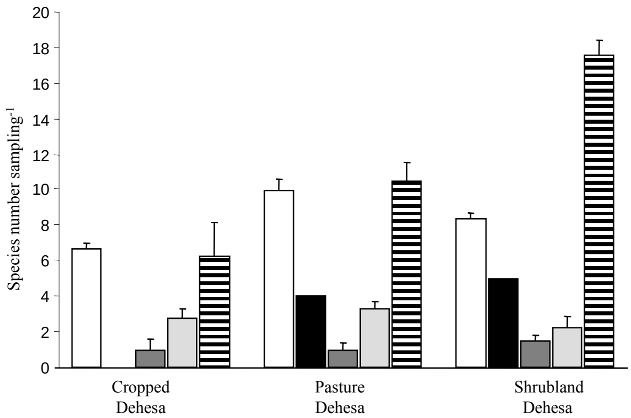

Figure 3. Patterns of richness of bird species (average number of passerine species +ES in plots of 2.5 ha; white), meso-mammals (herbivores, lagomorphs and carnivores in 150 ha; black), small mammals (rodents in 240 traps-night, dark gray), earthworms (earth worms in 0.5 m^2, light gray) and shrubs (woody plants in plots of 400 m^2) based on the type of understorey vegetation. The differences are statistically significant for passerine birds (test of Kruskal-Wallis: H_2=7.00, P =0.030, n=9) and shrubs (Domínguez et al. 2007), no statistically significant for small mammals and earthworms (H_2=0,83, P=0.661 and H_2=1.82, P=0.402, respectively; n=12) and could not be analyzed in the case of meso-mammals. Sources: Pulido and Díaz (1992) for birds, Tellería et al. (1992) for the meso-mammals, Díaz et al. (1993) for small mammals, Díaz et al. (1995) and Díaz and González (unpublished data) for earthworms and Domínguez et al. (2007) for shrubs

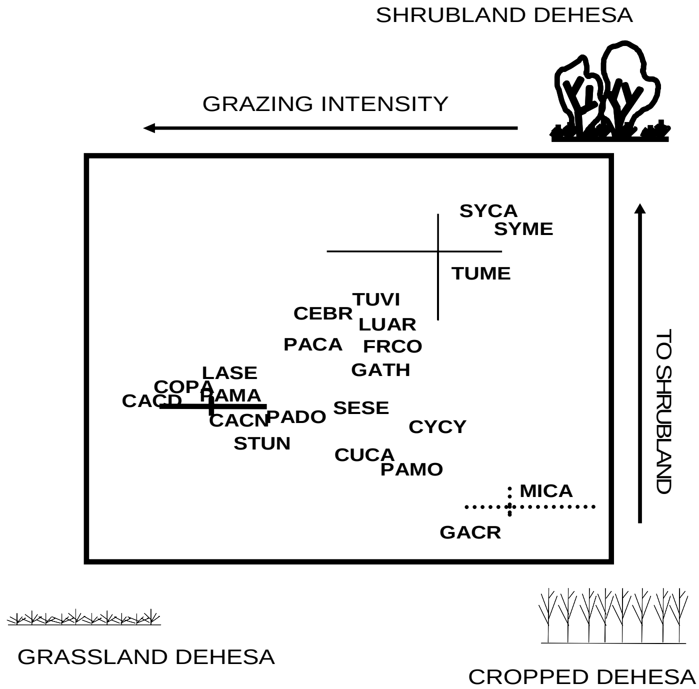

Figure 4. Patterns of habitat selection of breeding birds in dehesas based on structural gradients of the understorey vegetation as a result of the management of the farms. The range of values for dehesas with shrubs is indicated with fine continuous lines, in the dehesas with pasture with thick continuous lines, and dehesas with cereal crops with broken lines. The abbreviations indicate the average selection of habitat of each registered species (SYCA: *Syivia cantillans*; SYME: *S. melanocephala*; TUME: *Turdus merula*; TUVI: *T. viscivorus*; CEBR: *Certhia brachydactyla*; LUAR: *Lullula arborea*; PACA: *Parus caeruleus*; FRCO: *Fringilla coelebs*; GATH: *Galerida theklae*; LASE: *Lanius senator*; COPA: *Columba palumbus*; CACD: *Carduelis carduelis*; CACN: *C. cannabina*; PAMA: *Parus major*; PADO: *Passer domesticus*; SESE: *Serinus serinus*, CYCY: *Cyanopica cyana*; STUN: *Sturnus unicolor*; CUCA: *Cuculus canorus*; PAMO: *Passer montanus*; MICA: *Miliaria calandra*; GACR: *Galerida cristata*). Source: Pulido and Díaz (1992)

However, the mix of land uses within each farm allows the co-existence of groups of organisms associated with contrasting habitats. This is the case with birds that are highly associated with cultivated dehesas such as corn buntings *Miliaria calandra* or crested larks *Galerida crsitata,* or to dehesas encroached with shrubs, such as warblers, *Sylvia* spp. or blackbirds *Turdus* *merula* (Figure 4; Pulido and Díaz 1992), of sun-demanding species associated with pasture lands and shade-loving ones associated with shrublands (Marañón 1986), or of lizards associated with zones encroached by shrubs (*Psammodromus hispanicus* or *Lacerta lepida*) or to small rock outcrops (*Podarcis hispanica*, *Psammodromus algirus* or *Acanthodactylus erythrurus*; Martín and López 2002). Both the abandonment of farms and their eventual transformation to game estates or their intensification through increased stocking rates, reduces or eliminates this variety of uses of the farm (Moreno and Pulido 2009) and therefore its levels of biological diversity.

Coexistence of the dehesa with other landscape elements

The dehesa co-exists with other land uses and landscape elements at the regional scale, which extends over thousands of hectares. Water courses, small water reservoirs, and man-made infrastructures (roads, buildings, etc.) found within farms or along their boundaries allow the settlement of species and groups of species associated with particular elements of landscape. For example aquatic organisms found in ponds and river banks (freshwater fish, amphibians, and birds, and aquatic or riverside plants) and commensal birds and mammals and ruderal plants found around infrastructures (Díaz et al. 2006). On the other hand, large and mobile species use dehesas as foraging grounds, but need other habitat types as temporary or permanent refuge. Certain birds like common cranes *Grus grus* and pigeons *Columba palumbus* need shelter in reservoirs or tree thickets close to dehesa stands, and move from cultivated plots to pasturelands, encroaching plots throughout the winter, as they track changes in food availability and predation risk (Díaz et al. 1995; Díaz and Martín 1998; Figure 5). Large herbivores such as deer *Cervus elaphus* or wild boar *Sus scrofa* require shrub patches during daylight or as seasonal refuge, and graze in the adjacent dehesas during the night or during the dry season (Carranza et al. 1991). Finally, large predators such as the Spanish imperial eagle *Aquila* *adalberti*, the Iberian lynx *Lynx pardina*, the wolf *Canis lupus,* or the black vulture *Aegypius monachus* nest or rest in large areas of forests adjacent to the dehesa farms where they capture their prey (Díaz et al. 1997; 2006). A recent study based on radio monitoring of black vultures has shown that individuals nesting in forest patches do not forage in forests; rather, they travel up to dozens of kilometres daily, selecting dehesas for foraging farther away from their nests (Carrete and Donázar 2005).

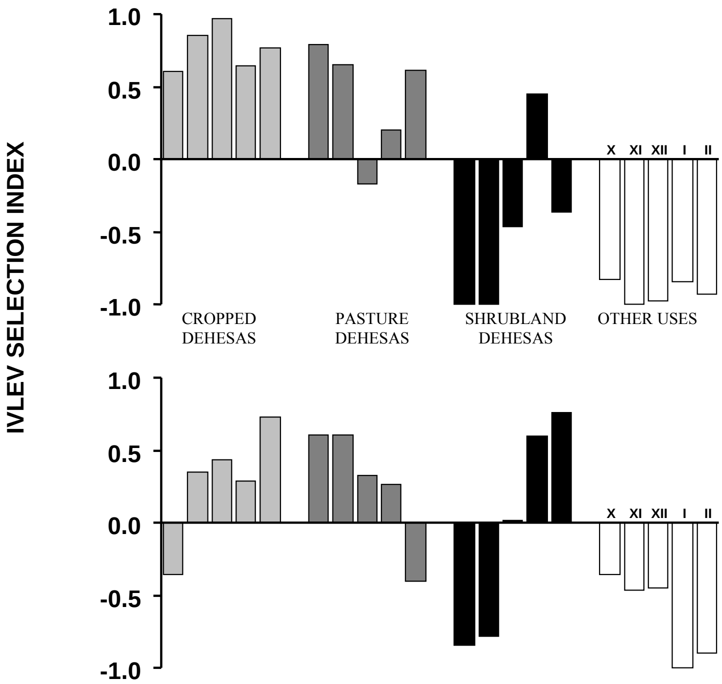

Figure 5. Changes in the habitat selection of common cranes *Grus grus* (above) and the wood pigeons *Columba palumbus* (below) during winter (October to February) in the dehesas of the south of the Rosarito reservoir (Tiétar valley, Toledo). Source: Díaz et al. (1995) and Díaz and Martín (1998).

Diversity and maintenance of the mix of habitats at different scales

The mix of forest and herbaceous elements at various scales is responsible for the high levels of diversity maintained by the dehesa. However, this level of diversity is not related to the maintenance of the coexistence between trees and other types of vegetation (Díaz et al. 2001; 2003). Recent studies has shown that the regeneration of the tree population is low or absent in grasslands with scattered trees, which is the landscape configuration that maintains the maximum levels of dehesa diversity (Pulido et al. 2001; García 2005; Pulido and Díaz 2005). The absence of regeneration produces the ageing of the tree population and a progressive decrease of its density, finally causing a transformation of the dehesa into a treeless pasture if there is no temporary abandonment of its productive use (Plieninger et al. 2003; Moreno and Pulido 2009). In the case of the trees in the dehesa, regeneration seems to depend on the activities of seed-dispersing animals (rodents like *Apodemus sylvaticus* and *Mus spretus* and birds like the jay *Garrulus glandarius*) that scatter/hoard acorns for their future consumption (Gómez 2003; Pulido and Díaz 2005; Muñoz and Bonal 2007), and on the facilitation of shrubs that provide protection to oak seedlings during their first summer (García 2005; Pulido and Díaz 2005; Smit et al. 2008). The scarcity of these key organisms in the dehesa would explain the absence of tree regeneration and therefore its ecological un-sustainability, in the same way as its recovery after its abandonment. The encroachment of shrubs in the dehesa decreases its productivity and biological diversity, but facilitates the presence of keystone species for the regeneration of holm oak, i.e. shrubs and acorn dispersing animals associated with high levels of shrub cover (rodents; Díaz et al. 1993; Muñoz et al. 2009) or trees (jay; Alonso 2006).

Conclusions: biological diversity and the sustainability of dehesa farms

The natural dynamics of the Mediterranean forests allow the coexistence of woody and herbaceous vegetation, but not at the local scale that characterizes the dehesa. Disturbances like wildfires or the action of large herbivores generate a mosaic of habitats at different successional stages, where herbaceous plants, shrubs, or trees dominate, but the scale of coexistence of these land uses reaches up to hundreds or thousands of hectares (for example, He and Mladenoff 1999). The shrub encroachment upon grasslands with trees decreases the number of plant and animal species locally, a process however, that is uninterrupted in the dehesa by human activities and its domestic animals. On the other hand, shrub encroachment favors a number of facilitative shrub species and seed dispersal animals, which are key for tree regeneration and hence for the ecological sustainability of forests and dehesas (Pulido and Díaz 2005; Moreno and Pulido 2009).

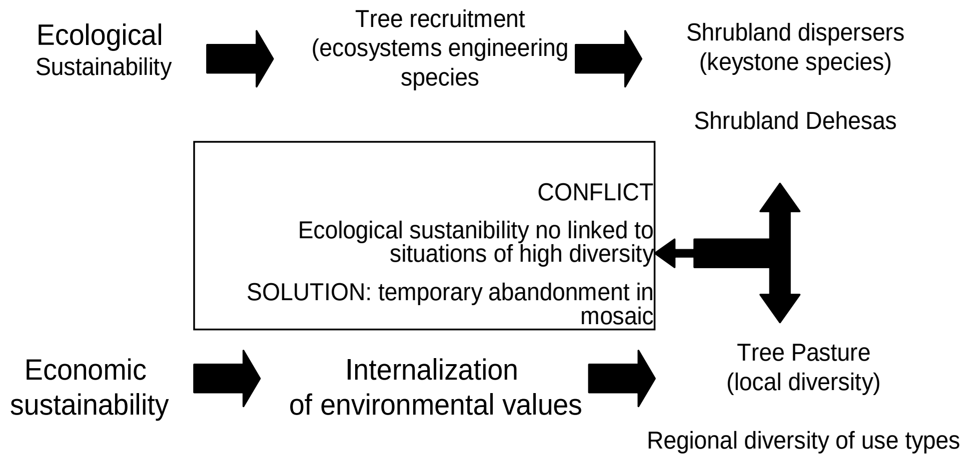

Figure 6. Conflict posed by the potential role of the biological biodiversity for the ecological and economic sustainability of dehesa farms. Temporary abandonment and rotational productive use in parts of the farms is needed, although there is very little information available to estimate the optimum time and area of abandonment (see Ramírez and Díaz 2008, Moreno and Pulido 2009).

On the Iberian Peninsual, human interventions seem unavoidable in order to maintain the coexistence of pasturelands and trees at relevant spatial scales (Hutsinger and Bartolome 1992). Although the biological diversity of the dehesa does not contribute to its ecological sustainability, it may contribute to its maintenance through the value that society gives to the species threatened by extinction or to those systems that maintain high levels of biological diversity (Díaz et al. 1997 and 2003; Campos et al. 2005). The high level of biological diversity maintained by the dehesa may be able therefore to contribute to its economic sustainability, if society values biological diversity adequately and when this value is shared by the owners of dehesa farm. Paradoxically, the maintenance of the economic sustainability through measures that favor only diversity or the abundance of threatened species, may if fact jeopardize the ecological sustainability of the dehesa, since there are critical phases of its productive cycle that depend on common species and landscape configurations that maintain low species richness (Figure 6).

The encroachment of shrubs in the dehesa, which is essential for tree recruitment, decreases the diversity as well as the productivity of the dehesa. Shrub encroachment then reduces income for landowners and also reduces biological diversity, so that it would not be subsidized, unless it is explicitly recognized that low-diversity situations could be essential for ecological sustainability in complex systems such as dehesas. Acknowledging the key role of shrubs and seed dispersers, as well as the design of actions at the landscape level that favours the coexistence of areas with high diversity but without tree regeneration, with other areas less diverse, but important for tree regeneration, is key to ensure dehesa sustainably (Ramírez and Díaz 2008, Moreno and Pulido 2009). In addition, these measures at the landscape scale may contribute to the conservation of species that are dependent upon mixed land uses. Although the implementation of these measures requires information not yet available on the period of shrub encroachment necessary for its recovery (see however Ramirez and Diaz (2008) for data taken during 20 years in dehesas of central Spain) and on the dependency of regional diversity on landscape configuration, this further understanding seems the only way to avoid paradoxical situations and maintain the economic and ecological sustainability of dehesas.

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Hunting in dehesas: a sustainable resource?

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History

Since early times, hunting has always been a part of human history. For some authors, the evolution of the human brain would not have been possible, from a physiological point of view, without the contribution of phosphorous from hunted animals (Arsuaga and Martínez 1998). Our cultural evolution is also strongly associated with hunting as shown in the cave paintings or by the first tools made by hominids. Presently however, this resource is not necessary for food; the development of agriculture and livestock cover these needs. But even with this, hunting has never been abandoned in any moment of our history and actually constitutes an important economic resource in the dehesas.

Before the 20th century, hunting was considered a privilege of the elite who enjoyed game hunting. Until the 1970s, hunting in the dehesas has been practiced as a complementary and recreational activity without any economic returns. During these years small game was abundant, possibly due to the absence of farm machinery, the abundance of predators, and the lack of economic revenue from this activity (Chapman and Buck 1989). The increasing mechanization of the dehesas changed this and it was during the

1980s when hunting began to be considered a profitable activity, especially the hunting of what is known as small game, which has increased notably. Contrarily, large game has been decreasing due to the impact of diseases on rabbits and the increasing intensification of farming.

Characteristics of the “dehesas” and “Montados”

“Dehesas” and “Montados” are tree formations with holm oak and cork oak, characteristic of the southeast of the Iberian Peninsula. Hunting is one of the multiple uses of dehesas. The combination of an open forest with herbaceous vegetation; either as pasture or as crops, which is characteristic of the Dehesas, has been man made. Today this formation covers more than three million hectares. Its benefits have been highlighted for quite some time, but its problems and constraints have only recently been investigated from a scientific point of view (Pulido et al. 2001; Díaz et al. 2003).

Dehesas are found in areas with a Mediterranean climate, with a marked seasonality in rainfall (rainy season is in autumn and winter and the dry season in summer) and temperature. Temperatures are mild during winter but very hot in summer. Aside from this seasonality, precipitation varies year to year with dry periods in some instances lasting many years. This characteristic makes good planning based on the estimation of livestock and hunting species stocking rate extremely difficult.

The soil of dehesas are generally poor and shallow, so that the most common vegetation are Mediterranean species that are able to stand climatic and soil conditions characteristic of these zones.

In brief, it can be said that the economic resources of the dehesas are varied. Cereal cultivation, pasture, tree fodder, acorn, cork, fuel wood and carbon, are the traditional products which nowadays provide low returns. The emergence of hunting as a profitable activity makes this resource more important.

The economic resource

In 2004 it was estimated that hunting in Extremadura produced a cash flow of 210 million euros. Most hunting is done in dehesas and due to this should be considered one of the most important resources of our region. A conservative value of hunting and its associated activities is:

–Recreational value: The gaming activity itself, renting of hunting areas, hunting license payments and trophies, forest guards, hunting dogs, personnel support, etc.

–Meat value: referring to the price of meat of the game

–Expenses of the hunter: Lodging, equipment, travel, food

These items show how the resources are shared among many involved across different sectors, affecting the local population of the places where the activities occur as well as those involved in the commercialization of meat and those involved in selling hunting equipment.

While agriculture and livestock has been losing economic importance, the viability of hunting has been increasing, making it possible for the local population to find an alternative source of income.

Game species

Many species small and big game species are found in the dehesas. In open grasslands we can find the hare (*Lepus granatensis*), the partridge (*Alectoris rufa*), or the rabbit (*Oryctolagus cuniculus*) as the most common species. In some areas trees doves (*Columba sp.*), thrushes (*Turdus sp.*), or *turtledoves* (*Streptopelia turtur*)can be found. As for big game, deer (*Cervus elaphus*) and wild boar (*Sus scrofa*) stand out as the most important species, but roe deer (*Capreolus capreolus*), the buck (*Dama dama*), and muflón (*Ovis ammon*) may also be important.

Some of these species such as the rabbit and the partridge, play an important role within the ecosystem, being the main prey for important protected species like the imperial eagle (*Aquila adalbertii) or* the Iberian lynx *(Lynx pardina).*

The situations of the big game and small game species are very different. In the last 20 years we have seen a marked decrease of the rabbit population due to *mixomatosis* and *hemorragia vírica*, to the extent that from more than 10 million rabbits being hunted annually has dropped to less that four million being hunted annually during the mid-eighties (Data of the National Statistics Institute). In the case of the partridge the decrease has been less pronounced but also important. Both species have lost their habitat on a large scale as agriculture production has changed and farm mechanization has spread (pesticides, short cycle crops, deforestation in riparian forests, and tree hedgerows, etc.).

In this same period, the hunting of big game has suffered a sudden increase as a result of the disappearance of predators such as wolves. In some areas, game species have replaced livestock or now share pasture and forage resources with them. In the same 20 year period, the red deer and the wild boar have been humted as many as three times more than before, in many cases compromising the natural regeneration of the natural vegetation and negatively affecting the small game species.

Is hunting a sustainable resource in the dehesas?

Based on the criteria of the IUCN, a sustainable resource is that which complies with three basic conditions:

•It doesn't reduce the potential use of the future population

•It is compatible with the maintenance and stability of the ecosystem in the long term.

•It does not reduce the potencial use in the future nor threathen the viability of other species.

Considering these criteria, it should be studied to what extent the current management of game reserves allow the consideration of this resource as sustainable in the long term. To analyze the question in a general way we will present two scenarios that correspond to the small and big game.

** Small game. The management is generally the responsibility of the hunters. The criterion is to increase the hunted animals at any cost but they generally focus on:

- The elimination of predators; some of these have not shown a negative influence in hunting species in an alarming way. In most cases there are no studies that validate this as an effective practice. It is good to remember that the predators eat the weak individuals exercising a selection that tends to improve the quality of the game.

- The release of animals raised on farms. They are released exclusively for hunting and if they are not killed they generally die a few days after realease since they are easy prey for opportunistic predators. These are animals of low quality which may spread illnesses and genetic problems.

These measures compromise the future use of the resource and the viability of other protected species. For these reasons, they are not considered as practices that will allow the continuation of a sustainable resource in the long term. In fact the rabbit population, as well as the partridge, has been continuously decreasing although the animals hunted of the latter include a lot of individuals raised on farms. Aside from these, the use of poisoned baits is creating a problem for the fauna, including those species that are not natural predators of the hunted species, as in the case of vultures.

Adequate measures to ensure that a resource is managed sustainably in the long term should be based on scientific information and be carried out with the supervision of a qualified and competent technician. Some of the measures proposed in studies demonstrating an increase in the population of small game without affecting the predators are:

–Establishing a mosaic of land uses. Agroecosystems have been simplified by the use of farm machinery. This has allowed the simplification of the dehesas and the elimination of hedges/hedgerows and riparian vegetation.

* The increase of the area with marginal vegetation provides refuge and food for game species. As there is an increase in the resources in the entire ecosystem the pressure of the predators on the hunted species is lessened.

* The sowing of cereal species with a long cycle allows the species to hide and prepare until they have completed their development and are able to escape easily from predators.

$ Water sources provide an important improvement in the physical condition of animals if this lessens their need to travel long distances in order drink.

- The adequate species of crops provides a secure source of food.
- The decrease in the gaming pressure is one measure in the long term that may favor the selection of those individuals that are resistant to diseases such as in the case of rabbits, allowing the partial eradication of the disease that affect this species.

**Big game. Normally the managers are the owners of the farms, and the management measures tend to substantially increase the number of animals of low quality through artificial feeding and enclosures that allows the control of the number of individuals, treating them as if they were domestic animals. Aside from this, inadequate exotic species have been introduced. The result is excessive browsing and a lack of regeneration of plant species present in the dehesas with the consequent ageing of the trees, one of the most important problems of our dehesas (Pulido et al. 2001). Aside from these, transmission of diseases between the (domestic) livestock and the game species is produced, resulting in a genetic depression in the animal populations and a pressure on the environment that may affect the totality of the ecosystem, and as such could not be considered adequate practices for the maintenance of the resources in the long term.

Adequate measures may come from obtaining adequate information, with the participation of technicians competent on the matter through the use of the browsing index and the regeneration of the vegetation. It will help to remember that in the Mediterranean environments to talk about calculations of stocking rate is not very realistic.

A control of the population following the principle of “quality over quantity” by the management of large farms or grouping of farms that will provide an adequate genetic flow, population size, and age structures, and breeding appropriate to maintain the ecosystem.

Elimination of exotic species like the *muflón.*

The avoidance of the introduction of species from the Northern countries that are bigger than the Spanish species and promoting a genetic control of the best animals (trophies).

Many of these measures, for small game as well as for big game, that are already under consideration and in the long term will improve, without doubt, the quality of game and the environment. In this way there are promising initiatives like the certification of game quality (Carranza and Vargas 2007) that ensure that hunting occurs in well-conserved environments and that the resources are managed in a sustainable way. Such programs should be supported by the administration and the hunters, as opposed to massive hunting and aggression toward the environment that has been done these last years. To this end, it is envisioned to issue a certificate of game quality for the hunting reserves and areas that follow these guidelines and practices to make hunting compatible with the preservation of the ecosystems.

In brief, it is possible to say that hunting in the dehesas is an important economic resource but requires a more adequate management that does not compromise its future nor the future of the ecosystems where it is practiced. In this sense, the participation of qualified technicians in the management and investigation of hunting is necessary for the good management of our dehesas.

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Efficiency in the use of natural resources for recreation and tourism

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Introduction

Man has undoubtedly left his mark on the environment throughout history and this mark has not always been positive.

For example, it should be mentioned that man's discovery of fire marks the point where he ceased to be just another element of nature with no effect on the existing ecosystems and became a being who could mold nature to fit to his needs, ultimately arriving to the discovery of agriculture and livestock thereby changing in one way or another his nomadic life.

However it was at the beginning of the industrial revolution at the end of 19th century, when the negative consequences of man's activities started to be noticeable, with an accelerating impact on the natural resources since the second half of the 20^{th} century. Since the end of the 19th century, people began articulating the need to protect natural areas as a form of avoiding the destruction of ecosystems and the animals and plants species found in them.

These ecological movements increased in number all over the world and were able to slowly raise awareness in the world population about the environmental destruction due to indiscriminate activities, for example, in the Amazonian region.

As a result, the World Commission of Development and Environment presented a report in 1987 to the United Nations called the Brundtland report, in which the concept of sustainable development was defined. Today, sustainable development is used as "a type of development that satisfies the needs of the present without compromising the capacity of the future generations in satisfying their own needs."

In the Rio Declaration of 1992, the way of understanding this concept changed, leaving behind the concept that sustainability is exclusively associated with environment and agreeing that development has an economic, social, and environmental dimension. Thereby reflecting an understanding that there will be sustainability when the equilibrium among the different factors that influence the quality of life is achieved.

Therefore, as explained in the Spanish Strategy for Sustainable Development (hereafter as EEDS, Ministerio de Medio Ambiente 2002), what is proposed is a longterm alternative with the objective of achieving a society which is more just, with more solidarity, more prosperous, more secure, healthier, and offers a longer life among and within generations".

It can be confirmed, therefore, that "sustainable development" is the combination of three aspects at the same time: economic growth that promotes social progress and respects the environment, social policies that stimulate the economy, and environmental policies that are efficient and at the same time economical." (EEDS, Ministerio de Medio Ambiente 2002).

The natural resources

A natural resource may be understood as any element present in nature that has not been changed by man, and is available anytime for the achievement of a concrete objective. From this definition it can be clearly seen that there is a manifest human interest in using said element for one´s own benefit with the objective of satisfying one´s needs and resolving one´s problems or maximizing an opportunity.

Lately, with the appearance and strengthening of commerce, man's exploitation of some resources has been progressively linked to the market value.

In this way, humans were driven to seek economic benefit for the use of natural resources. Strauss (1972) posed the question regarding which natural resources are those that may highly contribute to the economic and social development of a specific country.

Besides, the relevance of the economic benefit that one gets from the use of natural resources remains perfectly reflected for example, in the definition by the Law 26.821, article 3, of Peru (1997) where it is stated that *"considered as natural resources all the components of nature that may be used by men for the satisfaction of his needs and has an actual and potential market value"*.

Once the concept of natural resources has been clarified, it is also necessary to mention what types of natural resources may be found in nature. In principle these may be categorized in two groups: renewable and non-renewable.

Renewable natural resources are those that are always able to auto-regenerate when the circumstances are right, based on periodic cycles and in accordance to some determined renovation rate. Of course if the speed of the use of the resource is faster than its capacity to regenerate, there will be an over-exploitation of the resource and one can assume that if this situation continues over time, the resource will be depleted.

As examples of renewable natural resources we could mention among others the biological resources specifically plants and animals.

Due to its importance, the so called flowing resources or renewable, which are derived from the solar energy, are also worthy of special attention. For example, wind, the energy from waves, or direct solar radiation. We know that this renewable use may be depleted and although its use at present is minimal, in the future it will probably play an important role in the evolution of the human species. Because these are inexhaustible, the sustainability criteria are not applied to these types of resources.

As opposed to the natural renewable resources, the non-renewable are those that are not capable of auto-regeneration or those that even if they can regenerate have a very slow rate of auto-regeneration.

There are two subgroups within this:

- Those that are consumed when they are used: this would be the case of minerals and fossil fuels. For these, the sustainability criteria will consist of prioritizing the uses that will allow recycling, the re-utilization, or the recovery of resources as opposed to those where it is not possible to achieve these.

- Those that are not consumed while using them, including those resources of a general cultural character like caves, archeological deposits, natural landscapes, etc. The sustainability criteria applied will consist of respecting its maximum use intensity, understood as the maximum number of persons able to access the said resource by/per unit of time and space/area without producing significant deterioration.

Nature and cultural heritage

Although we can generalize, we will concentrate on some data which shows the increasing concern with the conservation of existing natural resources in Spain. Figure 1 shows the increasing evolution of the declared protected areas in our territory.

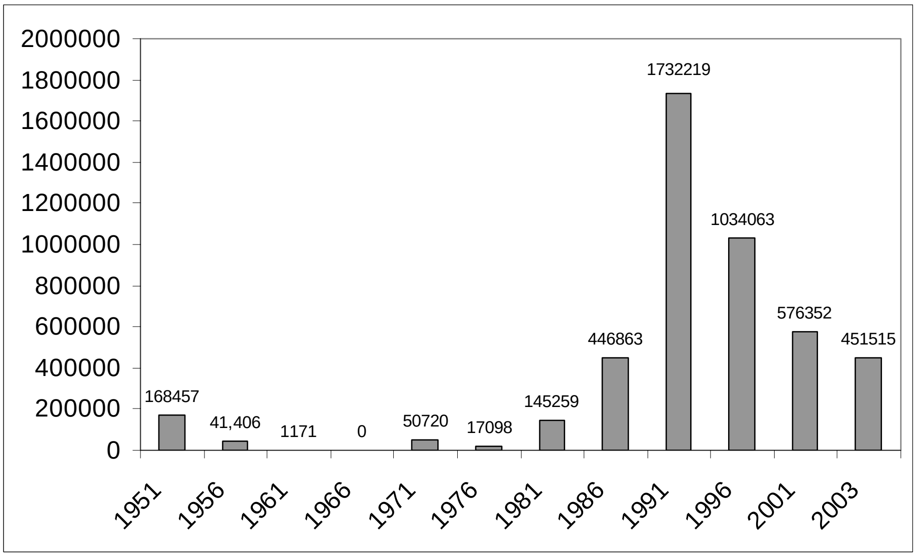

Figure 1. Evolution of the declared protected areas in Spain. Source: Ministerio de Agricultura, Pesca y Alimentación (2006)

As a result of this tendency there is a total of 13,858,906 ha of protected areas in 2004, of which 13,666,372 ha are included in the ***Natura 2000 Network*** and of which 192,534 ha are protected natural spaces, not included yet in the ***Network.***

Of the first figure, 13141079 ha of those correspond to protected terrestrial landscapes, while the remaining 717827 ha are protected marine areas. This means that in that year 25.95% of the total area of Spain is under some form of protection (Ministerio de Agricultura, Pesca y Alimentación 2004). It bears mention that in the Autonomous Region of Canary Islands, in 2004, 42.19 % of its territory was under a certain form of protection.

The figures above show that Spain has one of the highest biological diversity indexes in Europe due to the variety of natural habitats, wild species, genetic resources, and traditional knowledge related to the use of all of these. However, this biological biodiversity may be threatened by changes in land use and degradation from inadequate practices, pollution, and the introduction of exotic species among others factors. But aside from this, as we know, urban development, associated to the needs for infrastructure, has been an unstoppable phenomenon in past years, not only in our country but also in neighboring countries. This has provoked the fragmentation of territories, presently placing this index a little lower than 50% which makes the normal development of life within the existing ecosystem difficult. And in many cases this has forced the declaration of natural protected areas with the objective of avoiding their destruction, along with the disappearance of plant and animal species that live within them.

On the other hand, it should be stressed that Spain dedicates a large part of its territory to productive use, mainly agriculture, livestock, and forests, thereby contributing to biodiversity conservation in traditional agrosilvopastoral systems (e.g., dehesas, trees on agricultural lands, etc).

With regards to cultural heritage, it is evident that Spain possesses an important legacy as a result of the distinct cultures that have lived here during the various periods of our history. Many tourists visit each year to experience this legacy, with all the consequences, both positive and negative, that come with a large tourist trade. Due to this rich cultural heritage, it is not surprising that our country is one of the first on the list in terms of number of sites of the World Heritage of UNESCO. Thus, cities like Toledo, Segovia, or Cáceres are known worldwide, as are monuments such as the Alhambra of Granada or the Mosque of Córdoba. Traditional agrosilvopastoral management systems have also produced landscapes of cultural interest such as, the dehesas of Extremadura, the network of ways for livestock grazing linking the lowlands and the uplands, or the oak forests of Galicia. Mines, water mills, and irrigation channels built long ago by the Arabs should also be noted as characteristic of our more recent history.

However the threats to these legacies include:

- The excess of pressure due to uncontrolled activities such as urbanization, the industry, infrastructures, or tourism.

- The increasing abandonment of rural areas, that makes it difficult to sustain people dedicated to the tasks of the conservation of heritage.

Finally, it should be mentioned that at present, the atmosphere, water, and soil are also seriously threatened as a consequence of the development that has been referred to in previous paragraphs. The atmosphere is under serious contamination by troposphere, ozone, and greenhouse gases. These gases are responsible for global warming and climate change which ultimate effects are still unknown. On the other hand, water is a scarce resource in our country and more needs to be done in terms of awareness-raising and education in order to avoid wastage. Certainly, the modernization of inefficient irrigation systems cannot be delayed any longer.

As for the soil, the existence of extreme acidity conditions and forest fires, together with the degradation suffered due to destructive practices, has resulted in desertification in Spain. In addition, the overexploitation of water resources and the abandonment of rural areas have also contributed to desertification. Due to all of these, the emergence of phenomena like erosion, salinization, and soil degradation are increasing, for which measures must be taken so that their harm might be controlled.

With respect to the marine and coastal areas, Spain has around 8000 km of coast which together with a sunny, mediterranean climate is attractive to tourists. This fact is demonstrated by the average of 48 million foreign visitors each year that vacation on the Spanish coast. However, as a result of over-exploitation of tourism that has occurred in many coastal areas, the services that this sector demands have resulted in serious environmental problems that threaten the marine environment. Thus, the excessive urbanization, the coastal erosion, the pollution and exhaustion of the fishery resources may have irreversible consequences. To address this situation, it is no coincidence increasingly more municipalities are opting for the implementation of Agenda 21, noting that the municipality of Calviá in

Mallorca has been awarded with the most prestigious awards as an acknowledgement of the efforts put into the development of sustainable tourism which is respectful of the environment. In any case, we should not forget that 5% of the coast in a 10 km-wide strip was urbanized in 1990, while in 1995, 30% of the total population resided in coastal municipalities. This tendency is global, which demonstrates that the population tends to settle in places where they have access to water.

Finally, we turn our attention to forest, agriculture, and livestock resources since we cannot forget that a well-managed forest area constitutes an added incentive for the visitor eager to enjoy a pleasant landscape. However, although in our country forestlands occupy nearly 50% of the total land area, we cannot say that forest management is the most adequate most likely due to the fact that a big portion of this is private property. The absence of management and the increase in the risk of forest fires are important factors that place the survival of biological diversity and the quality of soil at risk. In addition, the use of products to control pests and diseases are also contributing to these phenomen.

Tourism and recreation

According to Mathieson and Wall (1990), two basic concepts that should be present so that tourism and recreation may take place are infrastructures and tourist demand. Aside from this, the interaction of the two produce the spatial and temporal incidence of tourism and recreation and consequently have economic, environmental and social implications.

Among the basic elements of tourism there are three worth mentioning:

- Dynamic: because to engage in tourism implies travel to a destination.
- Static: tourism brings people who stay at their destination
- Consequential: because tourism has an economic, physical, and social impact.

Among these, the static element involves a key factor that must be determined, such as the ***carrying capacity***, defined by Mathieson and Wall (1990) as *"the maximum number of people that may use a determined place without producing or resulting in any unacceptable physical change in the environment and without implying any decrease in the quality of the obtained experience by the visitors"*.

The consequential element considers the tourist concentration on one side, and the infrastructures and services that tourism requires in the destination area, and on the other, producing, in its totality, a series of effects that have to be determined Thus, economic effects are understood as the costs and benefits that are obtained from the development and use of the corresponding tourists services while the physical repercussions refer to the changes that are produced in the environment, such as the air, water, soil, vegetation or wildlife as a result of the construction that must be done. Finally, the social repercussions are the changes produced within the lives of the people residing in the tourist areas due to the influences of foreign visitors.

To analyze the repercussions of tourism and recreation on the environment, Budowski (1976, see Mathieson and Wall 1990), classified them as:

- Symbiotic: when tourism contributes to the conservation of the cultural/historical heritage, the transformation of villages and buildings into new installations, the drive for the conservation of natural resources or the control of the environmental quality.
- Conflicting: when an excessive increase in tourism activities occur to the detriment of the conservation of the values mentioned above.
- Coexistence: when the two above cases are combined.

In any case, what is clear is that tourism requires physical space, water, energy, and supplies, and generates a series of problems, like waste and the mobility of many people that only adequate planning may help to avoid Problems that perhaps in the future, if the current trends do not change, may result in irreversible damage.

Conversely, another phenomenon in Spain that is gaining momentum these last years is the development of local tourism, where tourists seek out enjoyment of the natural resources of their own cultural heritage. Currently, more than 60% of tourists that come to visit the rural areas, include in their plan a visit to a protected natural park. Given this, to avoid overexploitation, it is now more necessary than ever to engage in adequate area planning which is a complex process. Aside from this, among the challenges of the Action Plan of Durban (UICN 2003) it is important to mention the necessity of the involvement and participation of the indigenous communities, local communities, the youth, various ethnic groups, women and other groups with social interest in the identification and management of protected areas.

In this increasingly demand-driven process in rural areas, the evaluation and food quality protection of the European Union is also playing an important role, such as The Denomination of Protected Origin (DOP), the Protected Geographic Indication (IGP), Guaranteed Traditional Specialty (ETG), or Ecological Agriculture. Particular cases like that of Extremadura region with the DOP "Dehesa de Extremadura", the IGP "Beef from Extremadura" and with the ETG "Lamb from Extremadura (Corderex)" should be cited. There are other products which are in the process of securing some denominations because it has been demonstrated that it can significantly contribute to the economic, tourist, and social development of the corresponding areas.

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The decline of *Quercus ilex* and *Q. suber* in the Iberian Peninsula

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Description of the decline

The holm oak and cork oak are tree species highly representative of the landscape of the Iberian Peninsula, occupying about $2{\cdot}10^6$ and $1{,}8{\cdot}10^6$ hectares, respectively. *Quercus ilex* presents a widespread circum-mediterranean distribution, absent in the driest regions, while *Q. suber* ocupies the western half of the Mediterranian basin. In the 1980´s the progressive decay of individuals of these two species and their sudden death was first observed (Figure 1a). This decay was initially attributed to drought and pollution, with the attack of fungus and insects considered to be secondary factors (Brasier 1992); therefore this decline was referred to as "die-back" or "seca" (Tuset and Sánchez 2004). Presently the decline of these two Mediterrenean *Quercus* is an important problem that threathens the fragile and productive dehesas. The problem is widespread in the southeastern Iberian Peninsula, particularly in Algarve, Alentejo, Extremadura, west of Andalusia, and has been observed in some areas of Tras os Montes, Ribatejo, Toledo, and Ciudad Real (Brasier 1992; Moreira and Martins 2005). The decline of *Q. suber* has also been reported in Tunisia, Morroco, and Algeria.

The decline syndrome is caused by a group of symptoms without a fixed pattern (Gallego et al. 1999, Sánchez et al. 2002). Normally, the symptoms appear chronologically as follows (i) gradual discoloration of leaves starting around the edges, (ii) gradual discoloration of the crown starting at the more outer parts, (iii) defoliation some months later, (iv) abundant production of shoots and sprouts, (v) die-back of the sprouts and branches, generally starting from the outside of the crown towards the middle, and (vi) damage of trunk and branches, with the appearance of cankers, cracks and secretions. In addition to this, growth reduction and fine root reduction have been observed.

The decline mainly affects *Q. suber* and *Q. ilex*, although it has also been observed in *Q. pyrenaica* Willd, *Q. faginea* Lamk, *Q. canariensis* Willd and *Q. coccifera* L. Sometimes it also affects woody species associated to *Quercus*, like *Cistus* sp., *Crataegus monogyna* Jacq., *Genista* sp. and *Arbutus unedo* L. Three types of *Q. ilex* and *Q. suber* decline have been reported (Tuset and Sánchez 2004): (a) sudden death, when an apparently healthy tree dies in a short period of time, (b) progressive decay, when the tree starts to get weak and to shed its leaves, showing dead branches and twigs, and eventually dying a year or more later, and (c) lack of tree vitality, a process that is like the previous one but in this case the tree survives more years in a decaying state. The affected trees do not follow any clear spatial distribution (Del Pozo 2006), although normally they decay in groups, distributed along valleys, topographical depressions, or close to water channels (Brasier 1992). However, we also find decayed trees randomly, or in higher areas, with steep slopes and shallow soils.

Causes of decline

In agreement with Sánchez et al. (2000), who have adapted the models of other decay syndromes in Europe, the factors that cause the decay of Mediterranean *Quercus* may be grouped into three levels that usually occur over time. In the first place, the **predisposing factors** are permanent and contribute to the general weakening of the tree. These factors are long-term and do not necessarily show noticeable symptoms. These include the actual climatic conditions, with a slight increase in the average temperatures associated with an increase in the vegetative period and the irregularity of annual rains. Changes in soil condition are also included, such as erosion, soil compaction due to the use of agricultural machinery or livestock (Tuset and Sánchez 2004), and biological degradation. As an example of soil biological degradation, the absence of mycorrhizae in *Q. ilex* and *Q. suber* as a consequence of the impact caused by men and/or the actual climate may possibly have a negative effect on the vitality of trees. Inadequate silvo-agricultural practices are also a predisposing factor, like excessive pruning (Figure 1b), incorrect cork harvesting practises, damage caused during shrub clearing and tilling, and excessive stocking rates (Figure 1c and 1d).

The **aggravating factors** appear in an intensive way during a relatively short period, and they cause clear symptoms. The main factor is a prolonged drought that could last two to three years. It also includes defoliating insects like *Lymantria dispar* L. and *Tortrix viridana* L., which rarely cause the death of a tree (Romanyk and Cadahia 2001), but in coinciding with other adverse circumstances result in decline. *Coroebus undatus* Fabr. and Marsh may be included in this group, which is a bark borer of *Q. suber*, that aside from causing weakness of the tree, reduces cork quality.

Finally, the **contributing factors** usually are those responsible for the death of the trees. These agents are frequently present together with *Q. ilex* and *Q. suber* in equilibrum within the system, but they become fatal with the weakened condition of the trees previously described. This opportunistic pathogens are the soil oomycete *Phytophthora cinnamomi* Rands (Gallego et al. 1999, Sánchez et al. 2002), the bacteria *Erwinia quercina* Hildebrand and Schroth (Soria et al. 1997), the fungus of leaves and stems *Botryosphaeria stevensii* Shoemaker (Luque et al. 2002) (Figure 1e), the bark fungus *Biscogniauxia mediterranea* (de Not) Kuntze, the root rot fungi *Armillaria mellea (*Vahl. Ex Fr.) Kumm. and *A. tabescens* (Scop.:Fr.), and a newly described *Pythium spiculum* (Romero et al. 2007). Among the boring insects, the larvae of the beetle *Cerambyx welensii* (Küster) cause large galleries within the xylem of *Q. ilex* and *Q. suber*, especially if the trees are already weak. The loss of structural resistance due to the holes results in broken stems and branches and eventually the death of the tree.

Measures of mitigation

There is no simple solution to control the decline, although it is possible to mitigate the damage that it causes and to correct some of the originating causes. The **predisposing factors** are difficult to control, since we cannot do anything about the climate, and the soil conditions are technically difficult to modify. Erosion may be avoided by not performing any land preparation in areas with steep slopes and by reducing the grazing intensity, especially during those years in which due to drought, there is scarcity of pasture. Ploughing and harrowing should be avoided close to the tree, even at the cost of reducing forage production. In areas where there are trees with decline symptoms, cattle and the use of heavy machinery should be avoided since even a slight increase in soil compaction may alter the normal growth of roots (Cubera et al. 2009). In this case, pruning and cork harvesting should be avoided too. In areas where the trees do not show decline symptoms, branches that are more than 10 cm in diameter should never to subjected to pruning and cork harvesting should be done with extreme care, i.e. not injuring the phloem of tree and always disinfecting tools. Regarding the **aggravating factors**, the lack of rain during the vegetative period could only be mitigated by watering the trees, but this measure is not economically or technically justified. The control measures of the insects associated with the decay can be found in Romanyk and Cadahia (2001). Sometimes the **contributing factors** can be controlled through preventive measures or curative chemical treatments. The control of *P. cinnamomi* is complicated due to the high range of hosts, the long period between the establishment of the infection and the manifestation of the symptoms, and the longevity of its chlamydospores on the soil. Previous experiments undertaken with potassium phosphonate injected to the trunks of declined holm oaks did not show any convincing results (Porras et al. 2007). The fertilization of seedlings with phosphite inhibits the attack of *P. cinnamomi* in nurseries (Navarro et al. 2004), but this response is still unknown in the field. The initiation of a breeding program based on the selection of seedlings with certain tolerance to *P. cinnamomi* would be the best solution in the long term. Along this line, some genetic variability of the resistance of *Q. ilex* against this pathogen has been observed (Tapias et al. 2005). With regards to *B. mediterranea*, preventive measures are so far the best control measure (Sánchez et al. 2002). For the control of the rest of the pathogens and for *C. Wellensi,* there are no effective recommendations. Reforestation with seedlings (Figure 1f) and the avoidance of exposure of these new plants to the cited factors is another measure that should be put into practise.

Groups researching decline in the Iberian Peninsula

Presently there are six research groups in Spain and Portugal that are actively working together on the die-back of *Q. ilex* and *Q. suber*. In Spain, the majority of these groups were established between 1999 and 2001 during the development of the FEDER-CICYT project entitled “Causes of decay and die-back of Mediterranean *Quercus* L. forests. Preventive and buffering measures", coordinated by Francisco Vázquez. The team of Escuela Técnica Superior de Ingenieros Agrónomos y de Montes (ETSIAM) of Universidad de Córdoba, headed by Mª Esperanza Sánchez and Antonio Trapero, have developed the project "Decline of *Quercus* in Andalusia: biology and control of associated diseases". This project was performed in collaboration with the project "Climatic impact on decline and characterization of *Biscogniauxia mediterranea*", directed by Rosa Raposo from CIFOR-INIA, Madrid. The Department of Agroforestry Sciences (Universidad de Huelva), through Raúl Tapias, is presently collaborating with Paula Caetano (Universidade do Algarve) and Ana Cristina Moreira (Estação Agronómica Nacional, Oeiras) in the international project "Decline of holm oak and cork oak: an epidemiological study and measures for its control". Among other objectives, the genetic variability of *Q. ilex* against *P. cinnamomi* is evaluated, with the purpose of selecting resistant progenies or land races (Tapias et al. 2005), and identify markers of resistance. Aside from important contributions on the study of the decline syndrome, the team of Juan José Tuset (Instituto Valenciano de Investigaciones Agrarias) evaluates the adaptation of different species of *Quercus* in areas that have experienced decline (Sánchez et al. 2007). Recently, the Forestry Department of Junta de Extremadura, through José Luís del Pozo, finished an inventory of areas with die-back in Extremadura (Del Pozo 2006). Nowadays, the causes of decline in Cáceres and Badajoz provinces are being studied by the Forestry Research Group of the University of Extremadura at Plasencia. Finally, researchers like João Santos Pereira (Instituto Superior de Agronomía, Lisboa), Mari Carmen Rodríguez Molina (Centro de Investigación La Orden-Valdesequera, Badajoz), José Miguel Montoya Oliver (ETSI de Montes de Madrid), Carlos Porras Tejeiro (IFAPA, Sevilla), Gerardo Sánchez Peña (SPCAN, Ministerio de Medio Ambiente, Madrid), Jordi Luque Font (IRTA, Barcelona), Eustaquio Gil Pelegrín (CITA, Zaragoza), Milagros López González (IVIA, Valencia), Carmen Muñoz López (EUITF de Madrid), and Rafael Mª Navarro Cerrillo and Ricardo Fernández Escobar (ETSIAM de la Universidad de Córdoba) have all contributed to the study of decline of *Q. ilex* and *Q. suber*, sometimes in collaboration with the teams mentioned.

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a)

b)

c)

d)

e)

f)

Figure 1. a) Decline of a *Q. ilex* stand in Badajoz (Photo: E. Balbuena), b) Excessive pruning of *Q. suber* contributes to die-back and decline (Photo: UEX student), c) Ploughing may damage the superficial roots and compact the deeper soil layers (Photo: E. Balbuena), d) The excessive stocking rate may compact the soil and due to NH_4 from urine may cause toxicity on the roots (Photo: E. Balbuena), e) Branch of *Q. suber* affected by *Botryosphaeria stevensii* (Photo: A. Solla), f) Reforestation in affected areas as a main measure to solve the problem of decline (Photo: E. Balbuena)

SEXTANTE, a gvSIG–based platform for geospatial analysis

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Introduction

The SEXTANTE project [3] aims to develop a comprehensive set of extensions for gvSIG which add advanced spatial data analysis capabilities to it. All together, more than 200 extensions have been developed so far. SEXTANTE is being developed by the Junta de Extremadura (local government of Extremadura, Spain) to fulfill their needs in terms of geographical analysis. This follows the current line of work in the region, which started with the largely acclaimed "Linex" (a custom Linux distribution) and supports free software through the development of new free tools.

A bit of history

The SEXTANTE project was launched in 2004 with the primary goal of developing a GIS solution specifically designed for the needs of regional

[3] http://www.sextantegis.com

goverment foresters. Though it was originally targeted for forest management professionals, it has proved to be an all–purpose tool suitable for any user in need of strong geospatial analysis capabilities, and these days is developed as such. Additional elements are being developed within the project for forest inventory as well, but will not be covered in this article.

The first version of SEXTANTE was based on the German software SAGA[4], a GIS focused primarily on analysis. The original SAGA set of 120+ analysis modules was broadned by more that 70 new ones, and some modifications were also made to the core of the system. A very close relation existed between the SAGA and the SEXTANTE teams, and both the extensions and the core modification eventually made their way to the SAGA official distribution and are now included in current SAGA releases.

At the time, gvSIG was not yet a fully developed GIS product, and was deemed unsuitable for the goals of the project. However, gvSIG soon underwent an impressive development and quickly became a full–fleged GIS, with many features not found in SAGA, such as connection to Web services. The decision was made to consolidate all previous work and apply all expertise acquired in our work with SAGA in order to turn gvSIG into a powerful geospatial analysis tool. Although overall rich in functions, gvSIG had a lack of analysis functions (except for a small set of geoprocesses for vector layers, including operations like buffering, cut, merge and join, among others), so the results could be beneficial to both parties.

The following steps were taken to develop the current version of SEXTANTE as it is presented in this text:

• Creating a base layer on top of which extensions for geospatial analysis could be easily implemented. That would encapsulate the complexity of the gvSIG extension and plug–in architecture, and make it easier to implement new geoalgorithms, following the ideas of SAGA.

[4] http://www.saga-gis.uni-goettingen.de/html/index.php

• Emigrating all original SAGA extensions and all the ones developed in the previous version of SEXTANTE to gvSIG, using the aforementioned base layer. Some extension not related with analysis, such as input/output, were, however, not implemented, since they already existed in gvSIG. New ones were also added, up to a total of 209, aproximately half of which came from the original SAGA version.

• Including new elements to better exploit the possibilities of the set of analysis extensions. These elements will be reviewed in this article as well.

Let's see a bit more about SEXTANTE's architecture and its philosophy.

The architecture of SEXTANTE

While developing the base layer and the set of foundational classes that comprise it, the main idea was to make the implementation of new algorithms as easy as it is in SAGA, while overcoming its drawbacks. Taking the central ideas of SAGA, the architecture was written from scratch, creating a more flexible framework tightly integrated into gvSIG. This framework is based on a so–called extension/algorithm model, so each new geoanalysis feature has two separate parts: the algorithm that is the formulation of the analysis process, and the extension, which connects the algorithm to gvSIG.

Developers just have to concentrate on the algorithm itself, since extensions act only as a wrapper for the algorithm and almost no code has to be written to create them. Base classes offer most of the needed functionality, including the automatic creation of GUI elements.

Once the algorithm has been implemented and wrapped with an extension, it becomes part of the set of geospatial analysis features of SEXTANTE and, as such, can be used from any of its main elements. These elements give access to a set of functionalities based on all those algorithms and extensions, and they will be described in detail next.

Main elements

Four are the main elements of SEXTANTE:

• The *SEXTANTE toolbox* (Figure 1), which represents the main element of SEXTANTE. Most users will use only this element in a normal session. From its window, extensions can be run as single processes, and also as batch processes, executing the corresponding algorithm on a set of input data files.

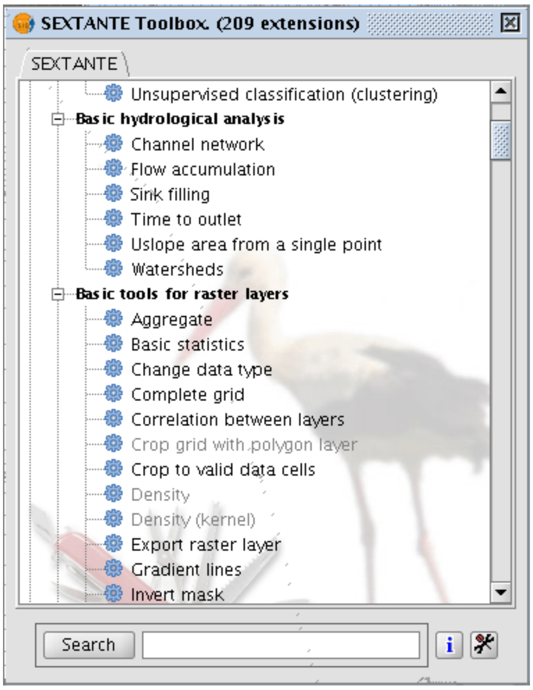

Figure 1. The SEXTANTE toolbox

• The *Graphical Modeller*. Extensions can be used to define a global process than involve several single processes, each of them consisting of a geoalgorithm. Relation between those processes can be defined so the input of one of them can be the output of a previous one, thus setting a workflow. All this is done through a intuitive interface that we will see shortly.

• The *Command Line Interface*. A built-in command line for advanced users, which gives more flexibility and allows for the creation of small scripts.

• The *Command History Manager*. Whenever a SEXTANTE extension is run, a new element is added to the SEXTANTE history. Using this element, the command history can be browsed and certain actions can be repeated, just by double clicking on a single command or selecting a block of them (Figure 2).

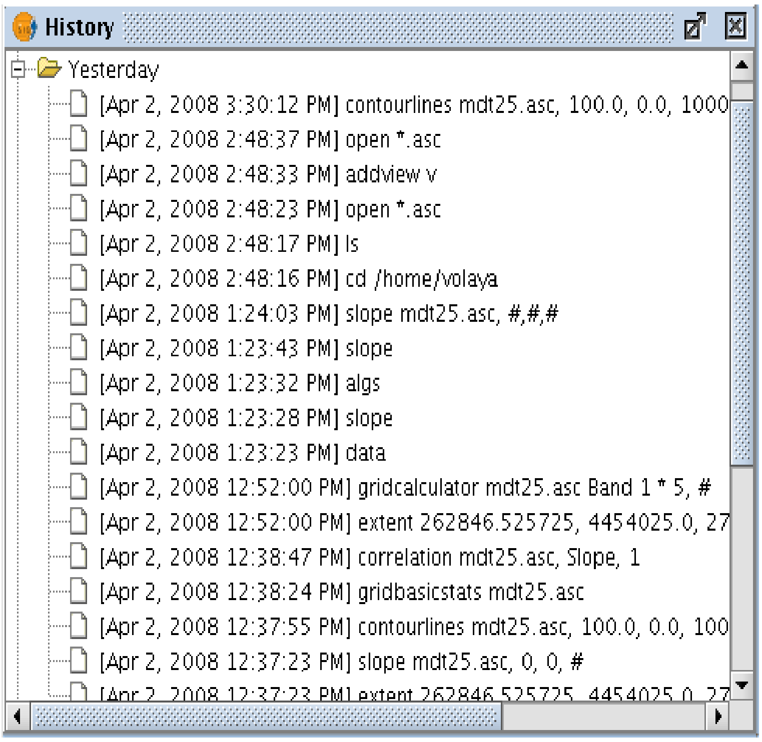

Figure 2. Commands can be re–run using the history manager

A toolbar with four buttons gives access to all these elements (Figure 3).

Figure 3. SEXTANTE toolbar

Executing a single extension

Running a single extension is as easy as double clicking on its name in the SEXTANTE toolbox. A new window will appear, which is automatically generated based on the requirements of the algorithm you are going to execute. However, it is easy to define a different interface if needed, as is shown in figure 4.

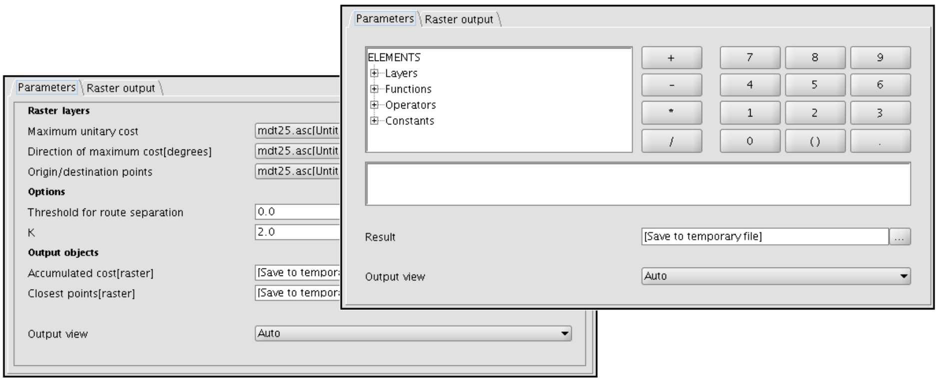

Figure 4. Parameters windows are automatically generated, but can be easily modified to adapt them to a particular extension

A tab named *Parameters* allows the user to select or enter the input data (layers, tables, numerical values, strings...), and also to select the output view if the extension generates new layers (those layers can be added to a new view or to a view other than the one —or ones– from which input layers are taken). New layers are saved by default in a temporary folder, and deleted once gvSIG is shut down. The user can enter a filepath in case he or she wants to store an output layer permanently.

When the extension generates raster layers, a second tab named *Raster output* (Figure 5) is found as well. Using this tab, the user can set the extent and cell size for all raster layers generated by the extension.

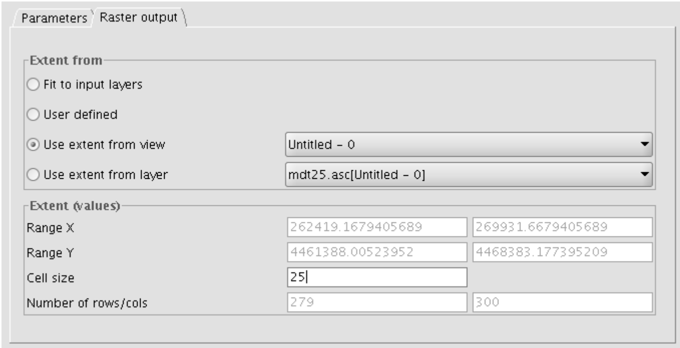

Figure 5. Raster output tab

Most GIS which include raster analysis capabilities need layers to have the same raster output and cellsize in order to combine them. Some GIS, like GRASS, require the user to define an output region. In SEXTANTE, this region is defined each time the extension is executed, and the user can enter the corresponding values manually, select them from an existing layer, select them from the extent of a view, or let SEXTANTE adjust them automatically based on the input layers characteristics. This last method is the one selected by default, so most of the time there is no need to use the raster output tab, since the default behaviour is the same as one could expect from any other GIS (especially if there is a single input layer, since the output layers will have its same characteristics).

With this philosophy, data from different sources can be seamlessly integrated to run a process, and the user does not have to worry about preparing those data beforehand. Moreover, preparation of data involves resampling techniques that most users really do not sufficiently understand, being an error-prone procedure. Since those re-sampling tasks are carried on by SEXTANTE, the developer of each algorithm is responsible for how the resampling methods are used, so he or she can let the user select which of them to use or, as in most cases, can hardcode it to better fit the algorithm.

Context help for each extension is included (only in Spanish at the moment, but an English version is on the way), and can be accessed from the dialogue box. Users can edit these help files to enhance them or add comments, using the built–in authoring tools (Figure 6). These tools guarantee that help files have the right structure and semantics to be used in different contexts within SEXTANTE, such as the command–line interface that we will later see.

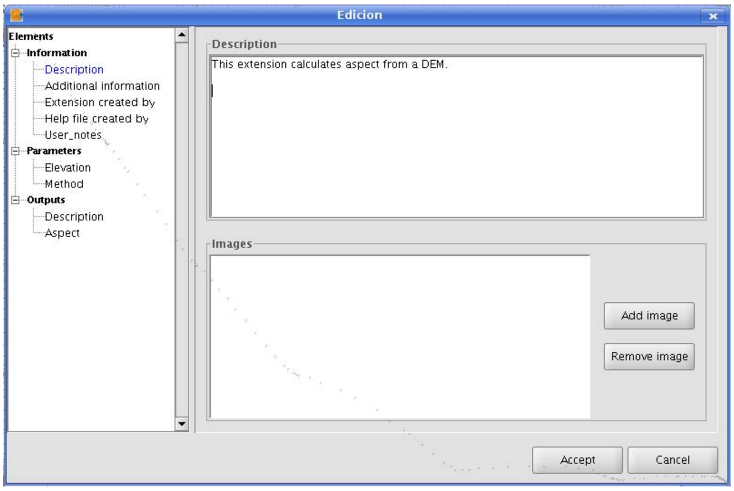

Figure 6. Help files can be edited using the built–in help–authoring tools

Context help can also be accessed directly from the SEXTANTE toolbox, and the whole set of extensions can be filtered using keywords, so as to make it easier to find the right extension in each case. Other funtionalities are available for this purpose, such as configuring tools that allow the user to set his or her own groups of extensions instead of the ones defined by default.

Creating a model

When working with a GIS, it is frequent to perform calculations that involve several steps. For example, the *Topographic Wetness Index* is defined by Beven and Kirkby 1979 as

$$TWI=\ln(a'/\tan\beta) \qquad (1)$$

where a' is the upslope contributing area and β is the slope.

Therefore, calculating this index in a GIS implies calculating a slope layer from a DEM, an upslope contributing area also from a DEM, and then combining both of them. A great improvement in productivity would be obtained if a user could easily and graphically define a single process that included all these steps, and could execute them all at once.

While proprietary GIS contain such tools (e.g. *ModelBuilder* in ESRI ArcGIS or *MacroModeller* in IDRISI) no free GIS has a similar functionality. GRASS commands can be used to create scripts and define compound processes, but most users do not find it user–friendly, and would prefer a graphical interface. Attempts have been made to integrate GRASS with scientific workflow systems such as Kepler (see Zhang et al.), but the complexity of the resulting solution is way beyond the skills of the average (or even advanced) GIS user.

SEXTANTE includes a graphical modeller which is unique in the FOSS4G scene, allowing users to quickly and effectively create a model, just following two steps:

- Defining the inputs needed by the model
- Defining the processes to run. Data for each process is introduced through a window similar to the one shown when executing the corresponding extension as a single process. In this case, however, instead of selecting input data from the current gvSIG projects, they are selected from the model inputs (defined in the previous step) and the outputs generated by other processes, thus defining a global workflow.

Figure 7 shows the main window of the model builder, with an example model. On the right side of the window, two tabs are found: *Inputs* and *Processes*. Double clicking on their elements, these can be added to the model to define its structure.

Models are saved in XML–based files, and can be easily shared between users.

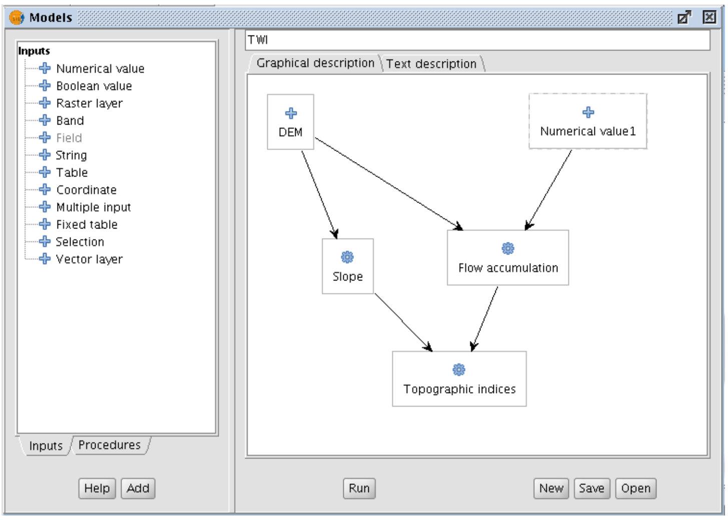

Figure 7. The graphical modeller window, with an example model

Once it has been created, the model is treated just as another SEXTANTE extension, as if it had been developed programming it directly. It can be run straight from the model builder or incorporated into the extension tree of the extension manager (just saving it to a user–defined models folder), and executed from there as a single process or a batch process, as we will see next.

Models can also have their own context help, which can be edited using the help authoring tools of SEXTANTE.

Executing an extension as a batch process

All SEXTANTE extensions (including models) may be executed as batch processes. That is, they can be executed repeatedly on a group of entry parameters without the need of calling the corresponding extension each time through the extension manager.

This can be used, among other things, to execute one operation (for example, the application of a filter) on a group of layers, like, for instance, all the ones in a given folder.

Executing a batch process is not really different from executing a SEXTANTE extension in the usual way. The user just has to set the parameters needed to run the corresponding algorithm, and its inputs and outputs. These tasks are done using a table similar to the one shown in figure 8.

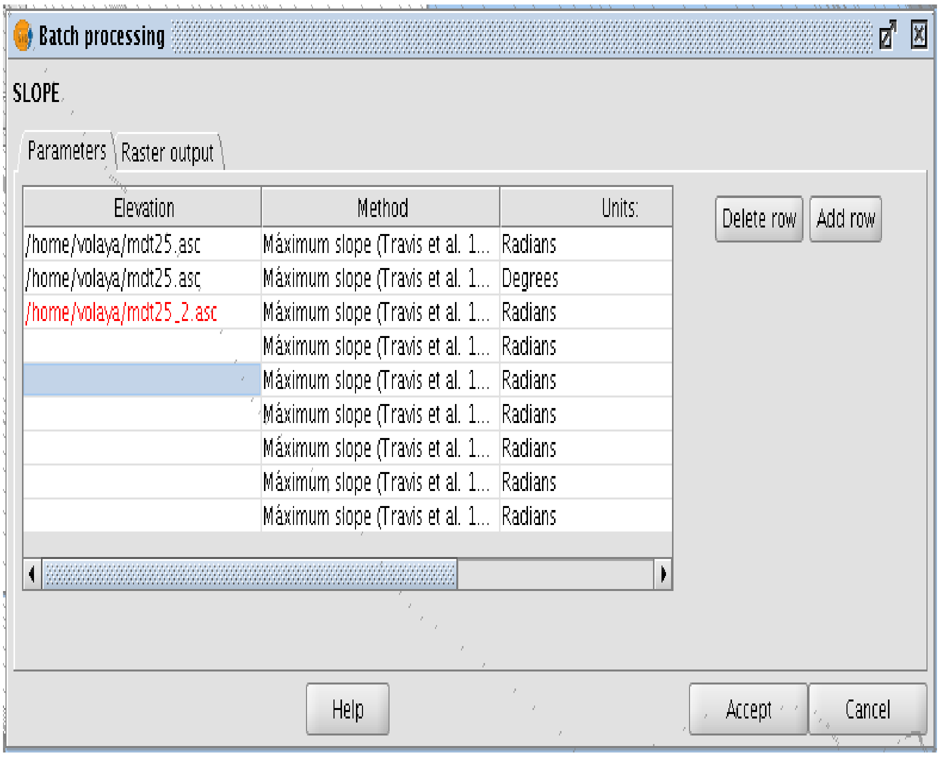

Figure 8. Batch processing window

Each line of the table represents an individual execution of the extension and the cells of this line contain the values of the parameters, in the same way as they would have been introduced in the different fields of the usual parameters panel.

Inputs are not taken from the current project, but directly from data sources (files). Output layers are not added to any view, but just saved in the selected filepath.

In order to make it easier to process large sets of files, several additional functionalities have been added, such as automatic completion of output filepaths using a predefined schema (an enumeration, or the value of an input field) and intelligent copy–paste features.

Using the command–line interface

Although most users will prefer using the graphical interface, the command–line interface provides a powerful way of running SEXTANTE extensions (Figure 9). When a certain task is repeated frequently, it is easier and more productive to use the command–line interface instead of the extension manager.

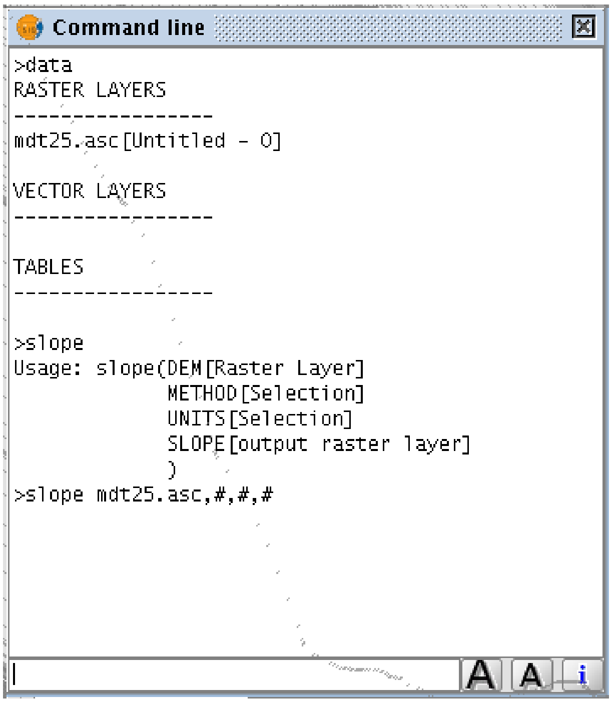

Figure 9. Command–line interface

Apart from running extensions, certain tasks such as opening layers or creating new views can also be performed from the command–line interface, so it is useful even for those users not working with SEXTANTE directly, but with only gvSIG functionalities.

Scripts can be written using any external text editor, and later run from within gvSIG. Those scripts can be used to create models and describe compound processes, but there is not yet a link between scripts and models created using the graphical model builder.

The community

Although SEXTANTE is a small project (three people with just one developer), the community built around it is considerable large, mainly due the increasing popularity of gvSIG and the effort made by the gvSIG team to promote SEXTANTE along with their own software.

Users can suscribe to one of the gvSIG mailing lists (there are lists for users and developers, and an international one as well, English being its main language), in which a large proportion of messages are related to SEXTANTE.

Apart from being a useful tool for anyone using gvSIG who needs advanced analysis capabilities, SEXTANTE is also a very interesting choice for developers. Due to its underlying architecture, especially designed to ease the implementation of geoalgorithms, SEXTANTE is becoming the choice of many developers, especially those who need to implement their analysis ideas into gvSIG.

Developers can access SEXTANTE source code using our main SVN repository, to get a daily updated version. Developers wanting to contribute to the project can use a second repository and contribute their SEXTANTE–based extensions. These will be added to the next stable release, provided that they meet the quality requirements of the project.

Future development

The current version of SEXTANTE v0.49 available from the project website is rather mature and is being used already in several real–life applications. However, there are still many improvements to be made, and the road map includes, among others, the following items:

• Adaptation to the new raster data architecture of gvSIG. gvSIG is currently refactoring its underlying raster data architecture. The current one has proved itself to be useful but somehow limited for analysis purposes, especially in memory management tasks. The SEXTANTE team is working closely with the gvSIG team to design this new architecture, so it will meet all requirements of SEXTANTE tools and will satisfy its users, regardless of their kind of work. The refactored architecture and the correspondingly adapted SEXTANTE version are expected to be ready by mid–2008.

• Adaptation to new gvSIG features: SEXTANTE tools will soon be available to be used from gvSIG elements such as 3D–views, making it easier and more convenient to use.

• Improvement of current SEXTANTE elements: The graphical model builder currently does not support loops or conditions, but will do so in the near future. Intellisense–like features are being implemented in the command–line interface, which will greatly improve user experience.

• WPS–related functionalities: External developers have been adapting some SEXTANTE extensions to offer their functionalities through WPS services. A more general adaptation will probably be developed soon. On the other hand, SEXTANTE will integrate itself with the WPS–client capabilities that are currently being devloped by the gvSIG team. SEXTANTE extensions will be able to wrap WPS processes and these could be incorporated into any of the elements of SEXTANTE such as the graphical model builder or the command–line interface.

Financial support is granted until 2013, by Junta de Extremadura. Generalitat Valenciana (local goverment of Valencia, Spain, and developer of gvSIG), has also been supporting SEXTANTE economically since last year.

More information

For further information, please visit our website at http://www.sextantegis.com.

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Fighting desertification in Mauritania. Remedial techniques for mechanical stabilisation and biological dune fixation

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Introduction

Mauritania is certainly the most arid country in the Sahel, as well as the most vulnerable to desertification. The plant cover has been profoundly damaged during the last decades. In fact, during this period the country has been facing an unprecedented progression of desertification, which results in important problems of overwhelming the socioeconomic infrastructures with sand. This problem continues to worsen due to the high degree of degradation of the various Sahelian-Saharan ecosystems of the country.

Since 1980 the determination of the Mauritanian authorities to provide the country with the necessary means to fight desertification has been reflected in the ratification of a national policy against desertification (PAN-LCD) and a national plan for environment protection (PANE).

Causes of desertification

Climatic hazards and, above all, the pressure exerted by man and his practices on natural resources, are among the causes of desertification.

The consequences of this alarming situation are characterized by:

- The displacement to South of isohyets, which stresses even further the chronic rain deficit of three-fourths of the country's surface;
- The reduction of the water table to its lowest level ever;
- The rupture of natural balances as a result of the modification of ecosystems;
- The destruction of the base of plant and animal production: farmlands, forests, pasturelands…;
- The systematic degradation of regions covered in the past by woody and herbaceous plant communities, and the reduction of their eco-climatic areas;
- The deterioration of different biotopes that constitute the ecological niche and the habitat of different endangered and rare wild animal species;
- The profound changes at the socio-cultural and religious levels of the rural populations, which were previously nomadic (about 70%), leading to an accelerated and anarchic sedentarization along the trunk roads and around the big urban centres and watering-places, resulting in the destruction of all vegetation in these places;
- The consumption of wood for energy purposes, which is now eight times higher than its production through the natural growth of woody plant communities.

The classification adopted by the PAN-LCD and the PANE divides Mauritania into five large ecological areas, which are characterized as follows:

- The Arid area, with Saharan climate, which covers 810,000 km^2 (78% of the country's surface). This area spreads from the extreme North of the country to the 100-mm isohyet, excluding the coastal corridor. It is comprised of the regions of Tiris Zemmour, Adrar and Tagant, and the North of the regions of Hohds, Brakna, and Trarza.

- The Western Sahelian area covers a surface of 75000 km^2 (7% of the country's surface). It spreads between the southern limit of the Saharan region and the northern limit of the Fleuve region. It comprises the Assaba region and a part of the Trarza region. The isohyets in this area are between 200 and 300 mm.
- The Eastern Sahelian area has a surface of 100,000 Km^2 (10% of the country's surface), and spreads from the southern limit of the Arid area to the Mali border. It is comprised almost entirely by the two Hodhs regions. This area represents 50% of the silvopastoral potentiality of the country.
- The Fleuve area, which covers 2% of the country's surface (22,000 km^2), and currently shows an important development of farming activities. On the other hand, the most beautiful stands of *Acacia nilotica*, unfortunately in an advanced stage of degradation, can be found in this area.
- The Coastal façade spreads along a 750 km-long narrow lane (50 km-wide), between Nouadhibou and Gouraye Department (Guidimagha).

Land occupation

In order to understand the problems related to land occupation in Mauritania, we have consulted the following documents: "Analysis of the forestry sector and proposal by Mauritania", drawn up in 1982 by the "Club du Sahel" P.29, and "Balance and diagnosis of the Sahelian farming sector and questions about the future of the Sahel", worked up in 1997 P.4.

As regards to the first document, the data related to land occupation are the following:

- Total surface: 103,070,000 ha
- Land surface: 103,040,000 ha

- Arable lands (including fallow lands): 195,000 ha
- Permanent pasturelands: 39,250,000 ha
- Forests and savannas: 15,134,000 ha
- Others: 48,461,000 ha

As regards to the second document, the data are the following:

- Farming potential: 500,000 ha (i.e. about 0.5%)
- Woody plant communities: 4,787,000 ha (i.e. 4.4%), including 48,000 ha of classified forests
- Herbaceous plant communities: 15,161,000 ha (i.e. 15.1%)

Considering fifteen successive years, the analysis of the documents indicates:

- That the farming potential has increased by 305,000 ha, from 1982 (195,000 ha) to 1997 (500,000 ha)
- That the forest surface has decreased by 10,795,000 ha, from 1982 (151,340,000 ha) to 1997 (4,339,000 ha)
- That the surface occupied by herbaceous plants has decreased by 24,089,000 ha, from 32,950,000 ha in 1982 to 15,161,000 ha in 1997

The consequence of the decrease of surfaces that in the past were characterized by a plant cover adapted to the different ecosystems, has led to a re-stimulation of certain eolian dune formations, which have begun again to move under the effect of the prevailing winds.

In view of the seriousness of this situation, it is imperative to fight the general effects of desertification as well as the specific effects of sand accumulation in order to protect the environment and improve the life conditions of the populations.

With this aim in mind, remedial techniques against sand invasion by means of mechanical stabilisation and biological fixation (reforestation) of dunes have been developed.

Mechanical stabilisation

Types of sand moving in Mauritania

Three major types of sand moving can be distinguished, depending on the eolian model:

Type 1: sand moving through sheet erosion

This is due to the moving of sand particles along the ground in a bare flat soil with no apparent formation of dunes. The result is a more or less thick "Aeolian veil" depending on the nature of the soil and on the size of the deposit. Several millimetric to centimetric ripple marks characterize the surface of this Aeolian veil. This kind of movement can be found in alluvial spreading areas (Batha) on dune cordons in the process of destabilisation.

Type 2: Sand moving by isolated Barchans

The Barchans (crescent shaped dunes) are of variable height, ranging on average from 1 to 5 meter high. They can be either locally formed from an ancient alluvial deposit or modified dune cordon, or come from a distant source. They usually move along a more or less flat, usually bare, rough ground, and the speed of their progress is proportional to their height.

Type 3: sand moving by inter-connected Barchans

These are Barchans joined together in the same alignment, which play the same role as the isolated barchans, but, in this case, the dune model is much more complex and the dunes can be several kilometres long.

Simplification of protection schemes

The aim is to:

- Reduce operation costs as much as possible.

- Facilitate the dissemination of information regarding the results in order to enable the implementation of the techniques at the management level.

Thereby, three protection systems have been proposed depending on the direction of the prevailing winds, which cause the sand deposits, by rising up, either obliquely or perpendicularly, palisades or fences with 30-40% porosity to permit the spreading of sand deposits inside them.

I-pattern system

This is applied when the winds are perpendicular to the infrastructure being protected.

L-pattern system

The perimeter is formed by two rectangles forming a right angle. This pattern is used when the prevailing winds are oblique to the infrastructure being protected.

Inverted L-pattern system

The inversion of the pattern is related to the position of the site with regards to the prevailing winds. It is important to take into account the concept of minimum threshold of protection. The intended goal is two-fold:

- To propose a realistic programme, which is feasible for the local communities, taking into account that the activities are cooperative, making the communities responsible for the management and durability of the benefits;
- To provide protection of the site against sand invasion. The minimal surface of the protection perimeter, which must be 30 m away from the site, is equal to the length of the site multiplied by the width of the protection

structure, set at 100 m, which is enough to arrest the movement of the dunes and to guarantee the protection of the site.

Mechanical stabilisation is the most important, difficult, and expensive stage, mainly because of the lack of materials required to carry out this operation. The obtaining of these materials involves coppicing of the following species: branches of *Prosopis juliflora*, *Balanites aegyptica*, *Leptadenia pyrotechnica*, *Tamarix senegalensis*, *Tamarix aphyla*, *Indigofora oblongifolia,* and *Euphorbia balsamifera*, rachis of palm leaves and of other invasive plants, like *Typha australis*.

The goal is to progressively arrest the dune movement by:

- modifying the dune modelling
- rising up 30-40%-permeable obstacles, capable of favouring the spreading of sand deposits inside them, and near the site to be protected.

The treatments cited below have been selected, taking into account the previous premises and the type of sand moving involved.

Sheet erosion: The wattle pattern is not-intercrossed**,** forming a rectangle as long as the site's length and 100 m wide. The density is 400 linear metres per hectare.

Isolated Barchans: The wattle pattern is intercrossed, forming a grid of 40 x 20 m rectangles, and the density is 850 linear metres per hectare.

Inter-connected Barchans: The wattle pattern is intercrossed, forming a net (meshing: 20 x 20 m) and the density is 1100 linear metres per hectare.

Sheet erosion + isolated Barchans: When both kinds of sand moving coexist in the same area, the wattle pattern is inter-crossed (20 x 40 m rectangles) where there is a Barchan and not inter-crossed in the rest of the perimeter. The density is 800 linear metres per hectare.

Biological fixation

The reconstruction of plant cover (herbaceous and woody plants) is a crucial factor in the regeneration of desertified areas. Tree plantations can efficiently combat the process of sand invasion.

Certain species are able to fertilize the soil, leading to an improvement of farm- and grasslands. Reforestation also constitutes a mid-term source of energy.

Reforestation techniques

Highly simplified reforestation techniques have been developed in order to reduce nursery and plantation costs and to extrapolate and bring these techniques into general use.

Nursery

Seedlings are grown in little polyethylene bags with a few holes in their lower third, in order to:

- Take up less space in the nursery
- Save watering (the higher the number of holes, the more important the water loss)
- Facilitate the transport to the site of plantation

Use of a standard substrate: It is a mixture of compost and sand (3 wheelbarrows of sand to one wheelbarrow of compost). The sand must be directly removed from unmodified dune soil, as that of former dune cordons without any provision of mineral or organic fertilizers. The filling of bags must be made with moistened substrate.

Use of seedlings not older than 3 months old: The younger the seedlings, the more dynamic their creeping roots, and the lower the direct costs of maintenance of the nursery.

Shifting of bags: This is carried out just once during the nursery period, about 7-10 days before planting, when the seedlings have developed dynamic roots and are ready for planting. The repeated shifting of bags in the nursery is labour-intensive and usually causes damages to the seedlings due to inappropriate handling of the bags.

On the other hand, important efforts are being made, as an innovative approach, to use bags made from palm leaves ('dokhliye') for seedling production. This will allow not only using a biodegradable material but also, and most importantly, increasing the income of women cooperatives that produce this kind of material.

Plantation of species adapted to drought and sand invasion

Fast-growing species resistant to drought have been studied. Four of them are local species: *Leptadania pyrotechnica* (Titareck), *Panicum turgidum* (oum rokba), *Aristida pungens* (Sbat) and *Balanites aegyptiaca* (Teichitt), all of them located in the northern region. The other four species are introduced species: *Prosopis juliflora* (Groun Lemhada), *Acacia holocericea* (PM), *Tamarix aphylla* (Tarva) and *Parkinsonia aculeata* (Ser sare), which is used for hedges.

The introduced species are used because of their fast growth on dune soils and their resistance to drought. Of the four introduced species, only two (*Prosopis juliflora* and *Tamarix aphylla*) have been finally selected. *Parkinsonia aculeata* was discarded because of its high water and mineral demand and for its difficulty growing under competitive conditions. These species form hedges used as windbreak.

Plantation

The major goal of this pilot project is to study and develop a set of measures and to establish the ideal conditions for autonomous growth of the plants, avoiding, as much as possible, the delicate problem of watering. Mostly, sandy soils are found in the Saharan and Sahelian regions. Despite their apparent hostility, especially visible during the dry season, sandy soils have the advantage of efficiently absorbing and stocking the water from the weak rainfalls of the rainy season. After nine months of intense dry heat and very high evaporation, the residual humidity in stable soils can be found at a depth of 70 centimeters or more.

Planting is usually carried out from the first rainfalls, after the junction of the surface humidity and the residual humidity. Although this is a restrictive factor, it is essential for reforestation activities under such dry conditions. If the seedlings´ roots find a layer of dry sand, their growth will stop immediately. In order to avoid this risk, several efficient adaptation techniques have been developed to reach the proper degree of humidity in the moment of plantation: the production of large seedlings, the use of the cylinder irrigation method, the planting in depth and the additional watering, using a system allowing us to moisten 25 cm per 10 l of water used. Thus, we can regulate the water provision as a function of the depth of the residual humidity in the soil.

Monitoring

The surveillance constitutes the most important stage, as it protects the plants against grazing and from construction, thereby favouring the soil stability and the development of the grass cover. In order to meet the goals assigned to it, this surveillance must continue for 2-3 years, to establish a sustainable management plan for silvopastoral areas, with the help of well-structured communities and socio-professional organisations.

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Carbon sequestration in the cork oak forests and in their substitution and degradation stages

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Introduction

With the aim of contributing to the knowledge of the ecology of the cork oak forests of Khroumirie (NW Tunisia), this study intends to compare the atmospheric carbon stocking capacity of cork oak forests to that of plant communities that represent their substitution or degradation stages. A thirty seven-year old cork oak forest regenerated from stump sprouts has been compared, under the same ecological conditions, to: two 30-year old stands of *Pinus pinaster* and *P. pinea* respectively, a 16-year old coppice stand of *Eucalyptus camaldulensis*, an ericaceae maquis, and planted grassland. The perturbations of the cork oak forests of Khroumirie caused by the afforestation with conifers and fast-growing hardwoods, the degradation to maquis communities under human pressure or its substitution by planted grasslands could influence the quantity of carbon stocked per unity of surface transformed. If the quantity of carbon stocked by these different substitution and degradation stages is compared to that stocked by cork oak forests, it could give us information about the impact of these transformations on the general climate. This study is in line with other studies, concerning carbon sequestration by growing plant organs, aiming to decrease accumulation of carbon dioxide in the atmosphere and limit its effect on the global warming (Cooper 1983; Jarvis 1989; Ryan 1991; Hoen et al. 1994; Karjalainen et al. 1995; Mortier 1995; Bohm 1997; Cooper 1998; Roulet et al. 1999; Sedjo 2000).

Material and methods

The forest stands studied consist of a 37-year old natural cork oak forest (coppice forest), two 30-year old stands of maritime pine and stone pine, respectively, and a 16-year old coppice stand of *Eucalyptus*. Both Ericaceae maquis and planted grassland represent the degradation or transformation stages of the cork oak forest.

A sample of thirty 400-m^2 plots have been systematically taken from every type of forest stand. The thirty plots settled respectively in the maquis and the grassland are 100 m^2. An exhaustive inventory has been taken in the plots of cork oaks, pines, and *Eucalyptus*. The diameter at breast height was measured in all the trees, and estimations of the number of branches per diameter and class of length were done for every inventoried tree, in order to calculate crown biomass. Two rectangular sub-plots (1 m wide and 10 m long) were established in each 400-m^2 plot, beginning in the centre and following the NE and NW diagonal directions. In the first sub-plot, the biomasses of maquis vegetation were calculated after its total coppicing. In the second sub-plot, only necromass, composed mainly of deadwood that could not be incorporated into the litter, was calculated. The litter biomass was calculated from litter collected in nine square sub-plots (1 m^2) set systematically ”in bouquet”, with a central sub-plot at a distance of 2 m from the other eight sub-plots, set on the eight respective cardinal directions. The growing stock of cork oak plots was calculated by means of a volume table based on a sample of felled trees, and analysed in order to differentiate the wood volume from the cork volume, and to separate the branch volume from the trunk volume. The fresh biomass of leaves and branches was calculated by a table giving the fresh biomass of leaves or needles as well as the wood biomass of branches as a function of their diameters at the level of their insertion point on the main stem. The dry biomass was calculated after determination from a sample from each plot of humidity rate of plant organs. The volume tables concerning pines and *Eucalyptus* are those made for the first forest series of Mekna by the Direction Générale des Forêts (1983).

The calculation of the quantity of carbon fixed by the plant organs is based on the incineration of 1 g of plant material (separated per organ type and plot) into a muffle oven at 550 °C for 5 hours. The weight after incineration represents the mass of the mineral matter that remains after the total oxidation of carbon. The difference of mass between both stages, before and after incineration, corresponds to the quantity of carbon in the material analysed. The average characteristics of the samples studied are shown in Table 1.

Table 1. Average characteristics of the samples. DBH: Diameter at breast height

Plant community	Age (years)	Density (tree ha^{-1})	DBH (cm)	Basal area (m^2 ha^{-1})	Height (m)	Volume (m^3 ha^{-1})	Fresh biomas (t ha^{-1})
Cork oak	37	372	21	12	7	91	n/a
Eucalyptus	16	796	13	11	11	173	n/a
Maritime pine	30	681	18	18	11	74	n/a
Stone pine	30	665	19	19	10	76	n/a
Maquis	30	n/a	n/a	n/a	n/a	n/a	89
Grassland	1	n/a	n/a	n/a	n/a	n/a	26

The relative precision of the estimation of volume of forest stands and of fresh biomass of maquis and grassland is 5.4% for the cork oak forest, 8%

for *Eucalyptus* coppice stand, 10% for pine stands, 17% for fresh biomass of maquis and 19% for fresh biomass of grassland.

Results

The carbon accumulation (85.7 t ha^{-1}) in the different aerial plant organs in the natural cork oak forest at year 37 was higher than that recorded in its degradation and substitution stages (Table 2): 65.8 t ha^{-1} for the stone pine stand, 51.6 t ha^{-1} for the maritime pine stand, 45.8 t ha^{-1} for *Eucalyptus* stand, 29.4 t ha^{-1} for the maquis and 10.3 t ha^{-1} for the grassland. The average annual carbon accumulation in the *Eucalyptus* coppice stand was estimated at 2.8 t $ha^{-1}year^{-1}$, which is higher than that of the cork oak forest (2.3 t ha^{-1} $year^{-1}$) and of the stone pine and maritime pine stands, which were respectively 2.1 t $ha^{-1}year^{-1}$ and 1.7 t $ha^{-1}year^{-1}$.

The carbon percentage in the aerial compartments was 79.1% in the woody organs of *Eucalyptus*, 59.1% in those of cork oak, 50.5% in those of maritime pine and 38.8% in those of stone pine.

The carbon accumulation in the branches represented just 0.2% of the total accumulation in the woody organs in *Eucalyptus*, 0.7% in cork oak and 10% in pines.

The carbon accumulation of the maquis of the tree stands was 39.7% in stone pine stands, 32.9% in the cork oak forest, 29.8% in the maritime pine stand and 15.5% in the *Eucalyptus* coppice stand. In the pure maquis, it represented 97.1% of the total carbon accumulation. The maquis was a significant carbon sink for carbon accumulation in the cork oak forest and its substitution stages, 30 to 39% of total carbon was sequestered in the maquis of cork oak forests and pine stands, and 15% in the maquis of the *Eucalyptus* coppice stand.

The average annual carbon accumulation per hectare in the maquis was estimated at 0.8 t ha^{-1} $year^{-1}$ in the maquis of the stone pine stand, 0.9 t ha^{-1}

$year^{-1}$ in the pure maquis, 0.7 t ha^{-1} $year^{-1}$ in the maquis of the cork oak forest, 0.5 t ha^{-1} $year^{-1}$ in the maquis of the maritime pine and Eucalyptus stands.

The total accumulation of carbon in the woody organs of the tree stratum and of the maquis represented 97.1% in the pure maquis, 94.9% in the *Eucalyptus* stand, 92% in the cork oak forest, 80.3% in the maritime pine stand and 78.5% in the stone pine stand. The carbon sequestration in the foliar organs of the trees, in the litter, and in the necromass represented just 2.9% in the maquis, 5.1% in the *Eucalyptus* coppice stand, 8% in the cork oak forest, 19.7% in the maritime pine stand, and 21.5% in the stone pine stand.

Table 2. Carbon accumulation in the different aerial compartments of a cork oak forest and in its degradation and substitution stages (in t ha^{-1})

	Cork oak	Maritime pine	Stone pine	*Eucalyptus*	Maquis	Grassland
Litter	5.1	9.3	12.7	1.8	0.5	n/a
Necromass	1.3	0.6	1.2	0.5	0.3	n/a
Maquis	28.2	15.4	26.1	7.2	28.5	n/a
Stem	45.3	24.3	22.7	36.2	n/a	n/a
Branches	5.3	1.8	2.8	0.1	n/a	n/a
Leaves	0.3	0.1	0.1	0.01	n/a	10.3
Total ha^{-1}	85.7	51.8	65.8	45.8	29.4	10.3
Total ha^{-1} $year^{-1}$	2.3	1.7	2.1	2.8	0.7	n/a

Discussion and conclusion

The average volume of wood per hectare for each formation type, and their corresponding average annual production, estimated at 2.4 m^3 ha^{-1} $year^{-1}$ for cork oak and pine stands and of 10.8 $m^3ha^{-1}year^{-1}$ for the *Eucalyptus* coppice stand are rather common in the region. The degree of accuracy of these estimations was always over 90%.

Leaf and branch biomasses cited in the literature are higher than those estimated in the present study. The leaf biomass (dry weight) of an 8-year old

Eucalyptus camaldulensis coppice stand in Zerniza (Poupon 1972) was estimated at 2.2 t ha^{-1} (while it was estimated at 0.01 t ha^{-1} in the *Eucalyptus* stand of this study).

In the present study, the branch biomass was estimated as 10% of the total biomass, while it has represented 20-30% of the total biomass in certain Mediterranean forests (Pardén 1957; Alexandrian et al. 1984). The values of litter accumulation were similar to those cited by several authors (Rapp 1967; Poupon 1972; Akrimi 1985).

The aerial biomass of the pure maquis and of the maquis of the stands was similar to most of the estimations for the mediterranean region (Alexandrian et al. 1984).

The conversion rate of dry biomass into carbon 49% for the biomass of dry litter and 55% for the dry biomass of plant organs. Both conversion rates were similar to those cited in the literature concerning this subject (Brown et al. 1986, Hoen et Solberg 1994; Boscolo et al. 1997; Delaney et al. 1997; Ortiz 1997; Ramirez et al. 1997).

The maximum carbon sequestration in the different aerial compartments of the tree and undergrowth strata in the cork oak forests and its degradation and substitution stages was estimated at 85.7 t ha-1 in the natural cork oak forest, 51.8 t ha^{-1} to 65.8 in the conifer stands, 45.8 t ha^{-1} in the *Eucalyptus* coppice stand, 29.4 t ha^{-1} in the maquis and 10.3 t ha^{-1} in the grassland. These values are similar to the average values of sequestration recorded for the temperate forest of North America, Europe, and the previous Soviet Union, and for the forests of China, which were 63, 70, 73 and 81 t ha^{-1} respectively (Sedjo and Sohngen 2000).

The carbon sequestration during the first 37 years of development of the natural cork oak forest was greater than that observed in the pine forests or in the short rotation *Eucalyptus* coppice stand.

The transformation of a cork oak forest into a pine forest causes a decrease in the carbon sink level at a rate of 20-34 t of carbon per hectare during the first 30 years of its cycle. Under the same conditions, the rate of decrease is 40 t per hectare in the case of the transformation into a short rotation *Eucalyptus* coppice stand, 56 t per hectare in the case of the transformation into an ericacean maquis, and 75 t per hectare when the cork oak forest is transformed into grassland. The elimination of the maquis, using different silvicultural treatments, in the natural cork oak forest or in its substitution stages, causes a decrease in the carbon sequestration level, ranging from 15 to 28 t per treated hectare. The transformation of the cork oak forest into a fast-growing conifer stand or into a short rotation *Eucalyptus* coppice stand could be advantageous in terms of carbon balance only if the production of the stands was respectively 2-fold and 5-fold that of the natural cork oak forest. Hence, it is important, when planning silvicultural actions concerning the cork oak forest management, to take into account the carbon balance.

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Management and opportunities of agroforestry systems

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Introduction

Agroforestry systems are sustainable land use systems (Agenda 21; UN 1992) that integrate a wooded and agricultural component (crops or pasture). Agroforestry systems practiced in temperate areas include silvopastoral or agrosilvopastoral systems. In the first case, only silvopastoral practices are integrated whereas in the second case the silvoarables and silvopastoral practices are both integrated. Other agroforestry systems practiced in the temperate zones are mentioned by Mosquera et al. (2007) and are described briefly in Table 1.

Of all the practices mentioned, we will concentrate on silvopastoral systems which are those most commonly used in Europe and in the north of Africa due to the importance of animal production in these regions. However, the rest of the systems also generate economic resources for the land owners (e.g. agroforestry farms).

In general, agroforestry systems were established when rural people settled in areas and cleared the forests to maintain their livestock. This union of livestock with forestlands was widely practiced up until the 18th century when the administrative separation of agriculture and forestry (mainly for wood) led to the prohibition of grazing in forestlands. In the 20th century, the separation across Europe was evident and affected not only the land owners but also those who studied the natural environment such as the agriculturists and foresters. This separation led to major problems in the agricultural sector and to the reduction of a large part of the forestlands in all of Europe, though in the past years this trend has been reversed.

Table 1. Agroforestry methods in temperate areas

Agroforestry Practices	Description
Silvoarable	Widely spaced trees in association with annual or perennial crops
Farm forestry	Forest land used for the production of trees and other minor crops such as medicinal plants, ornamentals, or for food plants (including spices)
Riparian strips	Strips with natural or planted trees, shrubs or grasses between crops/pasture and streams, waterlogged areas and ponds, with the objective of protecting the quality of water
Silvopastoral	Combination of trees and pasture for animal production
Improved fallows	Fast-growing species, preferably leguminoous and woody, planted during the fallow period. The woody species improve soil fertility and may increase economic production
Multipurpose trees	Fruit trees and other trees distributed systematically or randomly planted in cultivated or pasture areas with the objective of providing fruits, firewood, forage, and wood, among other services in the farms or wild areas

The agroforestry systems are traditional and sustainable ways of managing land in which productivity is based on the optimization of resources, and are therefore more in consonance with the environment. In comparison to agriculture and forestry, agroforestry posseses several advantages that will be discussed in detail. This work attempts to show the foundational principles that are the basis for improved ecological, social, and economic productivity that agroforestry systems provide.

Productive Aspects of Silvopastoral Systems

If we are to evaluate the cost and benefits of livestock production systems, we will see that there is an immediate return on the initial investment (livestock, fencing, etc.) and that furthermore, the benefits obtained extend over time. On the contrary, the establishment of forestry systems (plantation, seedlings, land clearing, land preparation, etc.) require a larger initial investment (Fernández-Núñez et al. 2007) that will not produce any return for many years when the first thinning in carried out, if commercial, and of course at the final harvest. In addtion, until this first thinning and before making any income, there are several maintenance activities that should be done such as shrub clearing, pruning and thinning. That is why in a pure forestry system the revenue is obtained at one point in time, at the end of the rotation period. Finally, the initial investment of silvopastoral systems is higher than those of livestock or forest, but is compensated sooner that in the case of forest since production occurs continuously. Moreover, in comparison with pure agriculture, the value of the land increases due to tree production in agroforestry systems. Studies done in Europe quantify this increase in productivity at 15% (Sibbald 1996). Another advantage of agroforestry from the production point of view, is the resilience of the system since its productivity is based on more than one product. If we focus on the silvopastoral systems, the presence of trees, its fruits, as well as its branches contribute to cheaper and better quality pasture for the animals in periods when pasture production is low, giving these systems an important strategic value.

In designing an agroforestry system, the ecological interactions between trees and pasture should be considered. Silvopastoral systems may be established either in an existing cleared area or in reforested agricultural land. This last practice is very important recently as a result of large-scale reforestation of agricultural lands. In the first case, the forest tree species already existed and therefor the improvement of the productivity of the systems should focus on the agriculture component after pruning and thinning. In the case of establishing an agroforestry system by reforestation, special attention should be given to the tree species since this is the component that will remain in the system the longest. Trees should be adapted to the soil and climate of the area and should have some desirable characteristics to avoid competing with the agricultural component such as few and small branches, a deep root system (i.e. not superficial), a self-pruning habit with a good distribution of branches and leaves that allows good penetration of light. Once the tree species are selected its arrangement and density should be considered in such a way that the interception of light is minimized for better crop productivity. Tree cover is a good criterion to establish the plantation density and the regulation of this during the life of the tree stand. Through this, Etienne (2005) realized that the maximum production of understorey happens with a 35% coverage with Q. ilex L., but of 50% with *Q. pubescens* Willd., with *Q. pubescens* always having better production. However in Atlantic zones with pasture under *Pinus radiata* D. Don, Etienne (2005) found that pasture production is reduced when tree cover is larger than 55%.

The tree distribution will also affect the quantity of light that the pasture receives in such a way that with the same density, there will be more light if the trees are planted along the plot boundary than if they are distributed homogenously on the pasture (Mosquera et al. 2005). However, in Mediterranean areas, the homogeneous distribution may be an advantage since it reduces the evapotranspiration, an important parameter in dry areas (Moreno and Pulido 2007).

If we focus on the agricultural component, the productivity of pasture may improve through fertilizer application, although liming is a practice that improves productivity in the case of very acid soils and those with a high percentage of aluminum saturation. However, the method of applying fertilizer to pasturelands should consider the type of fertilizer (organic, inorganic, phosphoric, nitrogen, potassium, etc.) and the timing of its application (especially with nitrogen fertilizer) that produce synergies in the growth of both the pasture and trees. Along these lines studies on sandy soils with little organic matter and with little water retention capacity showed that organic fertilizer improved the development of the pasture and the trees. In contrast, the mineral fertilizer reduced tree growth since it established a strong competition between the trees and the pasture. The result is different if the soil has higher levels of organic matter, which offsets the advantage due to the application of organic fertilizer. The practice of fertilizer application on crops planted under trees may also promote the improvement of the tree production that benefits from the nutrients not consumed by the pasture.

In general from the productive point of view, it should be pointed out that agroforestry systems are more difficult to manage since these are systems where one has to make decisions in relation to various components and also has to pay attention to the possible synergies and antagonisms that the management of one component may generate in the others. For example, it seems clear that pruning not only improves stem form and therefore, the commercial value of the wood, but also that it improves pasture production by increasing the quantity of light it receives. However this effect is not always so clear, as we have seen in the case of fertilizer application where more factors intervene such as soil type.

In general, it is clear that pasture production is reduced under some specific conditions due to the presence of trees (although it only means a reduction in basal area). This means that if we wish to maintain the production of pasture, and therefore, the stocking rate capacity of the system, we should increase to some extent the area used. Nonetheless, the use of silvopastoral systems increases the general productivity by area unit in comparison with the exclusively agricultural or forestry systems. In addition, it provides a series of environmental benefits that should always be kept in mind under the principles of sustainability that should be followed in agricultural production.

Ecological aspects of silvopastoral systems

The presence of trees in an agricultural system provides environmental improvements that come from the better use of soil resources, and at the same time are systems that reduce the risk of fire in areas of high risk while supporting livestock production. Furthermore, these are systems that due to the heterogeneity that the presence of trees produces, help the conservation of biodiversity. And finally, the presence of trees in an agricultural area reduces the soil erosion.

Agroforestry systems and nutrient cycles

Based on the fact that agroforestry systems use nutrients more efficiently through the presence of various plant components, they can greatly contribute to the quality of continental fresh waters while sequestering carbon.

The application of nitrogen fertilizer causes water contamination by nitrates. This is attributed in the first place to the complexity of the nitrogen cycle which makes it difficult to establish a way of optimizing it since it is easily leached (mainly nitrates) and volatilized (amino, NO, N_2O…). Secondly, the application of nitrogen is the simplest way that farmers know to increase production, if there is no necessity of other nutrients (mainly phosphorous and potassium).This makes the application of nitrogen the most widely used management practice. The optimum application of nitrogen depends not only on the quantity but also on the timing. In regard to the quantity, it is well-known that once the quantity of the nutrients applied is increased, the proportion of the nutrients used by the crop is reduced. The nutrients which are not used, in the case of nitrogen, are lost mainly by leaching, polluting ground water and streams. This is called "diffuse pollution" since the pollutant comes from many sources and therefore it is difficult to control. By introducing trees with a deep root system, a natural filter is established that is capable of using this resource, and furthermore enhancing tree growth and inducing a continuous recycling of nutrients (due to the falling of leaves) over time. It is also important to mention that the optimization of the application of nitrogen depends on the timing of the application. If the temperatures are low and rainfall abundant after its application, run-off and leaching is intensified and as a consequence, growth of pasture and crops will be reduced. On the contrary, if the temperatures are high and there is no rain, the loss is produced through volatilization in the case of application of purines or mineral fertilizers in the form of urea. Although climatic conditions are usually predicted and the practice of application of nitrogen is done in the traditional way with a strong attempt to make nutrient available to the plants, the weather variability may spell the difference between greater or lesser loss and damage. The optimization of the use of phosphoric fertilizer as a consequence of having trees and in comparison with areas without trees has been described by Nair et al. (2007).

Agroforestry systems may also be used to sequester carbon (Montagnini and Nair 2004). This advantage, of great importance in the past years because of the contribution of carbon dioxide to climate change, is based on the fact that the higher proportion of carbon in the agricultural systems are found in the soil and that agroforestry systems presents a more extensive and deeper root system (from the trees component) than those of pure agricultural systems.

Agroforestry systems and risks of fire

The risk of fire is due in the first place to weather conditions such as high temperatures and the absence of rain and in the second place to the productive capacity of the vegetation to produce wood fuels. This is why in areas like the Mediterranean zone that have prolonged droughts and high temperatures in summer; the risk of fire is high. The same also occur in sub Mediterranean zones or areas of transition to the atlantic climate, where a lot of plant fuel is generated in spring. Although the dry period is shorter than in the Mediterranean, it is sufficient to produce recurrent fires with yearly intervals that causes a lot of environmental damage, like the loss of biodiversity, release of carbon, and economic losses. With silvopastoral systems, it is possible to make use of the accumulated plant fuel through its use as forage, while at the same time reducing the risk of fire. The objective is different depending on the duration of the dry season. In those areas with a long dry season, the herbaceous plant layer that constitutes the understorey disappears, since the annual species predominate (the perennial types cannot resist the drought) which makes the control of understorey shrubs important up to the point where the risk of fire is at the minimum but the soil is protected. This aspect is especially important on sloping lands. However in areas with shorter dry periods, the achievement of herbaceous cover should be the main objective since there is less risk of fire and less erosion.

Agroforestry systems and biodiversity

The presence of trees in agricultural areas increase the biodiversity due to the different light conditions that it generates within the understorey, favoring the presence of some species over others. In addition, trees may act as corridors for animal and plant species by linking forest areas in deforested zones. The use of these systems in poor or marginal areas promotes the use of local or native livestock species, most of them endangered. Finally the reduction of the fire risk also supports biodiversity conservation.

Agroforestry systems and soil conservation

Soil conservation in agroforestry systems is attributed to the presence of tree cover in comparison to exclusively agricultural system. This aspect is of special relevance in the Mediterranean zone where it is possible to lose up to 200 tons of soil each year. The roots of the trees not only contribute to the generation of organic matter but also helps to bind soil aggregates and anchor the soil.

Social aspects of the agroforestry systems

The advantages to adopting agroforestry systems seems clear, since it allows a more rational use of resources, increases stability (by obtaining various products), while at the same time allows an increase in the area planted with trees and the various accompanying environmental benefits.

Moreover, it allows the continuation of the traditional management systems supported by improved technologies, increasing the value of the land, which can be used by society for recreation. All these promote rural tourism, a source of income for many European farmers, and may help reduce the abandonment of the rural areas which is happening in many areas due to the immigration to the cities and the ageing of the rural population.

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Economic Assessment of Silvopastoral Systems

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Introduction

The economic assessment of forest and agriculture alternatives in a specific social and physical (soils and climate) context, will help us predict the behavior of that alternative once put into practice, and will in turn provide the owner the basis upon which to select the more adequate alternative.

The objective of this work is to present simply, a model to quantify the economic productivity of a silvopastoral system when compared to an exclusively agriculture and forest systems, based on the animal production in the first case and wood production in the second.

It is intended to make a study that will show the land owner which of the following options is more profitable:

1. A forest plantation for wood production
2. Livestock for meat production
3. A silvopastoral system where wood production and
meat production is combined.

To determine the most economically adequate alternative, the Total Economic Value (TEV) should be quantified; this is calculated by adding the productive value, the recreation and the environmental value in each alternative with the objective of making a comparison (figure 1). However, in this work we will focus on the calculation of the productive value since the recreation and the environmental values are not readily available although the ways to estimate them will be mentioned.

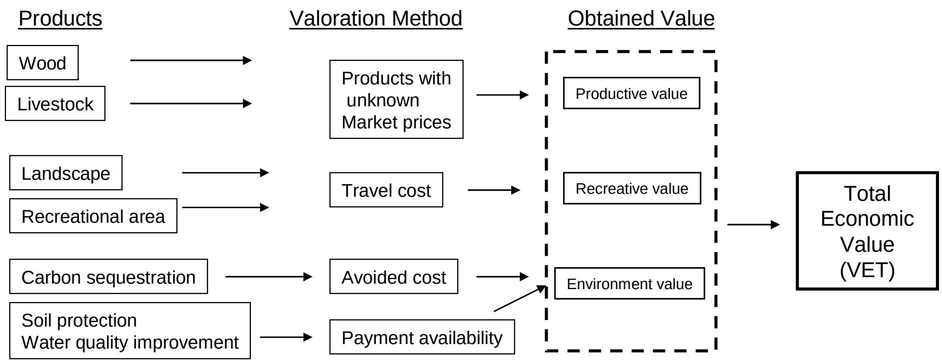

Figure 1. Diagram of the economic assessment of one alternative land use through the identification of the products, the evaluation methods and the value obtained

Determination of Productive Value

We define productive value as the monetary value of those products that have a market price (the wood and the livestock in a silvopastoral system).

In order to conduct the economic analysis of each one of the three proposed alternatives, we should know the operations where we will incur costs and which benefits as well as what operations needed during the tree life cycle.

To be able to help the land owner, we will do the economic balance of each one of the three possible options. The said economic balance will be made up of the determination of the Net Actual Value (NAV) or Net Present Value NPV (NAV-NPV) (equation 1)

~Net Actual Value of investment (NAV): the total of all the updated values from all the expected net cash flows of the said investment, deducted from the value of the initial investment. If one investment alternative has a positive NAV it is profitable. Between two or more investment alternatives, the most beneficial is the one that has a higher NAV. The absence of NAV means that this alternative has the same profitability if the same amount is invested in the market with an interest equivalent to the discount rate used.

~ Useful life of the project (n) the expected duration of the alternative (forest, silvopastoral, or agriculture).

~Initial investment (K): investment that is necessary to start the selected alternative.

~Interest rate or discount rate (r) return index used to discount future flows to its actual value.

~Net cash flow (R_j): total of all the benefits less all the costs incurred during the useful life of the selected investment alternative.

$$VAN = \sum_{j=1}^{i=n} \frac{R_j}{(1+r)^j} - K \qquad \textbf{(Equation 1)}$$

It should be pointed out that at the time of determining the NAV of each one of the proposed alternatives, with the objective that they may be compared to each other, the duration or useful life used is the same for all. This useful life or duration is determined by the cycle of the forest species planted.

The costs and benefits and the operations needed to carry out each system quantifying the initial investment of each alternative are explained below. In each alternative, concepts such as investment, costs, and benefits will be defined (Figure 2).

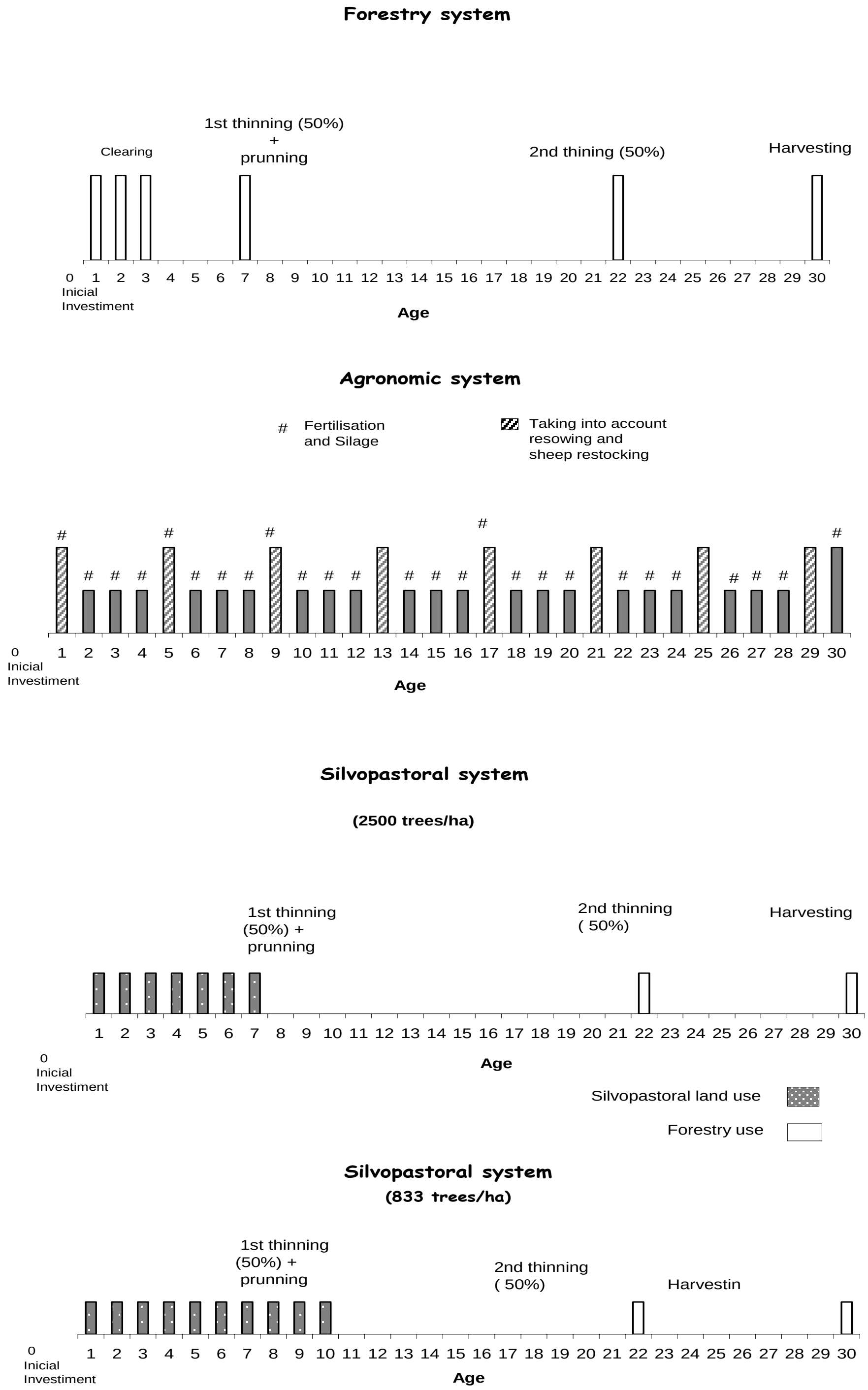

Figure 2. Initial investment, costs and benefits of each of the alternatives is analyzed within an established period (30 years)

Alternative 1: Forest System

Investment

To be able to establish a forest system it is necessary to carry out a series of activities which will result to an initial expense on the part of the land owner. We can group the first set of activities as those needed for land preparation (harrowing, ploughing, clearing shrubs) and the other as the requirements in the establishment of the plantation (buying of plants, cost of labour necessary to carry out the plantation operation.)

Costs

It will be necessary to carry out a series of forest maintenance once the plantation is established that will involve an expense on the part of the land owner. Such activities include the clearing of shrubs, pruning and thinning during the first years. Once the forest has reached the rotation age, harvesting will also incur an expense to the land owner.

Benefits

The benefits obtained from the forest will come from the selling of the wood obtained during thinning (intermediate reduction of density) as well as the final cutting. The benefit obtained in this case will be high or low depending on the final use/destination of the wood (wood particles to make plywood, sawn wood, veneer).

Alternative 2: Livestock System

The livestock system will be based on the raising 35- kilo sheep for meat production. The livestock system selected will be put in a concrete physical context (soils and climate) from which some months will be deducted when the animals are grazing and others when the animals are stabled. The considered costs will be different since when the livestock are stabled they will need to be fed with silage or hay and the cost of either buying or sowing and harvesting should be kept in mind since this cost is not included in pasture. On the other hand, it is also considered with the objective of facilitating the management, a system of grouping deliveries at the end of winter which will allow us to make the period with maximum nutritional needs (lactation period of the sheep) coincide with the maximum and highest quality production of pasture in spring. From the average production data of pasture and taking into account the consumption of the sheep herd, it is possible to make calculations of the stocking rate that the system would be able to support.

Initial investment

With the objective of comparing the different alternatives, we will suppose that all the necessary plots will be established with pasture. For this, land preparation that will cover harrowing and ploughing will be necessary. Once the land is ready, the land owner needs to sow and apply fertilizer. Another activity that will also imply expense is the initial buying of the herd.

Costs

During the entire analysis period, the owner will have to face a series of annual expenses from the livestock production. The said expenses will consist of payment for the shepherd of the herd, health maintenance, fertilization, silage, replacement of sheep that will be done based on the actual annual production of pasture, since all the examples that we will see at the final part of this article are based on real annual pasture production.

Benefits

The benefits of this alternative are obtained from the selling of lambs and sheep.

Alternative 3: Silvopastoral System

This system is a combination of the first two mentioned, for which the same concepts of investment, cost, and plantation density will be integrated. It is important to remember that the tree cover should not be more than 55% since in this case the pasture production would be greatly reduced.

Initial investment

The initial expenses to start a silvopastoral system will be the cost of the combination of the two previous alternatives. On one hand, the costs from the establishment of the tree cover: land preparation (harrowing, ploughing, and clearing of shrubs) planting of the selected tree species (cost of the plant, labor cost necessary to establish the plantation) and on the other side from the livestock: sowing, fertilization, buying of initial stock.

Costs

The annual costs that we should consider within the silvopastoral alternative are costs from the livestock activities, such as the shepherd of the herd, health maintenance cost (veterinary), the cost of fertilisation, the cost of silage, and the cost of buying the herd. Aside from this, due to the presence of a forest area, we should remember that this also implies a series of expenses on the part of the owner such as the thinning, pruning, and the final cutting of trees.

Benefits

The benefits obtained will be from the livestock: selling of the lambs and sheep having in mind that the said activity will be limited once the trees have reached the pole stage on the one hand and from selling of wood from thinning and final harvest on the other hand.

Determination of Recreation Value

Due to the improved benefit of other people as a consequence of the silvopastoral system, the recreation value is now computed as an inherent part of the value of this system as well for forestry systems. To be able to obtain the recreation value of a zone **the cost of travel method** is applied. This will allow us to know how much people are willing to spend to visit the site. This method is based on the price a person is willing to spend to have access to an area which is the total expenses required for the travel (Xunta 2004).

Studies done in Galicia have shown that the recreation value of the forest and silvopastoral alternatives will be 9% of the obtained productive value in these two alternatives. This percentage should be calculated in each study area since this will depend on factors relative to the proportion of the forest area within the territory (the value is higher if it is rare), of the spending capacity of the population, and others.

Determination of the Environmental Value

The concept of environmental value will group the environmental benefits that the forestry systems offer as habitat protection, soil protection, improved water quality, etc. these elements are valued through the **contingent value method** this determines the disposition of the society to pay to guarantee the maintenance of the ecosystem. This valuation is done through interviews. In the case of the alternatives with forest cover, it is important to give value to the carbon sequestration in the atmosphere. For this the **Avoided-induced costs** will be applied, a method that consists of giving value to that sequestration as the cost of avoided reforestation or the cost to produce the sequestration equivalent to that produced by the existing biomass (Xunta 2004).

The environmental value of the forest and silvopastoral system conducted in Galicia corresponds to the 33% of the productive value obtained from the said alternatives and even so will vary based on the specific conditions of each zone.

Given that the recreation and environmental values are values that do not directly affect the economy of the land owner and that they variy in each social context, we will focus our work on securing the productive values of the three alternative land uses (forest, livestock, and silvopastoral) Although we will apply the obtained percentages for the recreation and environmental values in Galicia in a short discussion of the **TEV** (Total Economic Value) obtained from the three proposed alternatives.

Case Study: Galicia

The area where we are going to evaluate the three alternatives is situated in Galicia (NW Spain) and is characterized by an annual precipitation of 1350mm with an average temperature of 12 ºC. The climatic conditions of the zone limit the growth of the pasture both in summer because of drought and in winter because of low temperatures. As a result, the sheep may graze approximately 7 months in a year and the rest (of the year) they must be kept in stables and fed with silage complimented with fodder (Figure 3).

In the case of the livestock and silvopastoral alternative it was necessary to estimate the stocking rate in pasture (SR_p) for each year. For this, and from the determined nutritional needs of the sheep herd during the grazing period and during the period when they are kept in the stables and on the other side from dried materials obtained from the zone the stocking rate is determined in the first place through equation 2

$$SR_p = Prod/ C \qquad \text{(equation 2)}$$

where: SR_p: Stocking rate in pasture, Prod: Annual production of dried materials (kg DM ha^{-1}).

This value was obtained from a silvopastoral system in Galicia, and has considered the decrease of the pasture production. C: Consumption of livestock quantified at 1.74 kg DM $sheep^{-1}$ day^{-1} (Zea-Salgueiro 1991)

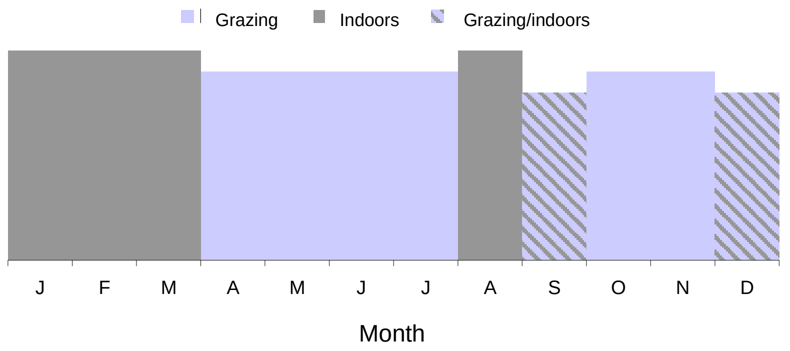

Figure 3. Annual management system selected for the sheep herd

Once the stocking rate is determined it is necessary to consider the period when the animals are kept in the stables (150 days per year) and as a consequence we should forecast the annual need for silage. These needs are obtained by applying the equation 3, where it is considered that at an average rate one sheep consumes 0.75 kg DM of silage day^{-1} (Zea-Salgueiro 1991) and the number of sheep is determined by calculating the stocking rate (equation 2).

$$N_{silo} = 0{,}75 * SR_p * 150 \qquad \text{(equation 3)}$$

where: N_{silo} = needs of silage per year (kg DM silage $year^{-1}$)

0,75 = average consumption of silage per day per sheep (kg DM silage day^{-1} $sheep^{-1}$)

SR_p = stocking rate in pasture

150 = days that the animals are kept in the stables per year

Once the annual need for silage is determined, the next step is the calculation of the area for silage that should be available (equation 4). Studies done before show that 1 ha of land produce 7,096 t DM silage year^{-1} (Mosquera-Losada et al. 2004).

$$S_{silage} = (N_{silage}) / (P_{silage}\ ha^{-1}) \qquad \text{(equation 4)}$$

where: S_{silage} = surface area of silage (ha)

N_{silo} = needs of silage (t DM silage)

P_{silo} = Production of silage (7096 t DM silage year^{-1})

Finally we will determine the annual stocking rate (SR_a) of the system through the equation 5:

$$SR_a\ (\text{sheep ha}^{-1}) = SR_p/(1\ \text{ha} + S_{silo}) \qquad \text{(equation 5)}$$

where: SR_a = annual stocking rate of the system (sheep ha^{-1})

SR_p = stocking rate in pasture (sheep ha^{-1})

S_{silo} = area of silage (ha)

Remember that the stocking rate should be determined for each year of livestock use where in the case of the livestock alternative will be 30 years and in the case of the silvopastoral alternative will depend on the period when the trees reach the pole stage (100% ground cover). In our case with a plantation density of 2500 trees per ha, 100% ground cover is reached at the age of 7 years, whereas if density is 833 trees per ha or less, a 100% ground cover will be reached at 10 years of age. The scheme of corresponding yearly cost and benefit may be seen in the Figure 2.

Once these calculations are done, the productive value of each alternative is established using the equation 1. The results obtained (Fernández-Núñez et al. 2007) reflect that in the first place from an economic point of view all the proposed alternatives are profitable for the land owner, but that the established silvopastoral system with low density of plantation (NAV = 9020) results in the highest benefit followed by the exclusive livestock alternative (Table 1). The results showed that in establishing a silvopastoral system, the density of the plantation is very important since we saw that an increase in the said density lowers the economic benefits obtained. This lowering of economic benefit on one hand may be attributed to the fact that the landowner was obligated to spend more to implement this alternative, and on the other hand since the livestock production of this type is reduced over time due to the development of tree mass, while in the case of establishing a silvopastoral system with a lower tree density, the livestock production is extended and thus the benefits obtained from the said activity are also extended.

Table 1. Total economic value (€ ha^{-1}) of the studied silvopastoral system alternatives

	Alternative			
	Forest	Livestock	Silvopastoral	
€ ha^{-1}			(2500 pies ha^{-1})	(833 pies ha^{-1})
Productive Value	5900	7731	6804	9020
Productive Value	915	-	1056	1400
Environmental Value	3357	-	3871	5132
VET	10172	7731	11731	15552

Keeping in mind the general evaluation of the different proposed alternatives, we can see that livestock production is the least profitable for the land owner and for society in general, since it also has less environmental and recreation values.

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Silvopastoral systems and biodiversity

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Introduction

Forest lands include forest and tree stands, bird communities, shrubs, natural meadows, and other pasturelands that in Spain are grouped under the generic name of forestland. For centuries, these lands have been pastured and browsed by different animal species and regularly renewed by forest fires, which can be prescribed or accidental. As a result of these fires new and existing plants may re-sprout in a changed environment.

The increase in the organic biomass due to the abandonment of traditional use of forest resources (firewood, pasture, fertilizer, wood etc.) has caused an increase in the risk and number of forest fires which are now one of the main environmental problems in the northeast of the Iberian Peninsula. Abandonment of traditional forest use is the result of many factors such as immigration of people from the countryside to the city and to other countries, the use of modern machinery, new farming systems, use of mineral fertilizers, reforestation activities, the low price of wood, and the increase in livestock and milk production, replacing the native breeds of animals by others that have higher nutritional requirements (Rigueiro 1985; Sineiro et al. 1985).

As an agroforestry system, the Silvopastoral Systems (SPS) have an important role in the conservation of biological diversity within the deforested and fragmented habitats, providing resources for animal and plant species (Beer et al. 2003). The SPS do not have the same biological diversity as the natural ecosystems and as such they cannot be considered an alternative. They are instead an improved system of use of degraded environments, since the addition of trees may protect the diversity itself as well as the adjacent forests, and at the same time provide other benefits necessary for the appropriate functioning of the ecosystems (Bichier 2006).

Aside from this, the existence of trees may be considered as corridors between tree stands. Many authors have shown the benefits of agroforestry systems in relation to biodiversity (Nair 1994; Harvey et al. 2003; Bichier 2006) and others such as the prevention of fires (Rigueiro 1985).The diversity in the SPS is both at the level of the system´s components as well as the products and services obtained (Nair 1994; Silva-Pando and Rozados Lorenzo 2002).

Silvopastoral Systems en Galicia

Based on the dominant tree species and the topographic conditions in Galicia (not in Spain) different types of SPS exist. The dominant trees are eucalyptus (mainly *Eucalyptus globulus*), pines (*Pinus pinaster, P. radiata, P. sylvestris*), oaks (*Quercus robur, Q. pyrenaica*), chestnuts (*Castanea sativa* and hybrids) and others (*Betula celtiberica, Alnus glutinosa*). In the case of the Eucalyptus and pines, they have been established as a result of reforestation activities conducted in shrubs areas with an average diversity of shrub and herbaceous species, in some cases endemic in Galicia or in the Iberian Peninsula (Silva-Pando et al. 2002).

Table 1. Browsing preferences of different animals used in Galician silvopastoral systems (Silva-Pando et al. 2002) Acg Annual current growth, 1 = well eaten, 5 = not eaten * fern rhizome

	Rubus	*Ulex*	Erica buds	High	Cytisus	Quercus robur	Castanea sativa	Fern	Eucalyptu s	Pinus
Sheep	5	3 (*cca*)	5	5	5	5	5	5	5	5
Goat	1	2 (*cca*)	2	4	2	1	1	4	5	1
Cattle	5	5	2	3	4	5	5	2	2	2
Horse	3	1	2	5	2	3	3	5	5	5
Pig								1*		

Most animal species graze in a discriminatory way (Table 1), which results in the dominance of some species over others. This, together with the effects of selviculture, result in a change in the composition of the understorey with the reduction of biomass of gramineous (*Agrostis, Brachypodium, Dactylys, Pseudarrhenatherum*), and some woody shrubs (*Rubus, Vaccinium, Hedera, Ulex, Erica*), whereas for some species there is an increase in biomass as in the case of *Erica arborea* (González Hernández and Silva-Pando 1996; Silva-Pando et al. 2002).

Table 2. Evolution of the plant composition under *Pinus pinaster* in Marco da Curra, 3 years after clearing the pre existing shrubs (Silva-Pando et al. 1998)

Species	**1984**	**1985**	**1986**	**1987**	**1988**	**1991**
Agrostis capillaris	4.4	5.5	4.4	4.5	4.5	4.4
Erica mackaiana	+	1.1	1.1		r	+
Potentilla erecta	1.1	2.1	1.2	+	+	+
Rubus sp.		1.1	r	+	+	1.2
Agrostis curtisii			r	+		1.2
Pteridium aquilinum		2.2	1.1	+	+	+
Daboecia cantabrica	+	1.1	+			
Galium saxatile		+	1.1		r	
Hypochaeris radicata				+	1.1	+
Avenula sulcata			1.1			1.1

Biological Diversity

Grazing causes a change in the plant composition of the pasture. A trial plot was established in Marco da Curra (A Coruña) in 1981; the experiment was established in a reforestation with pines (*Pinus pinaster, P. sylvestris*) with a high and dense understorey of *Ulex europaeus*, and other shrubs (*Erica* sp., *Ulex galli, Calluna vulgaris*) and some *herbaceous* (*Pseudarrhenatherum longifolium, Agrostis curtisii*). After a shrub clearing, livestock was introduced (goats and sheep). In 1992 a mix of *Dactylis* sp. and *Trifolium* sp (white clover) was sown. Table 2 shows the evolution of plant composition of the native vegetation under *Pinus pinaster*. A modification of the initial vegetation may be observed with an increase of herbaceous plants with higher nutritional value. In the sown areas (Figure 1, 2), the increase in the number of species and the biodiversity index of Shannon-Weaver (S), established a certain correlation between the inventories with more specific richness and those that represent a higher Simpson's Equity Index (S), although a direct relation is not always observed (Gonzalez- Hernández et al. 2006).

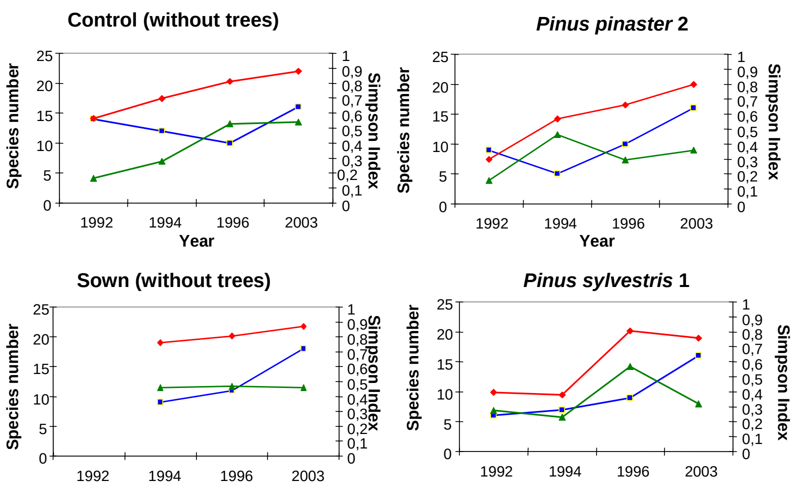

Figure 1. Evolution of the number of species ■, diversity (♦Index Shannon-Weaver) and richness (▲Simpson's Index) in sown pasture, without overstorey plants or under different overstorey plants in Marco da Curra (González-Hernández et al. 2006)

It was also observed that the modification in the plant composition is by family (González Hernández et al. 2006). In any case, the number of species is fewer and its plants composition is different than that in native forests of oak (*Quercus robur*), though higher than in ungrazed reforestation or sown pasturelands. The inventories of 2003, six years after grazing has been discontinued, show recovering flora, incorporating new species (Figure 1,2).

Studies of other biological groups have demonstrated that trees have an important role in the conservation of wild animals in terms of provision of food, refuge, and shelter (Naranjo 2003). This author shows that the SPS in Columbia contain a significantly higher number of bird species than the pasture lands with low tree and shrub cover. Other examples show higher diversity of biological groups in the SPS as compared to lands used for monoculture. In one comparison between the forest and different pasture lands (Munroe et al. 2003), the benefits of having trees are observed when compared to degraded pasture lands without trees (Table 3) as well as a higher preference of birds for landscapes with trees.

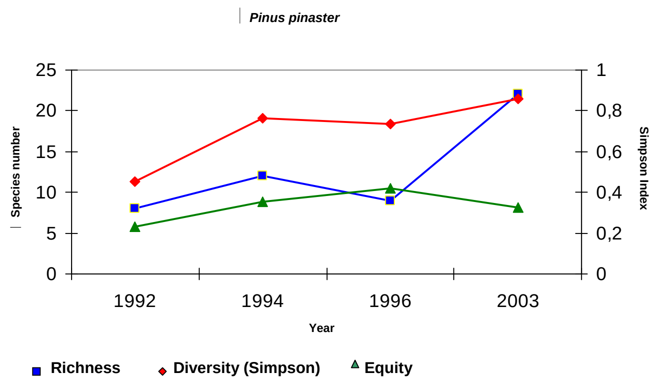

Figure 2. Evolution of the number of species and (Shannon-Weaver) diversity index and (Simpson) equity in sown pasture under open *Pinus pinaster* forest in Marco da Curra (González-Hernández et al. 2006)

Harvey et al. showed that although the SPS has less importance in biodiversity conservation as compared to forests, it still has a significant role to play by maintaining the linkage between different ecosystems that made up this landscape. Another similar study of Pérez et al. (2006) applied to various biological groups (structure of the forest, trees, birds and mollusks) has also shown that the existence of tree cover and livestock around may have a positive effect on biodiversity conservation (Harvey et al. 2003; Naranjo 2003).

Table 3. Total number of families, species and individuals of identified birds in each habitat with its Shannon-Weaver (H') diversity index and equity (E) in the Central Pacific region of Costa Rica (Munroe et al. 2003)

Treatments	Nº families	Nº species	Nº individuals	Diversity H´	Equity €
Secondary forest	27	59	383	3.72	0.91
Pasture land with trees	23	43	410	3.29	0.88
Hedgerows	19	37	217	3.21	0.89
Degraded pasture lands	17	30	146	2.97	0.87

Within biological diversity we would include the structural diversity, i.e. as a function of the arrangement of trees within the plots (Nair 1994).

Diversity of products and services

Agroforestry systems, including the SPS, provide diverse products and services. Table 4 shows the main products that may be obtained from Iberian trees. The adequate combination of these trees and animals allow multiple productions (Nair 1994; Silva-Pando 2006), and allows the increase and diversification of income as well as the creation of habitat for diverse species of plants and animals, increasing the general diversity of these systems. They also provide shade and shelter for animals, reduce the total biomass that may act as fuel, serve as windbreaks, and provide wood for fencing and construction, firewood, and others.

The recovery of pastured or degraded lands through SPS with tree plantation may bring environmental benefits and make these systems sustainable (Naranjo 2003).

The adequate combination of trees with agricultural crops allows the diversification of income and tends to assure the revenue and the regularization of the same. As an example, with wood production in a plantation, the acquisition of revenue is mainly at the end of the rotation period, while in a SPS the revenue may be produced during the entire cycle, from forage and meat, as well as other products (small fruits, mushrooms, medicinal and aromatic plants, resins, and firewood) in addition to the final product which is wood.

Conclusions

Agroforestry systems present lower plant diversity than the natural forest ecosystems but may form corridors between tree stands and forests.

The Galician SPS show an important variety of animal and plant species that contributes to the diversity of systems, products, and services obtained.

Table 4. Agroforestry Characteristics of Iberian trees. Y = Yes; N = No. Climate: A = Atlantic; S = sub Mediterranean; M = Mediterranean. Precipitation: a = <600 mm; b = 600-1000 mm; c = 1000-1500 mm; d = > 1500 mm. Saw wood: N = inadequate; S = low quality; SS = average quality; SSS = high quality. Fruits: SH = human consumption; SA = animal consumption (Silva 2006)

Species	Climate	Rainfall	Saw wood	Use	chips	Resine	Fruits	Grains	Honey	Medical	Buds	Pasture	Ornamental	Tannins
Abies alba	S	b,c	SSS				N						Y	
Acacia dealbata	A	c	N				N	Y					Y	
Acacia melanoxylon	A	b,c,d	S				N	Y						Y
Alnus glutinosa	A	c,d	S		Y		N			Y	Y	Y		Y
Arbutus unedo	S	b,c	N				SH			Y	Y		Y	Y
Betula celtiberica	A	c,d	S	Y			N			Y		Y		Y
Castanea sativa	S	b,c	SS				SH		Y			Y		Y
Cedrus atlantica	M	b,c	SS				N						Y	
Corylus avellana	A	c,d	N				SH			Y		Y	Y	
E. camaldulensis	M	b	S	Y					Y	Y				
Eucalyptus globulus	A	c,d	S	Y					Y	Y				
Fagus sylvatica	A	c,d	SSS				SA					Y	Y	
Fraxinus angustifolia	M	b	S		Y					Y	Y	Y		
Fraxinus excelsior	A	c,d	SS		Y					Y	Y	Y	Y	
Ilex aquifolium	A	c,d	N				SA			Y			Y	
Juglans nigra	S	b,c	SSS				SH							Y
Juglans regia	S	b,c	SSS				SH							Y
Juniperus communis	M	b	SS		Y		SH	Y		Y	Y		Y	
Laurus nobilis	S	c	N							Y			Y	
Olea europaea	M	a,b	N				SH	Y					Y	
Pinus halepensis	M	a,b	N			Y								
Pinus nigra	M	b	S											
Pinus pinaster	A	c,d	S	Y	Y	Y				Y		Y		
Pinus pinea	M	b	S		Y		SH						Y	
Pinus radiata	A	c,d	S	Y								Y		
Pinus sylvestris	M	c	SS		Y							Y		
Populus alba	M	b,c	S	Y								Y	Y	
Populus nigra	M	b,c	S	Y								Y	Y	
Prunus avium	S	c	SSS				SH		Y	Y		Y		
Quercus ilex	M	a,b	S		Y		SA							Y
Quercus petraea	A	d	SS				SA					Y		
Quercus pyrenaica	S	c	S		Y		SH							Y
Quercus robur	A	d	SS		Y		SA					Y		Y
Quercus rotundifolia	M	b	S		Y		SH							Y
Quercus suber	S	b,c	S				SA							Y
Robinia pseudacacia	A	c,d	S		Y			Y	Y		Y	Y	Y	
Taxus baccata	A	c,d	S				S			Y			Y	

Grazing usually results in the decrease of the biomass and fuel and an increase of the herbaceous plants. The diversity may decrease at the beginning of grazing but this is maintained and may even be recovered once the grazing has been stopped or reduced.

The practice of SPS may contribute to sustainable development and biodiversity conservation in the rural environment. In the case of Galicia, interest in SPS is reflected in the increase of areas devoted to this land use. They are presented as a sustainable alternative to land use that may contribute to sustaining the rural population.

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Qualitative study of the reproduction cork in the cork oak forests of Ain Draham

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Introduction

The Tunisian cork oak forests represent only 3% of the total cork oak forest surface and produce only 2.6% of the total cork production in the Mediterranean region. The most important cork-producing areas in Tunisia are located in Jendouba governorate, with 85% of the total Tunisian production and 79% of the total Tunisian productive surface. Ain Draham cork oak forests yield 2714 t per year, or 45% of the total cork production, corresponding to 33.5 % of the total Tunisian productive surface. Eighty-five percent of the cork produced in Ain Draham is reproduction cork, 5.1% is virgin cork, and 9.1% corresponds to discards and wastes (Régie d'Exploitation Forestière 2001, 2002, 2003, and 2004).

The corkwood quality is decisive in determining the suitability of the product for cork-stopper making and product promotion in view of the fact that the yields and, particularly, the quality profile of cork stoppers depend above all on the quality of the corkwood plank used. The corkwood planks are commercially classified into 6 quality classes, determined by visual inspection. The cork quality is mainly established according to the porosity due to the presence of lenticels which cross the corkwood plank radially, from phellogen to the outside (Pereira et al. 1996). Some defects, as ant galleries or woody inclusions cause a strong depreciation of cork (González-Adrados and Pereira 1996). The knowledge of cork thickness and quality is therefore important for the producer as both factors are the decisive ones for the product promotion. The parameters involved in cork quality classification of Ain Draham cork are analysed in this work.

Material and methods

The sampling that was the base for this study was done in 2006, in three cork oak parks. This includes the 2004 production of Chihia, Oued Zeen, and Ain Draham forests. These forests yield on average, 2400 t of cork annually. The sampled parks have been coded from 1 to 6, and are located in Chihia I (1), Ain Draham IV (2), Chihia II (3), Oued Zeen II(4), Ain Draham III (5), and Ain Draham I (6).

The sampling was done systematically in every park after having measured the total length of the cork piles and divided this length by 30, to obtain 10 x 10 cm samples at regular intervals. The samples of reproduction cork taken from every park were treated with boiling water for one hour, following the industrial protocol for cork preparation, and introduced into an air oven at 30°C for 24 hours, to eliminate the water absorbed during the boiling operation. After drying, cork planks have on average 7% moisture content. The total thickness of every cork plank was measured and the planks were assigned by visual assessment to one of the six qualities of the commercial classification. For every dry sample, the density (kg m^3) and the productivity per unit of decorticated surface (estimated as the weight of cork produced per unit of cork-generating surface –kg m^{-2}) were calculated;

growth and porosity were studied by analysing transversal and longitudinal sections of 10 cm-long 1 cm-wide planks removed from the centre of the samples. The surfaces were prepared for the observation by sandpapering and compressed-air cleaning. Numbers corresponding to the years of growth were written in the middle of every transversal section with a fine ballpoint pen and the years of growth were measured using graph paper on a scanned image of known scale. Only the years of complete growth were measured, thus excluding the previous debarking year and the harvest year (i.e. ten complete years were measured in total). These measurements allowed the determination of the number of years per production cycle, considered as the number of years of complete growth plus two half-years corresponding to the debarking years.

Porosity was measured through direct observation of lenticels on a scanned image of the plank back. The pores are darker than the cork mass and can be easily delineated. The following parameters were determined for each sample: porosity coefficient (percentage of the total pore surface in the total cork surface), average pore surface (mm^2), measured with graph paper on a scanned image, number of pores, and average pore surface, arranged according to surface classes (less than 1 mm^2, 1-2 mm^2, and 2 mm^2), representing small-, medium- and large-surfaced pores respectively, from 10 cm^2 of the centre of the plank. Calculations of means, analyses of variance, and mean comparisons were done with “Statistica, version 5.0” software. The one-way analysis of variance was done for every variable studied, to study the effect “park”. The mean comparisons were done using Newman-Keuls test (95% confidence level).

Results

General characteristics of reproduction cork in the cork oak forests of Ain Draham

The average thickness of planks after 12 years was 28.9 mm; the average thickness of the annual cork ring was 2.4 mm (Table 1). This thickness easily allows, at the end of a twelve-year rotation, the achievement of the minimum dimension (27 mm) needed to make cork stoppers.

The sample distribution, according to thickness classes (Table 2), shows that 45.6% planks were less than 27 mm-thick and could not be used for making cork stoppers, thus been diverted to the production of cork disks. On the other hand, 8.1% planks exceeded the optimal dimension (40 mm) for cork making (Pereira et al. 1994).

Table 1. Average values of different characteristics of reproduction cork in the six parks studied

Thickness class (mm)	Thicknes s (mm)	Annua l ring (mm)	Density (kg m^{-3})	Production (kg m^{-2})	Porosity (%).	Frequency (%)
9 to 22	19.7	1.60	286.1	5.6	8.6	15.2
22-27	24.6	2.02	263.8	6.4	9.1	32.6
27-32	29.6	2.50	251.0	7.4	8.6	26.8
32-40	34.8	2.91	235.5	8.1	10.0	20.2
40-45	43.1	3.59	226.8	9.69	10.0	5.0
45-54	50.0	4.13	220.06	11.05	9.1	2.1
Average	28.9	2.40	254.8	7.25	9.1	100.00

The average production per square meter of cork-generating surface was 7.2 kg m^{-2} (Table 1); the highest production (11.0 kg m^{-2}) characterized the thickest cork, and the lowest one (5.6 kg m^{-2}), the thinnest cork.

The average cork density was 254.8 kg m^{-3}. The highest density (286.1 kg m^{-3}) characterized the thinnest cork, and the lowest one (220.0 kg m^{-3}), the thickest cork.

The average porosity coefficient for the whole forest of Ain Draham was 9.13% (Table 1); the highest coefficient (10.0%) characterized the 32 to 40 mm-thick cork, and the lowest one (8.6%), the 9 to 22 mm-thick cork.

Average thickness of planks and of annual cork rings

The comparison of the average plank thickness of the different parks (Table 2) shows that park 6 differed significantly from the other parks, with an average thickness of 34.7 mm. The other parks did not differ significantly from each other. As regards to the average annual cork ring thickness (Table 2), park 6 was again the only one that differed significantly from the rest, yielding the highest values.

Productivity and commercial quality classification per unit of cork-generating surface

According to the commercial quality classification, 25.7% production was of good quality and 73% of medium quality. Parks 1 and 2 produced the best quality cork (39% of production was within qualities 2 and 3), as opposed to park 6 (more than 56% of production was within qualities 5 and 6).

The average productivity of cork-generating surfaces was 7.2 kg m^{-2}, similar to the productivity reported in other studies (Pereira et al. 1987). When comparing the productivity of the parks studied (Table 2), the only significant difference was between park 6, which produced 8.1 kg m^{-2}, and park 2, with the lowest productivity (6.3 kg m^{-2}). The former produced thick-cork planks and the latter, thin-cork planks.

Cork density

The average cork density for all parks 254.8 kg m^{-3}. This result is similar to those cited in the literature (Pereira 1998). When comparing the cork density of the different parks (Table 2), no significant differences were found, though the least dense cork corresponded to park 6 (237.9 kg m^{-3}) and the densest one (268.7 kg m^{-3}), to park 1.

Porosity coefficients of cork and average section of lenticels

The average porosity coefficient of the reproduction cork of the cork oak forests of Ain Draham was 9.1% on average. Parks 4, 5, and 6 had high porosity cork and parks 1, 2 and 3 had a less porous cork (Table 2). The average section of lenticels for all the parks was 1.1 mm^2.

The comparison of means allowed differentiating three different groups (Table 2): the first group was constituted by park 1, which shows a high average section (1.5 mm^2), the second group was constituted by park 2, with an intermediate average section (1.2 mm^2), and the third group included parks 3, 4, 5 and 6, with a low average section (1 mm^2 or less).

If the lenticels are grouped in accordance with their low, intermediate or high section, it can be observed that the general porosity was constituted on average by 48.5% low-section lenticels, 47.1% medium-sized-section lenticels, and 4.3% high-section lenticels. Parks 1 and 2 characterized by the presence of medium-sized and large lenticels. Park 1 had a higher proportion of large lenticels than park 2 (21.7% vs 4.5%).

Table 2. Average values of different characteristics of reproduction cork in the six parks studied

Park number	{1}	{2}	{3}	{4}	{5}	{6}
Thickness mm	27.4	25.9	28.6	28.1	29.0	**34.7**
Annual ring mm	2.2	2.1	2.4	2.3	2.4	**2.8**
Production kg m^{-2}.	7.3	6.3	7.4	7.0	7.1	8.1
Density kg m^{-3}	268.7	250.6	268.1	253.1	250.3	**237.9**
Porosity %	7.17	7.45	7.01	**10.81**	**11.08**	**11.28**
Lenticel section mm^2	**1.59**	**1.28**	0.97	0.96	0.94	1.009

Discussion and conclusions

The comparison of the average thickness of cork planks produced in a twelve-year rotation show that park 6, in the first series of Ain Draham, located in the fresh depressions of Oued Delma, produced a thicker cork than the average thickness. A two-year decrease in the current rotation period could correct this defect. Cork in parks 2 and 3 in the series Ain Draham IV and Chihia II had the lowest thicknesses. A longer rotation could correct this situation.

The cork produced in park 6 was of lower quality, thicker, more porous, and heavier than cork of the other parks. In contrast, cork from parks 1 (series Chihia I) and 2 was thinner, less porous, and lighter. The reproduction cork of the forests of Ain Draham, the first producing region in Tunisia, compared to that of the region of Alcacer, the first producing region in Portugal (Ferreira et al. 2000), was thinner (28.9 mm vs. 33.8 mm), with a thinner average annual ring thickness (2.40 mm vs. 4.09 mm), was lighter (7.2 kg m-^{2} vs. 8.8 kg m^{-2}), less dense (254 kg m^{-3} vs. 266 kg m^{-3}), with a higher porosity coefficient (9.13% vs. 4.6%), and with a smaller lenticel section (1.12 mm^2 vs. 1.6 mm^2). The classification of cork according to thickness shows that 45.4% cork of Ain Draham is low-thickness cork, while only 25% of that in Alcacer belongs to this category.

The analysis of cork in six cork-producing parks of the cork oak forest of Ain Draham has allowed the distinction of cork of different qualities depending on the sites and their ecological conditions. The environmental and geographical component found in this study must be separated from the genetic component, which can also influence the anatomy, the number of lenticels and, consequently, the quality of cork.

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Silvopastoral systems for forest fire prevention

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Silvopastoral systems for forest fire prevention: experiences from Galicia (NW Spain)

Grazing in forestlands has been a common practice in most parts of the Iberian Peninsula and in some regions it is still important. Generally natural pastures in shrublands were used or improved pastures were established. In the northern Iberian Peninsula, experiments have been carried out on the management and use of pastures in shrublands and improved pastures (Sineiro 1982; Sineiro et al. 1999; Osoro et al. 1999).

Introducing livestock in tree stands has been more problematic, as the administration has usually banned the access of livestock to forests and tree stands due to the possible damage the animals might do to trees and seedlings. This prohibition has led to intentional burning of forest in some areas.

Grazing in forestlands is has been an area of conflict in some regions like Galicia. Therefore, it is necessary to properly plan and manage livestock grazing in forestlands with silvopastoral systems as the potential solution to the conflict.

Silvopastoral systems have been studied in Galicia beginning more than twenty years ago. This work started at the Forest Research Centre at Lourizán (Pontevedra), later joined by the Agrarian Research Center at Mabegondo (A Coruña) and the Department of Plant Production of the Politechnic University of Lugo. Various publications have demonstrated the effectiveness of methods developed to reduce understorey fuelwood and the risk of forest fires as a result (Rigueiro 1985, 1986, 1992, 1997and 1999; Silva 1988, 1991 and 1993). The establishment of improved pastures –with more productive, nutritious, digestible, and palatable species for the livestock-, under trees has also been studied. Finally, landscape and accessibility of forests are other observable benefits of silvopastoral systems. (Rigueiro 1985 and 1992; Silva 1993; Piñeiro and Pérez 1988). The tree species that has been used/planted are *Pinus pinaster* Ait., *Pinus sylvestris* L., *Pinus radiata* D. Don, *Betula alba* L., and *Eucalyptus globulus* Labill. Presently other tree species are being tested and researchers in the province of Lugo are developing a system with horses in forests of *Pinus radiata* D. Don, comparing the effect of continued and rotational grazing in the reduction of understorey fuelwood (Rigueiro et al. 2001).

In the following section we present the most interesting results on the use of livestock as a shrub clearing tool "desbrozadora" that feeds from natural pasture understorey, thus reducing the quantity of the fuelwood and the risk of forest fires.

Trees

The studies on the control of understorey fuelwood through grazing have been done primarily in pine forests of **pino bravo** or **local pine** (*Pinus pinaster* Ait.), Scot pine (*Pinus sylvestris* L.) and **radiata pine** (*Pinus radiata* D. Don) and eucalypt plantations (*Eucalyptus globulus* Labill.). Pine and eucalypt forests currently cover most parts of Galicia -between 70% -80% of the total forested area -and these are planted trees. Tree density (number of trees per hectare, ground cover fraction, basal area) is related to the productivity of the understorey, since high densities reduces the light that reaches the soil (Dodd et al. 1972).

Natural understorey pasture

The herbaceous-shrub layer in the Galician pines and eucalypt forests is ususally dominated by fruit-producing, sun-demanding species and by sun-demanding grasses. Therefore, it is important to know the nutritional quality and palatability of the main herbaceous and shrub species that grow in shaded conditions, like some herbaceous monocotiledons (for example belonging to the genus *Dactylis, Molinia, Holcus, Agrostis, Lolium, Briza, and Pseudoarrhenatherum*), herbacesous dicotiledon (like those of the genus *Achillea, Erodium, Lamium, Plantago, Rumex, Trifolium, Senecio, Stellaria, Urtica, Capsella, Mentha, Taraxacum,* and *Daucus*), shrubs (like those of the genus *Cytisus, Ulex, Erica*, *Lonicera*, *Pterospartum*, *Daboecia*, *Rubus*, *Genista,* and *Calluna*) and small tree branches of less than de 0.5 cm in diameter (like those of *Alnus, Betula, Fraxinus, Quercus, Pinus, Fagus, Salix, Populus*). The main results of our studies show that herbaceous species have higher nutrient content, which makes them more interesting in extensive systems (Rigueiro et al. 2002). The herbaceous dicotyledons have higher mineral contents than the monocotyledons (Rigueiro et al. 2002; Pinto et al. 2002). Species of the genus *Cytisus*, *Rubus,* and *Ulex* have more forage potencial than those of the genus *Erica* or *Calluna*, and *Pterospartum* has a low content of protein even though it is a legume. Trees have higher nutritional quality than shrubs, and during summer they have the same protein, phosphorous, and mineral content as the herbaceous plants, which makes them interesting for those regions with poor pasture production during summer.

The pino bravo and the white eucalypt have light crowns that allow high levels of sunlight to penetrate below, even when in forest plantations. As a consequence, these formations have a herbaceous-shrub layer dominated by sun-demanding species. The productiviy of the understorey is between 2.5 and 3.2 t of dry matter per ha^{-1} $year^{-1}$. On the other hand, in plantations of Scots and radiata pine, light penetration through the canopy is lower. For this reason, only shade-tolerant species can grow underneath and productivity is around 1.4 and 2.8 t of DM per ha^{-1} $year^{-1}$ (Silva 1993).

In the different studies, the various experimental plots showed, before experiments started, an understorey biomass of 25 to 50 t DM ha^{-1} predominantly, of woody species. For effective shrub control, animals should consume the more palatable and nutritious young sprouts. Therefore before introducing the animals, it is better to reduce the understorey first: by trampling, burning, or **slashing** (manual or mechanical) (Rigueiro et al. 1997).

Livestock management

The livestock must be compatible with trees and should be of hardy, native breeds which are able to nourish themselves primarily with natural pasture growing under the trees. In the first phase, when the woody pasture is abundant, it is advisable to introduce goats and horses, animals that can take a high proportion of woody pasture in their diet. Due to the management of the pasture, the understorey vegetation evolves by reducing the abundance of the woody species and increasing the herbaceous. During this phase, it is advisable to use sheep and cattle. However, goats and horses should continue to graze to avoid the recovery of the woody shrubs (Rigueiro et al. 1997).

Horses are compatible with eucalypts and pines, including during the early life of the trees. Horses can control the growth of thorny shrubs and other bushes and hard graminae quite well. Horses are compatible with broadleaf tree species only when they cannot reach the foliage. Goats can graze in forests of white eucalypt, even if young, without damaging them, but this does not apply with pines and other broadleaf trees. Goats can control thorny shrubs, heather, and other shrubs and grasses well. Sheep and cattle consume herbaceous pasture well, and if they are hardy local breeds, they can eat the soft sprouts of woody species and are considered compatible with pines, eucalypts, and other broadleaf trees when they cannot reach the crowns (Rigueiro 1992, Rigueiro et al. 1997).

The experiment in the public forestlands of Marco da Curra (Monfero, A Coruña), found at 550 m altitude, slate soils and average annual recipitation of 1593 mm and an average annual temperature of 10.6 ºC, with *Pinus pinaster* Ait. of 30 years of age and with a density of 450-700 trees per ha and in pines of *Pinus sylvestris* L. of the same age with 500-800 trees per ha. Good results were obtained with an initial stocking rate of 2 goats per ha. This stocking rate changed as the grass layer became established, and was established at 1 goat and 3 sheep per ha after the third year. The livestock was managed based on a model that may be considered extensive rotational grazing, with the objective of achieving high stocking rates at one point in time so that the fuelwood will be controlled effectively, including the less palatable species. The experimental plot was divided into 4 sub plots and the time of occupation per sub plot was approximately one month, and the set aside for a period of 3 months (Rigueiro 1992 and 1997).

In the experimental plots of *Eucalyptus globulus* Labill. of the forestland Coto de Muiño (Zas, A Coruña), owned by the National Paperpulp Company, situated at 420 m altitude and slate soils, the average annual precipitation is 1640 mm and the average annual temperature is 11,9 ºC. Tree density is 2000 trees per ha and the owners have used livestock for more than 30 years, in free or continued grazing. The general stocking rate is of 1 goat per 2 ha and 1 horse per 4 ha, grazing together. There is excess pasture in spring and the cattle from their neighbours are allowed to graze, with an approximate stocking rate of 1 cattle per ha (Rigueiro 1992 and 1997).

Presently we are developing an experiment with native horses (Galician mountain horse) in forests of *Pinus radiata* D. Don, in the communal forest land of Sam Breixo (Parga-Guitiriz-Lugo). The altitude is 500 m and the trees are 25 years old. At the beginning of the experiment tree density was 800 trees per ha, but later the density was reduced to 400 trees per ha after thinning. The average annual temperature is 10.9 ºC and the average annual precipitation is 1477 mm. The general stocking rate is of 0.5 animals per ha and and two grazing systems are compared: continuous (two replications in two plots of 6 ha each) and rotational (two replications in two plots of 6 ha divided each one in four subplots of 1,5 ha; the occupation period is of one month and rest period of 3 months). The most abundant species in the experimental plots of Sambreixo are: (*Ulex europaeus* L., *Ulex gallii* Planchon), blackberry (*Rubus* sp.), heather (*Erica umbellata* L., *Erica cinerea* L., *Erica ciliaris* L., *Calluna vulgaris* (L.) Hull), *Cytisus striatus* (Hill.) Rothm., *Cytisus scoparius* (L.) Link, *Genista florida* L., *Pterospartum tridentatum* (L.) Willk., the common ferns *Pteridium aquilinum* (L.) Kuhn, *Daboecia cantabrica* (Hudson) C.Koch, *Halimium lasianthum* (Lam.) Spach., *Pseudoarrhenatherum longifolium* (Thore) Rouy, *Agrostis curtisii* Kerguélen, *Agrostis capillaris* L., *Holcus lanatus* L., *Holcus mollis* L., *Avenula marginata* (Lowe) J.Holub, *Molinia caerulea* (L.) Moench, etc. Seedlings of oaks (*Quercus robur* L.), chestnut (*Castanea sativa* Miller) and birch (*Betula alba* L.), are frequent and the regeneration of pines is almost absent.

Control of fuelwood

The control of live fuelwood of the livestock in the eucalypt forest of the forestland of Coto do Muiño (Zas, A Coruña) is very important. In one plot harvested three years ago and where after tree cutting the tree and shrub residues were burnt, the animals were able to reduce the understorey biomass by 80% as compared with a fenced plot. These results are very positive from the point of view of the forest fire prevention, since the area has hardly been affected by forest fires in the past years, while surrounding areas have been burnt (Rigueiro 1992).

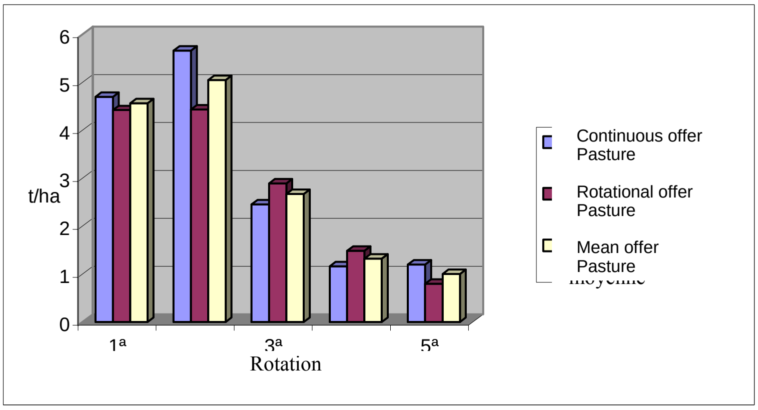

Figure 1. Available Pasture (biomass) *Ulex* sp. at the start of each rotation, in the first five rotations (20 months), in the experiment at Sambreixo

In the pine forests of Marco da Curra (Monfero, A Coruña) before the experiment started, the understorey shrubs had a total biomass of 40-50 t ha^{-1} of DM and an average height of more than 2 m. The control of the vegetation of the understorey is very effective, predominating presently the herbaceous species, with the maximum height of 10-15 cm and a biomass of 0.5-2 t ha^{-1} of DM (Silva 1988). In fenced plots in this forest the above-ground biomass recovers at a rate of 5 t DM ha^{-1} year^{-1} (Rigueiro 1992).

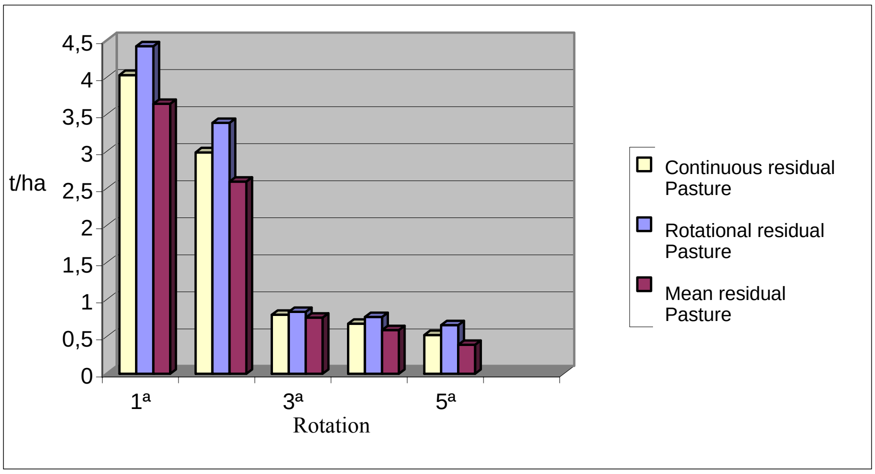

Figure 2. Residual Pasture (biomass) of *Ulex* sp. at the end of each rotaion, in the first five rotations (20 months), in the experiment at Sambreixo

In the experiment at Sambreixo, as mentioned above, the effects of rotational grazing and continous grazing of horses in a forest of *Pinus radiata* D. Don, in reducing the fuel wood in the understorey was compared, and the risk of forest fire was assessed. Figure 1 shows the pasture available (biomass) in each rotation (when the animals graze in each subplot in rotational grazing and the simultaneous estimation in the continuous grazing) for the *Ulex* sp, the dominant species of the understorey. We observed that the pasture available initially (first two rotations) was higher in the plots under the continuous grazing, later reversing this trend, until the fifth rotation, where, due to more pressure of the rotational grazing, the available pasture became higher again in the plots under continued grazing. In Figure 2 we can observe the residual pasture (biomass) (when the animals leave each subplot in the rotational grazing and simultaneous estimation in the continuous grazing) for the same species of shrubs. In the two first rotations the residual pasture is higher in the plots under continuous grazing, a tendency that is maintained, although buffered in the rest of the rotations. In 20 months of grazing the available pasture was reduced to 66% and the residual to 87.5%, as an average between the two management systems, data that indicates the efficiency of grazing in the reduction of the understorey fuelwood. The shrub clearing effect is initially higher in rotational grazing, but tends to be the same in the two systems over time. Horses control well the shrub layer dominated by *Ulex*, showing preference for these legumes, but when the effect of grazing makes the regrowth of these species difficult, horses consume and control other shrubs that are less palatable, like *Rubus* sp.

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Non-Timber forest products of agroforestry systems in Galicia

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The forest biomass

Given the large forest area of Galicia (58% of the total surface area of the region (IGE 2006)), the utilization of the non-wood forest biomass as an energy source could be an interesting alternative for the increase and diversification of the benefits from the forests. "Biomass" is defined as the biodegradable fraction of the products, waste, and residues from agriculture (including plant and animal residues) and forestry, and of related industries production such as the industrial and municipal that produce biodegradable residues (Directiva 2001/77/CE), with forest biomass being the primary biodegradable portion of products and residues generated in forestlands and processed for energy purposes, as well as those residues from energy crops (Estrada de Luís et al. 2006).

In the case of the mountains of Southern Europe, these would be composed of plant materials, originating from selviculture activities such as pruning, selection of shoots, thinning, silvicultural treatments, and shrub clearing. The combustion of the biomass has traditionally been the main source of energy since the discovery of fire up until the industrial revolution. Lately, this utilization has generated a lot of interest, among other reasons due to the global climate change, whose origin seems to be associated with the present energy system. The generation of energy through forest biomass opens the door for the utilization of a resource that up until now has been considered a non-renewable residue and the source of an additional expense for forest owners.

On the other hand, the wood and furniture industry can use small-size timber and wood chips more efficiently, since the residues produced in the process are used to generate part of the energy that the industry itself consumes.

Mushroom harvesting

The growing importance of wild mushroom gathering is based on the fact that it provides a higher income than other non-timber forest products (Oria de Rueda 1991), which necessitates the forest being managed in such a way that would encourage the sustainability of the mushroom resources, such as the persistence of tree formations associated with mushrooms of interest. Currently, some mountains and forests of Galicia have high productivity and good mushroom potential which has encouraged many sub-regions to develop the harvesting of wild mushrooms for economic reasons, activity that is supported by the high price as well as the strong market demand. It is estimated that the Autonomous Region of Galicia annually trades mushrooms with a value of between 24 to 30 million of Euros (based on the price paid to the collector) (Rigueiro 2001).

An important method to increase the fungi production is reforestation with tree species that are associated with important edible mushrooms and the use of michorriza in the reforestation sites. Scientits in Spanish research centers and universities has studied the inoculation and the michorrization process in nursery plants which has brought about the trading of different types of michorriza and various fungi species, as well as the commercialization of inoculated seedlings of forest trees.

The most economically important wild mushroom are endotrophic michorriza, like *Boletus edulis* Bull.: Fr., *B. pinophilus* Pilàt & Dermek, *B. aereus* Bull.: Fr., *B. aestivalis* Paulet: Fr., *Lactarius deliciosus* L.: Fr., *L. semisanguifluus* Heim & Leclair, *L. sanguifluus* Paulet: Fr. and *Cantharellus cibarius* Fr., although there are also a lot of other edible species with good organoleptic characteristics like *Tricholoma portentosum, T. terreum*, *T. columbetta*, *Cantharellus tubaeformis* Fr., *C. lutescens* Pers.: Fr., *Hydnum repandum* (L.) Fr., *H. rufescens* Fr., *Russula virescens* (Schaeff. ex Zant) Fr., *R. cyanoxantha* Schaeff. Fr., *Boletus erythropus* Fr. y *Boletus badius* Fr., some of which are starting to be traded.

Medicinal and aromatic plants

The demand for medicinal and aromatic plants has increased these last years and it is estimated that this trend will be maintained in the future due to the great demand for natural medicines and plant therapy. On the other hand, this is a resource that is frequently ignored and unused in Galicia, due to the competition from countries with cheaper labour cost, as well as the abandonment and ageing population of the rural areas that make harvesting more difficult.

The species that are traditionally gathered in Galicia among others are: *Gentiana lutea* L., *Arnica montana* L., *Frangula alnus* Miller, *Ruscus aculeatus* L., *Laurus nobilis* L., *Achillea millefolium* L., *Valeriana officinalis* L., *Hypericum perforatum* L., etc. It should be noted that the utilization of these species, especially those from which roots or branch cuttings are used, notably reduces their natural populations. This fact should be considered if we want to make sustainable use of the natural populations of these plants and to give incentives to their cultivation.

Honey production

Bee keeping in Galicia had its maximum expansion before the arrival of sugar, making honey an important food in terms of its sweetening and its medicinal and energetic properties. But it was in 1880 when the first mobile man-made hives were first installed by Don Benigno Ledo. This could be considered the beginning of modern bee keeping which reached its peak in 1975, the year when the fixed hives appeared (*colmenas de alzas*).

Honey production is very much related to the forest environment and forest trees and shrub species, given that depending on the tree and shrub species present in area, beekeepers can produce honey from one specific species (monofloral) or from many plant species (multifloral). In the Galician Region, the majority of the honey produced is the multi-flower type, although monofloral honey from eucalyptus, chestnuts, heather, or blackberry are also produced.

Presently there are 100,000 man-made beehives in Galicia (Yánez 2001) that annually produce between 1,500 to 2,000 tons of honey (Rigueiro 2001), as reported by the bee keepers, which provides between 6 to 12 millions of Euros per year. To improve the trading of honey, the “certificate of origin” was created and is labeled “Honey from Galicia” which indicates that it is Galician honey and produced in the traditional way.

The Regulatory Council of this denomination specifically listed more that 30,400 man-made beehives belonging to 392 bee keepers, with 39 packaging plants which in 2005, certified more that 35,000 tons of honey.

Nuts and seeds

Galicia is the Spanish region that produces and exports chestnuts with an annual production estimated at 8000 tons with a value of more than 1.3 million Euros, making up to roughly half of the national production. Internationally, the biggest consumers of this product are France, Japan, Argentina, and Italy. The chestnuts most valued for their quality and size are those from the eastern provinces of Lugo and Ourense, although these zones has a marked ageing of the rural population, which has resulted in the abandonment of chestnut production and consequently the lowering of the quality and quantity and this variety of chestnut. Sometimes the chestnuts are not harvested at all.

Presently, chestnuts are consumed either roasted or glazed, perhaps due to the absence of a culinary culture of the chestnut. However, the use of chestnut flour in the elaboration of infant foods in the north of Europe and for specialized pastries in France bear mention. The chestnuts may be a good source of additional income for rural families, but for this use to be feasible it is necessary for these zones to have adequate management practices and sustainable fruit harvesting. Harvesting is usually done during October and November, classifying the fruits by quality which results in an increase in the price of the product on the market. The raising of Galician pig under chestnut forests is also spreading in Galicia, and is a way of benefiting from these forests without big investments.

There are three enterprises in Galicia that are involved in chestnut processing. These companies have started to be known in the international markets and the potential of the sector is considered to be great, given that the elaborated products command a higher value that would further benefit the rural areas.

Other nuts like walnuts, hazelnuts, or stone nut do not have as much economic value as the chestnuts, although they may always contribute to the diversification of agroforestry in the production of high quality and economically viable products.

Wild fruits and berries

In Galicia, the gathering of small wild fruits such as blackberries and raspberries for fresh consumption is traditional, although the commercialization of cultivated raspberries has now reached approximately 800 t (EFI 2006).

The local species harvested are *Rubus idaeus* L. (raspberry), *Rubus* spp. (blackberry), *Ribes petraeum* Wulfen in Jacq. (red bush), *Ribes rubrum* L. (red and white currant) and *Vaccinium myrtillus* L. (myrtle blue berry).

It must be considered that the gathering of these small fruits in the wild may bring about the problem of conservation and the loss of a wild food resource in the forest. One possible solution is the cultivation of local varieties which could contribute to the conservation of local sources. In Galicia, some experiements involving the cultivation of American species such as *Vacciunium corymbosum* L have proven successful.

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Medicinal plants: Cultivation posibilities

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Introduction

Up until the beginning of the 19th century, medicines were prepared exclusively from natural products in which medicinal plants played a large role. With scientific advancement, especially in the field of chemistry, and the possibility of separating and synthesizing the active essentials of plants, natural medicine was abandoned and the role of synthetic medicines increased. However, since the late 70's as initiated by the World Health Organization (WHO) and driven in part by the secondary effects of synthetic medicines and the inefficiency of these in curing some illnesses that affects human beings, the use of medicinal plants has gained more and more prominence in the world economy.

Based on the data of the Statistics Office of United Nations, the value of imported medicinal plants between 1992 and 1996 to main international markets (European, American (USA and Canada) and Japan) has increased to 196 million dollars in four years, and continues to be a market on the rise (Srivastava 2000). It is estimated that the world market of medicinal plants moves close to 500 billion American dollars (Laird and Pierce 2002) annually.

At present, the WHO estimates that 80% of the world populations are still using medicinal plants for curative purposes. The use of the plants for curative purposes extends not only to the so called “underdeveloped” countries, but it is also very important in the West where 25% of the medicines prescribed by doctors are exclusively of plant origin or derivates of other modified plants in pharmaceutical laboratories (de Silva 1997). Currently, it is estimated that 7000 of the medicines used in the western world come directly or indirectly from active essentials contained in these plants. Some interesting examples are cited in Table 1:

Table 1. Active essential and pharmacological action of some medicinal plant species

Active essential	Pharmacological Action	Medicinal plant
Codeine	antitusigen, analgesic	*Papaver somniferum*
Morphine	analgesic	*Papaver somniferum*
Digitoxina	heart	*Digitalis purpurea*
Artemisine	anti-malaria	*Artemisia annua*
Ruscogenines	antivaricose	*Ruscus acualeatus*
Taxol	antineoplasic	*Taxus brevifolia*
Valepotraites	tranquilizer	*Valeriana officinalis*

At present, medicinal plants are not only attractive and successful in the pharmaceutical industry; they are also demanded by other important sectors such as: the perfume industry, cosmetics, food/dietary supplements, and para-pharmacies. The demand and interest for medicinal plants on the part of the modern society has not necessarily been matched by an increase in the populations of these plants, which has resulted in the over-exploitation of some of the natural populations. This has resulted in the near extinction and in some extreme cases, the total extinction of some plant species on the one hand, and on the other hand, a huge increase of imported materials from various sources and doubtful quality (Fernández-Pola 1996, Lange 1998). 90 % of the traded European medicinal species in Europe come from natural populations. At the end of the 90’s in the last century, the quantity of the medicinal and aromatic plants harvested from the wilds in the east and the southeast of Europe was estimated at 30,000 to 45,000 tons of dried plants, which is equivalent to 300,000 tons green plants (Lange 2004).

From various venues it is noted that the domestication and cultivation of medicinal plants would be the best way to respect the environment, allowing the continued growth of the species and natural populations and guaranteeing a stable market, quality of the product, and economic feasibility at the same time. Aside from this, the cultivation of this resource would facilitate the identification and training of qualified technicians and farm workers in the rural areas.

Cultivation of medicinal plants

One of the main difficulties of cultivating medicinal plants is due to the lack of tradition of large scale cultivation of most of these plants; there is no established efficient technology for the production of the biomass and the active essentials.

In Spain, based on the yearly agricultural statistics, 7,000 hectares of land were dedicated to the cultivation of aromatic and medicinal plants from which 4,000 was dedicated to the production of lavenders. Other aromatic and medicinal plants well-cultivated in Spain are, saffron, hops, espliego, chamomile, anise and salvia. In Spain as well as in other countries that produce medicinal plants, the planting is basically done in open fields and following the traditional planting models.

However fields trials done on some of these plants shows that the production and efficiency is not only determined by agronomic factors but that the quality of the final product is greatly affected by environmental conditions such as where they are cultivated, the height (altitude) of the place, sun exposure, orientation, temperature (maximum, minimum and the fluctuations), soil type, and water availability.

From here the selection of plants should be made based on two criteria:

1. That they are plants in demand whose market does not suffer sudden fluctuations in time.

2. That they are plants that easily adapt to environmental conditions where they will be cultivated.

For this, before starting to cultivate, it is recommended to make a market study (National and International) and know which industrial sector we are targeting for our production. The price of the final product is not only determined by the quality (active essentials content), but is also affected by the destination. The wholesale market and retail herbal markets give more importance to the visual aspect. The liquor, perfumery, and food industries value more the smell, while laboratories value more the active essentials content.

These aspects are very important since they condition the process of transformation and treatment that the plant material should go through once harvested and before reaching the market.

Regarding the second point mentioned, at the time of the selection of the species for cultivation, it is advisable to make an inventory and catalogue of the local flora. The natural presence of these plants in the zone is very much valued since these plants are already adapted to the environmental conditions. It is also recommended to make an initial selection of materials based on the quantity of its active essentials, since within the same area it is possible to have different qualities. Before cultivation it is important to make trial domestication in small plots to know if the quantity of active essentials is what is expected and to be able to foresee possible problems (plagues, plants nutritive needs) (Wijesekera 1991; Cristobel et al. 2006).

Plantation

Once the species is selected, the establishment may be conducted through direct sowing or with seedlings. The first option is only recommended for those species whose seeds are highly available, cheap, and have high germination percentage. In the majority of the cases, it is advised to make a seedbed and to use selected seeds. However one of the major problems of these crops is the availability of quality seeds which usually are very expensive and make the plantation expensive.

The density of the plantation varies based on the dimensions of the selected plants and the availability of water (14,000 plants per hectare for big plants and 45,000 for smaller plants). Spacing is selected not only based on the plants, but also the machinery that the farmer has for the establishment and maintenance of the plantation. The more widely used is 80-120 cm between rows and 30-50 cm among plants within the same row (Fernández-Pola 1996).

Plantation Maintenance

Most of the medicinal plants are hardy plants with little nutritional needs, but each year we should replace the nutrients extracted by the plants, for which we have to apply maintenance fertilizer, normally during spring and also depending on the cultivated plants. The aspect that preoccupies most producers of medicinal plants is the control of weeds, especially at the initial phase of the cultivation, since medicinal plants are not very competitive with annual plants that may displace them easily (Weller 1996). Up to 80 % of the maintenance time in a field dedicated to the cultivation of medicinal plants is spent on the removal of weeds. The control of weeds is something that should be resolved before starting the cultivation. Since the market demands active essentials free of chemical residues, at present the methods used in controlling the weeds (compatible with the methods of ecological agriculture) are manual, mechanical, and mulching methods. The main difficulty of the first two is the need for labor. Mulching has a high cost of establishment, but later will not need much attention. These are appropriate for perennial plants. In some crops, its effectiveness has been demonstrated reaching an increase of up to 114% of the medicinal plant production (Galambosi and Szebeni 1992; Costa-Rocha et al. 2005).

Cultivation of medicinal plants in agroforestry systems

These methods are adequate above all to plants that are shade tolerant and are widely practiced in tropical countries. The main advantages are the diversification of the production and the achievement of an economic benefit within a shorter period of time. Furthermore, other aspects of the nutrient cycle are positively influenced such as the water balance and the control of plagues and sickness of plants.

There are various ways of integrating medicinal plants in this type of multi-use systems (Rao et al. 2004):

1. Introduce plants that are shade tolerant in mature forest plantations

2. Cultivate medicinal plants that need light which has a short term cycle in early forest plantations.

3. Insert medicinal plants with other plants

1. This model imitates what naturally occur since the forests are the main supplier of aromatic and medicinal plants in the world (FAO 2003). Other countries has been practicing this since long ago, combining the forest and forest plantations with the cultivation of medicinal plants that are more or less shade tolerant and require soil rich in organic matter that retains the humidity and mild temperature. Ginseng (*Panax ginseng*) is cultivated in this manner in pine forest and other conifers in the northeast of China (Rao et al. 2004).

The traditional agroforestry system known in the Yunan province of China as “Dai and Jinuo” consists of cultivation of medicinal plant *Amomum villosum* in cleared forest areas (Saint-Pierre 1991). In this system, the forests are cleared until the shade is of 30-40% and then followed by the sowing or planting of the medicinal plants (Rao et al. 2004).

These traditional systems of Asia have reached other areas of the world like in Costa Rica where the *Cephaelis ipecacuanha* is cultivated in natural forest (Hager and Otterstedt 1996) and the *Panax* ginseng is cultivated in the US and Canada under tree cover of *Acer rubrum*, *Juglans nigra,* and *Acer sacharum.*

1. Plants that needs light (*Echinacea* spp., *Achillea* spp., etc.) may be cultivated in recent forest plantations obtaining an economic benefit within a very short period of time (Rao et al. 2004).

The major inconvenience of these integrated systems is the difficulty of using machinery in the cultivation and harvesting of these medicinal plants.

2. Some widely known medicinal plants are obtained by intercropping with timber trees in India where have been a lot of experiements with various trees such as *Acacia auriculiformis*, *Albizia lebbeck* or *Eucalyptus tereticormis*, *Albizia lebbeck* or *Eucalyptus tereticormis* and different medicinal plants *Curcuma longa, Curcuma aromatica*, *Curculigo orchioides* and *Zingiber officinale* (Chadhar and Sharma 1996, Mishra and Pandey 1998; Prajapati et al. 2003).

The studies made with these type of agrosystems production show promising results, not only economically, but also show the potential for social and environmental advantages. Yet there are still some unknowns to be unmasked. For example there are still unknowns regarding the spacing of the plantation of tree species that allows the good production of wood and good production of medicinal plants. Up until now, research indicates that the total biomass of medicinal plants such as its active essentials, is influenced by the shade projected by the trees. Surely the initial spacing of the plantation should be modified based on the growth of the trees, if we want to have the same benefits from the medicinal plants.

Another important aspect that is being investigated, is the influence of the tree species selected on the synthesis and the composition of the active essentials of the medicinal plants (Rao et al. 2004).

Other types of use also exist like the intercropping cultivation of aromatic and medicinal plants with cereals (Crossman et al. 1999; Palada and Willians 2000). The first published studies about this type of intercropping show that after the first year, the production of the biomass of the medicinal plants decreases (Palada and Williams 2000). We should remember however, as was mentioned earlier, that the multiple use systems do not only have economic advantage. As was indicated by Rao et al. (2004), the agroforestry systems offers the production of aromatic and medicinal plants without displacing the traditional crops, thus offering the advantage of diversification.

Each country needs its own multidisciplinary research teams in which different specialists should be involved such as botanists, agricultural technicians, geneticists, economists, representatives from consumer industries, and agriculturists

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Quality of Vegetation in Silvopastoral Systems

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Introduction

The knowledge of the nutritive quality of the vegetation is essential to the evaluation of the resources available for grazing, as well as in the development of effective management strategies in silvopastoral systems (SS).

This chapter emphasizes the significance of nutritional parameters that are related to energy and protein content of range forages. Both parameters are usually the most limiting to range animal productivity (Holechek et al. 2004) and are measured by variables such as digestibility, crude protein, carbohydrates (structural: ADF, NDF, lignin, silica; and nonstructural) and phenolic compounds (specially nitrogen-complexing compounds). These essential nutritional components of vegetation will be discussed based on data obtained from our studies on nutritional attributes of forest vegetation, both in Galicia (northwest of Spain) and in the Pacific Northwest (Oregon, USA). As a result of the inherent dynamic and complexity of SS, these nutritional parameters fluctuate, therefore having ecological and management implications that will be also discussed.

Indicators of nutritional quality in silvopastoral systems

Plant species composition of forest communities determines the nutritional quality of vegetation. Nutritional quality parameters vary greatly among plant species, the portion of the plant consumed, maturity, genetic, and environmental factors (Van Soest 1982). Digestibility and protein of forage are important components of diet quality, and are related to herbivore diet selection. Carbohydrates are the basic source of energy for animals. Plants have two basic types of carbohydrates: those associated with the cell wall (cellulose, hemicelluloses, and lignin) and those associated with the cell content (nonstructural carbohydrates such as sugars and starches). Digestion of cellulose and hemicellulose is a much slower process than is that of starch and sugar. Lignin cannot be utilized, and is considered the primary anti-quality component in forages. It is the principal constituent of woody material in trees and shrubs.

Digestibility

Energy availability in forages is generally expressed in terms of their dry matter digestibility (DMD). Although animal energy requirements vary with age, sex, reproductive status, weather and cover availability, ruminants in general cannot maintain body weight on diets with DMD coefficients less than 50% (Weiner 1977; Maizeret et al. 1991).

Forbs and leaves of shrubs usually reach their potential extent of digestion more quickly than grasses. This appears to be partially explained by thin cell walls that facilitates quicker microbial access to cell solubles (nitrogen, aminoacids, non structural cabohydrates…). They are easily broken down by the animal´s digestive system and are a readily available source of energy. Substances resistant to microbial digestion located in the cell wall, and detrimentally associated with digestibility, are lignin, cutin, and silica. They are arranged differently in the cellulose/hemicellulose matrix in monocots, compared with dicots (Van Soest 1982).

An important issue to consider in range management is the fact that forages with rapid rates of digestion generally have higher intakes than those with slower rates (Van Soest 1982). Rates of digestion are different depending on the animal since residence time of forage in their digestive tract is different. Lower forage digestibility in goats corresponds to lower residence time in their digestive tract compared to cattle and sheep (Huston and Pinchak 1991). Ruminants are more efficient digesting fibre than monogastric animals such as horses.

In Galicia forestland, heaths (*Erica* sp., *Calluna* vulgaris) have been reported as a group of plants with very low DMD values, ranging from 16-25% (González-Hernández and Silva-Pando 1999). Other common shrubs such as gorse (*Ulex* sp.), huckleberry (*Vaccinium myrtillus*), blackberry (*Rubus* sp.) and grasses averaged 40-50% of DMD. Digestibility of black dogwood (*Frangula alnus*), ivy (*Hedera helix*), honeysuckle (*Lonicera periclymenum*), all common in Galician oakwoods, ranged from 50 to 64%. Based on the minimum requirement of 50% of DMD, many plants of Galician woodlands have low digestibility values, and this nutritional parameter can become an important limiting factor in animal production when grasses and forbs are not available (González-Hernández and Silva-Pando 1999).

Protein

Unlike energy and most minerals, protein cannot be stored by the body, so a continuous supply is required. They are important as enzymes, antibodies against diseases, and hormones. Many studies have used the

Kjeldahl technique to measure crude protein (total nitrogen X 6.25) content of forages to determine adequacy of diets. Protein requirements are often expressed as percent crude (total) protein (CP).

In general, ruminants require a diet containing 5-6 % crude protein (CP) for maintenance and early pregnancy, increasing to nearly 12% during lactation (Hobbs et al. 1981). Age, sex, and reproductive status, influence protein needs of individuals. For instance, mature horses diets require coefficients of 8 to 10% of CP to meet protein needs, whereas for young horses this coefficient increases up to 10-12% CP. Many woody plants in Galician forests would meet ruminant basic crude protein requirements (González-Hernández and Silva-Pando 1999) except for *Erica* sp., *Calluna vulgaris, Daboecia cantabrica, Halimium umbellatum*… The highest content of CP occurs in legumes (*Cytisus* sp., *Genista* sp., *Ulex* sp.), and plants commonly found in oakwoods such as *Hedera helix*, *Lonicera periclymenum*, *Rubus* sp., and *Frangula alnus* all had levels of CP superior to 9%.

Nitrogen-complexing compounds

Available protein in diets is a function of plant crude protein, the amount of non-digestible fiber-bound protein, and the extent of protein precipitation by tannins. Thus, available protein, rather than total protein content, is the physiologically important parameter relative to animal requirements and metabolic capabilities (Robbins et al. 1987) and therefore, tannin content has more recently become a significant nutritional parameter to consider in the diet selection by herbivores.

Tannins are phenolic compounds that are widely recognized as digestibility reducers for browsers feeding upon woody plants (Robbins et al. 1987; Happe et al. 1990), and also as compounds that may act as toxins (McArthur et al. 1993). They appear in about 80% of shrubs and only in about 15% of herbaceous plants (Perry 1994). Tannins may form stable complexes with dietary proteins that are usually indigestible in the rumen and then excreted in feces. Another anti-nutritive effect of tannins can occur when the digestibility of forage is reduced, if microbial protein binds with tannin and rumen microflora is negatively influenced by tannins. Some plants of Galician woodlands with tannins are: *Rubus* sp., *Erica* sp., *Calluna vulgaris*, *Daboecia cantabrica*, *Halimium lasianthum*, *Vaccinium myrtillus*, *Alnus glutinosa*, *Quercus robur*, *Salix atrocinerea*, *Fagus sylvatica*, *Betula alba*. In Galician forests, many forage species contain significant levels of astringent tannins with the potential to greatly reduce the availability of protein for livestock and deer. Digestible protein is likely to be a significant limiting factor in forest communities containing predominantely plants of the Ericaceae family, especially if grasses or forbs are not available (González-Hernández et al. 2003). However, other plants commonly found in the Galician woodlands such as woody legumes, grasses, and some shrubs did not contain tannins: *Cytisus multiflorus, C. striatus, Genista florida, Pterospartum tridentatum, Ulex europaeus, U. gallii, Hedera helix, Lonicera periclymenum, Frangula alnus, Ilex aquifolium,* and grasses such as *Agrostis curtisii, Dactylis glomerata, Pseudarrhenatherum longifolium*….(González-Hernández et al. 2003).

To quantify the impact of tannins on nutrient availability for elk and deer, predictive equations were obtained from conducted feeding trials with known quantities of tannins, allowing the prediction of protein digestibility (Robbins et al. 1987):

$$DP=-3.87+0.9283X-11.82Y$$

where Z is digestible protein in grams per 100 gr of feed, X is crude protein content as percent dry matter, and Y is amount of bovine serum albumin precipitated (astringency as an index of tannins biological activity).

Solving the equation for the crude protein required for ruminants, assuming no astringency, yields dietary requirements of approximately 1% of DP for maintenance and early pregnancy, and about 7% DP for lactation.

Herbivores may ameliorate the effects of certain tannins in natural forages on protein digestibility through physiological and behavioral adaptations, and some animals are able to deal with tannins better than others. As plants have developed the enzymatic means to synthesize defensive chemicals, animals have evolved detoxification mechanisms to overcome plant defenses such as tannins. Browsing animals are better able than grazers to resist adverse effects of dietary tannins and phenolic compounds, which are common constituents of shrubs and trees. Browsers like deer have salivary tannin-binding proteins that counteract the astringent effects of tannins, but these salivary proteins are absent in sheep and cattle (Austin et al. 1989).

More recently, polyphenols have shown biological effects of nutritional interest, revealing that condensed tannins also form stable complexes with metal ions and are, like other polyphenols, good reducing agents. They can also exert a positive effect, by preventing frothy bloat, or by improving the nutritional utilization of alimentary nitrogen (Jean-Blain 1998). Although protein protected by tannins and soluble phenolics may improve ruminant performance if consumed at low levels, the complete nutritional significance of the non-specific complexation of proteins is less clear.

Fluctuations of the nutritional quality of vegetation in SS

The nutritional quality of forage in SS is constantly changing because of the inherent dynamic plant-animal interactions in the SS, as well as the seasonal variation that occurs in the physiology of the plant. Actively growing plant parts have much higher protein content than do those that are dormant, and variation in available protein among different vegetation communities will be a function of species composition (González-Hernández and Silva-Pando 1999). Equally, maximum values of digestibility occurred during the growing season, since soluble components of plant cells decreased at senescence (González-Hernández and Silva-Pando 1999). Tannin content also varies with maturity. It was the highest in the growing season, and generally decreased from spring through summer, fall, and winter in some studies carried on plants of the Pacific Northwest (Happe et al. 1990; Starkey et al. 1999; González-Hernández et al. 2000). An adaptive strategy in the animal is reflected in food habits that shift seasonally to take advantage of forages such as grasses or forbs with lower tannin content and/or capacity to precipitate proteins (Starkey et al. 1999).

Animals will also tend to select the most palatable portions of the plant resulting in changes of its structure and development. Young and leaf tissues are generally more palatable than old and stem tissues. Animals in the SS will also select the most palatable plants, resulting in an alteration of the botanical composition of the system. Defoliation will affect plant development depending on its intensity, frequency, and season.

Nonstructural carbohydrates (NC), a readily available source of energy, have commonly been used as a key indicator of plant vigor and an index of the consequence of grazing (Caldwell 1984). Overharvesting, either by cutting or grazing generally reduce NC, and the concept that disappearance or persistence of grazed plants correlates with amount of total NC reserves has been propounded and reviewed many times (Heady and Child 1994).

In Galicia, unbrowsed plants of *Pterospartum tridentatum*, a shrub of the leguminose family, contained significantly more NC than browsed plants. NC content also decreased significantly with the degree of browse utilization (González-Hernández et al. 2002). The same study showed that gorse (*Ulex gallii*) tolerates defoliation better, with no differences between NC in unbrowsed and browsed plants NC. *Ulex gallii* had a faster regrowth after browsing pressure than *Pterospartum tridentatum*.

Ecological and management implications

A pluralistic approach and a holistic perspective is necessary in the management of grazing ecosystems, with knowledge of plant herbivore interactions that include nutritional attributes of plants, their phytotoxicity and antifeedant properties, as well as the different tolerance of herbivores, which is generally associated with adaptation to tannin rich environments.

Animal nutritional status in SS is influenced by vegetation type, animal, season, stocking rate, grazing system, and use of the food resource. The seasonal pattern of production, species richness, and nutritive value, will determine the temporal character of silvopastoral systems. Therefore, the application of specialized seasonal grazing plans coordinated with the cycles of forage demand, supply, and quality are required to meet animal nutritional needs as well as to cover optimal management of SS.

An understanding of the defoliation effect and the potential of plant adaptation is fundamental for the professional rangeland manager. High animal density produces an ageing of the vegetation with an increase of lignin content and a decrease in organic matter digestibility (González-Hernández and Silva-Pando 1996). Changes in the relative proportions of shrubs, herbs, and ferns under grazing conditions has implications for sustainable management (González-Hernández et al. 1998).

In some cases, a diversity of stand-types and ages is recommended. Tannin content also varies with forest type and stand type. Tannins increase with light incidence, and some studies have found that although clear-cuts commonly contain more forage biomass than older forests, tannin astringency significantly reduces the availability of protein in shrubs and ferns in clear-cuts (Starkey et al. 1999). Thinning and selective harvest may provide management tools to provide for timber harvest, increased growth of trees, and an optimum forage resource. However, further research is required to describe the response of astringency over a wide range of canopy coverage and exposure to solar radiation.

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Support to the transformation of comunal forest land in Galicia

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Introduction

In Galicia comunal forest land (MVMC) occupies more than 650,000 hectares (22% of the total land area of the region). These areas are marginal and have been abandoned in recent years. Generally, MVMC are found in poor soils and characterised by difficult terrain but with areas ranging from few to several thousand hectares. Many of the MVMC cover average to large areas. In the past, these forest lands were confiscated from the communities owning them and the traditional uses were banned for 40 years.

Possibly, during that period the communities lost their interests and their links with forest management. The process to regain landownership of the communal lands started in 1978, though the process is not yet concluded as there are still some forests not yet registered as communal. In a highly fragmented region with so many smallholdings, the communal forests are a counterexample as some of these consist of hundreds if not thousand of hectares. Although the MVMC are usually found in areas with poor or degraded soils, steep slopes, and high elevation, they constitute a good alternative for improving the economic situation of the rural population and an opportunity for young farmers, which could help to reduce outmigration from rural areas.

The pasture establishment program

In 1984, the program of pasture establishment in open areas of communal forests was initiated with the objective of promoting livestock grazing, improving existing pastures, and expanding the grazing areas. The program also aimed to establish associations of farmers and new production systems in these communal lands. Today, the program is still on-going and consists of:

A legally constituted association of communal forest land owners. This organization can apply for support from the regional government to make improvements in the forests under their jurisdiction.

Once a proposal is submitted, a government technician will assess the potential of the proposed area for pasture production and the value of the native vegetation for grazing animals. The technician will also assess the capacity of the association to manage and maintain the communal land during a minimum period of 5 years. If the technician's report is favourable, a project will be designed, which will include:

An analysis of the socio-economic characterisitcs of the community, a description of the activities to be implemented in the communal forest, such as the conservation or the clearing of the spontaneous vegetation, land preparation, liming and fertilization, fencing, pathways, or any other investment that will facilitate livestock management.

The investments will depend on the needs and financial capacity of the members of the association.

The regional government will also assess the counterpart of the association such as labour for fencing or other, so that the government will only provide equipment or materials that the association cannot afford to suppy itself.

The project document must also include the conditions and technical characteristics of all the constructions designed, including a list of the duties and responsibilities of the association. These should be agreed by the majority of the members of the association (although those members who will not participate in the project may be excluded). Generally, the responsibilities of the community are:

-To maintain for a minimum period of 5 years, providing organic and/or mineral fertilizers to maintain soil fertility but avoiding leaching or damage to the environment.

-To share and distribute the fertilizer provided by the program.

-To fence the area with the materials provided by the program and according to the prescriptions of the government technician.

-During the first years, management and use will be supervised by the government technicians as the sustainability will depend on the proper management..

-To facilitate access to the pasture areas and to the forest lands to new members who will have to pay a share of the investment made by the association in the improvements.

-Other responsibilities determined by the association.

The implementation process

Once all the legal requirements of the improvement project are satisfied, the project will be implemented in the following manner:

-Project bidding, so that a company will implement all construction and improvement operations (generally the implementors are the public company TRAGSA) and appointment of a civil servant as project director.

-Land preparation for the establishment of the improved pasture, including fertilization, liming, and use of the natural vegetation.

-The project director will supervise the implementation of all neccessary activities and will provide technical support to the members of the association for pasture management.

-In a short time, the improved pasture area will be established and ready to be grazed. Some forested areas or other parts of the communal forest may be protected if neccessary.

What is the goal of the program?

The goal of the program is to establish improved pastures in communal forests. Moreover, there are some objectives in relation to rural development, rural livelihoods and environmental and landscape improvement. These are summarized as follows:

-To avoid economic degradation in the region.

-To reduce woody biomass in the forests, as nowadays the wood stocks of fast-growing trees are high compared to demand and therefore the wood is not harvested. This increases the risk of fire, which threatens people's lives and homes. The problem of forest fires has increased in the past twenty years as people abandon rural areas and the forest area increases. This situation was especially serious in 2006 in Galicia and elsewhere in the world because of worsening climate conditions. It is obvious that all means and equipment for forest fire prevention and fighting is not sufficient given the large accumulation of woody biomass in forests.

-To replace shrubs with quality pasture in such a way that potentially dangerous high forests and shrub lands become fragmented.

-To clear forest lands of shrubs with the introduction of livestock. The use of both fencing and the right stock rate is more efficient in the control of woody biomass than the use of herbicides or mechanical land clearing. The livestock can graze under the trees, although due to reduced light penetration under the tree canopy this pasture is less nutritious and less palatable. Therefore, it is necessary to provide livestock with better quality pasture. This is achieved with the improvement program.

- To contribute to the enhancement and conservation of landscape and biological diversity, as the establishment of improved pastures modifies the flora and fauna. Thus, careful project design and pasture establishment is neccessary so that it would be easy to revert to the initial situation if neccessary.

-To contribute to maintaining rural population and to support young farmers in settling in rural areas by supporting their economic activities and improving their quality of life, thus helping to bring back their self-esteem and the satisfaction neccessary in order to have a positive view of rural life.

Program ownership and beginning of forest land management

Once the pasture, fencing, and the infraestructure have been successfully established, the organization is given full ownership of the project. The management systems adopted are basically three:

-To divide the improved area in plots of similar size for individual use. These plots are assigned to the members for a maximum period of 11 years after which a new assignment will be made. By law, the same plot cannot be assigned for two periods to the same person. This is to avoid any claim of ownership.

-Communal management of the whole area. This system requires that decisions are made by the group, not based on individual plots, and serve the objective of food security in periods of scarcity. The stocking rate in each plot as well as management practices are also decided by the group, although the ownership of the animals remains with the member. All expenses will be shared in equal parts by the members of the group.

Group members eventually form a cooperative or an Association of Agrarian Transformation (SAT) and collectively manage and use the communal land, creating a sustainable and efficient medium-size rural enterprise. In some cases some associations for the management of private lands also join the cooperative, thus allowing overcoming the constraints of smallholdings and satisfying the objectives of the land consolidation program without any additional cost. However, in spite of the advantages of the system, at times personal problems and conflicts arise. In these cases, the government technicians become mediators and take an active role in conflict resolution. Therefore, monitoring and supervision of the program should continue over time.

Program results

In the past 23 years, more than 450 projects have been implemented in more than 15.000 ha. A correlation exists between the number of projects and pasture improvement activities and a decrease in forest fires. A study conducted in Becerreá on the effects of the program implemented in the uplands and involving many villages covering a 50% of the municipal land area concluded that:

-The stocking rate increased by a rate of two in those areas under the project. Also, the returns from livestock and compensation subsidies substantially increased. The aquisition of farm machinery for harvesting the forage increased as well. These improvements were able to compensate for the decrease of animals as farmers retired or abandoned farming. The annual rate of decrease of farms in the area was 3% but it was almost nil in those project areas. Another reason for the decrease in forest fires is the change in burning practices. Before, farmers systematically burnt the same farm every 3 to 5 years for pasture regrowth. Now burning is not practised anymore as farmers are more interested in improved pasture with high nutritional content.

-In summary, the report concluded that the management and use of the communal forest lands and the establishment of improved pastures are key to the survival of farming communities in these areas.

-The use by other farmers of those improved pastures which were abandoned as farmers retired also provides evidence of the success of the program. Currently, there are important food processing companies interested in the management of these areas.

-The positive impact on the landscape is noticeable. The program also contributes to fire risk reduction by creating a mosaic of land uses.

-Although pasture improvement on communal forest land of Galicia has clear advantages and is effective in solving the main problems affecting the rural populaton, all that has been done so far is not enough and there is more to do in the future. This research will help in the design of new programmes in the future. In fact, projects on raising milking cows, for which there is a great demand for commercial farms and to conserve the native cow breeds, has just started this year. It is important to note the case of the Limiá cow breed, whose population is being conserved as a result of the project implemented in the village of Penamá, in Allariz. Also of great ethnographic value is the raising of celtic pigs in extensive grazing system in riparian areas, oak forest, the cultivation of native varieities of cereals (wheat and barley), and the conservation and construction of traditional farm buildings such as the “horreo” and the “pallozas”.

The present and the future of the pasture improvement program in communal lands

Today, farmers are still demanding new programs and new projects in order to diversify their objectives and activities and with special attention to environmental problems. They also want to have an impact on the spontaneous vegetation, steep slopes and areas with low soil fertility by grazing these areas with goats and horses. These activities on sloping lands can be more efficient than managing them by conventional means. It has been shown with these practices than even with the right stocking rate of goats, the native broadleaved forest can regenerate. Therefore, it is logical to continue in this line of action.

Currently there are new calls for proposals such as the program for multifunctional forest and landscapes of 2007. This program includes silvopastoral projects and actions such as:

-Forest improvement and pasture management

-Fencing and protection of reforested areas

-Constructions for integrated livestock and forest management

-Ponds and water points for livestock and to combat forest fires

-Shrub clearing and prescribed burning

-Widely spaced tree plantations for silvopastoral use

-Integrated pasture establishment and management

This program only provides 60% of the investment and the farmer association will be responsible for project design and implementation. In reality, this type of support will be probably be used by well-organized communities with some important forest resources. These are the large coastal communities that do not exclusively depend on income from forest and farming. The inland and upland communities are poorer, depend on their farm and forest land and have a lower capacity to become organized and consequently will need more generous investments such as those of the PASTURE IMPROVEMENT PROGRAM IN COMMUNAL FOREST LANDS. Therefore, the programme should continue to help the communities which have not yet been beneficiaries of the program, or those more innovative and those that need to ensure their persistence in the short-term.

The Galician government is aware of the problem and thus it has notably increase the funding devoted to the program. There is also the need to create a permanent team of technicians whose mission is to facilitate the integrated management of the forest resources.

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Chemical composition of several species of the maquis in the northwest of Tunisia

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Introduction

The northwest of Tunisia is characterized by an uneven and mountainous landscape, where the soils are not suitable for farming and are occupied by natural forests. The climate is typically Mediterranean, with mild humid winters and hot dry summers. The average annual rainfall reaches 940 mm, 70% of which occurs between October and April. The average temperature is 12.8°C in winter and 32.3°C in summer (Kayouli and Buldgen 2001). Such soil and climatic conditions explain why goat farming is the main activity of small livestock farmers in the region. It is an extensive livestock farming, which exploits 31,000 ha of oak forests, heathers, myrtles, rockroses, and branchipodes.

In addition, goats are raised by small farmers who do not have enough money to intensify their production (Kayouli and Buldgen 2001) and are a source of income for many families. This kind of livestock farming is characterized by low production (Steinback 1988), and the primary reason for this seems to be the seasonal variation of the quantity and quality of the shrub biomass. The aim of this work is to study the seasonal changes in the chemical composition of the most representative shrub species of the maquis in the northwest of Tunisia.

Material and methods

Plant material

Thirteen shrub species have been studied: *Arbutus unedo*, *Calycotum villosa*, *Cistus salvifolius*, *Cytisus triflorus*, *Erica arborea*, *Genista aspalatoides*, *Myrtus communis*, *Pistacia lentiscus*, *Phillyrea angustifolia*, *Quercus suber*, *Quercus coccifera*, *Smilax aspera,* and *Viburnum tinus*.

Table 1. Shrub species studied

Latin Name	English name	Vernacular name	Family	RF (%)[1]
Arbutus unedo	Strawberry tree	Linj	Ericaceae	8.9
Calycotum villosa	Calycotome	Guendoul	Fabaceae	6.9
Cistus salvifolius	Cistus	Mellia	Cistacae	5.5
Cytisus triflorus	Golden chain	Hedhbel	Fabaceae	0.5
Erica arborea	Heather	Bouhaddoud	Ericaceae	30.5
Genista aspalatoides	Broom	Chouket arnab	Fabaceae	3.3
Myrtus communis	Myrtle	Rihane	Myrtaceae	5.6
Phillyrea angustifolia	Phillyrea	Ktem	Oleaceae	15.7
Pistacia lentiscus	Mastic tree	Dherou	Anacardiaceae	6.0
Quercus coccifera	kermes oak	Kechrid	Fagacae	8.0
Smilax aspera	Sarsaparilla	Sekkerchou	Smilacaceae	1.6
Viburnum tinus	Viburnum	Merrir	Caprifoliaceae	7.5

[1]RF: Relative frequency, determined by Kayouli and Buldgen (2001).

The choice of these species is based on a previous study of the preferences and the plant parts eaten by the goats, their representativeness and their accessibility to the animals in the area of study. Their Latin, English and vernacular names, their botanical families, and their relative frequencies (RF %) are shown in Table 1.

Sampling

Our study was confined to the plant parts most usually eaten by goats, i.e. the leaves and twigs with a diameter shorter than 2 mm. The other parts - in this case, the flowers and fruits- were not taken into account, as these organs are not available during the whole year.

For one year, monthly samples were taken from the same individuals, regardless of the vegetative cycle. In addition, the monthly sampling was done on the same day for all the plants. It must be pointed out, therefore, that no samples of *Calycotum villosa* were taken in summer (July-September) because of the absence of leaves. The sampling was carried out by removing ten plants per species. All the material removed of a given species (around 300 g) were mixed to constitute the species sample. The samples were oven-dried at 40°C and ground, with a 1 mm grid.

Identification of vegetative stages

In the moment of sampling, the identification of the vegetative stage of the species was carried out in accordance with the following definitions:

Vegetative growth: shoot emergence - leaf development

Flowering: flower bud formation - well expanded flowers

Fructification: fruit set - fruit or seed dissemination

Dormancy: end of fructification - beginning of bud-break

Chemical analyses

Every sample was analysed twice to measure the mineral (M) and total nitrogen (N) contents, following the official methods (AOAC 1999). Total fibre (NDF), lignocellulose (ADF), and sulphuric lignin (ADL), were fractioned using the non-sequential method of Van Soest et al. (1991).

Statistical analyses

Data regarding dry matter (DM), organic matter (OM), total nitrogenous matter (TNM), total fibre (NDF), lignocellulose (ADF), and lignin (ADL) were analysed by ANOVA with the help of GLM procedure (SAS 1985). Tukey-test was used for comparison of means.

Results

Frequency of the different vegetative stages

The frequencies of the four vegetative stages (described above) recorded during one year are shown in Table 2.

Table 2. Frequency (%) of the different vegetative stages during the year in the species studied

Vegetative stage	Seasons							
	Spring (April-June)		Summer (July-Sept.)		Autumn (Oct.-Dec.)		Winter (Jan.-March)	
	1[1]	2[2]	1	2	1	2	1	2
Growth	70	70	23	0	0	31	39	24
Flowering	22	8	46	0	8	15	0	15
Fructification	8	22	31	46	46	31	15	15
Dormancy	0	0	0	54	46	23	46	46

[1]: First half of the season (1- 45 d); [2]: Second half of the season (46-90 d). Vegetative growth: shoot emergence - leaf development; Flowering: flower bud formation - well-expanded flowers; Fructification: fruit set - fruit or seed dissemination; Dormancy: end of fructification - beginning of bud-break

The spring is characterized by the vegetative growth of 70% of the shrub species studied, and the absence of dormant species. During the first half of the summer, about 46% species had flowered, 31% had set fruit and 23% had continued their vegetative growth. In the second half of the summer, 54% of the species go into dormancy. *Myrtus communis*, *Phillyrea angustifolia*, *Pistacia lentiscus*, *Quercus suber*, *Q. coccifera* and *Viburnum tinus* are still in the fructification stage. The vegetative growth stops completely in all species in the second half of the summer, even though 50% of the species still bear fruit. From the second half of autumn on, the vegetative growth restarts in *Cistus salvifolius* and the three leguminous species (*Cytisus triflorus*, *Genista aspalatoides,* and *Calycotum villosa*).

Dry matter content

The season significantly (P<0.05) affects the dry matter content. The global average dry matter content (considering all seasons and species together) was 46.4% (Table 3), and the average value recorded in autumn (41.7%) was the lowest one (P<0.05). The average values obtained in the rest of the seasons were not significantly different (P>0.05), though they were rather high in summer (51.1%), and intermediate in spring (46.9%) and winter (47.2%).

Table 3. Seasonal variation of dry matter content of 13 shrub species

Species	Season				Average
	Spring (April -June)	Summer (July -Sept.)	Autumn (Oct. -Dec.)	Winter (Jan.- March)	
Arbutus unedo	45.1 ^{a}	46.5 ^{cd}	42.1 ^{b}	47.5 ^{a}	45.6 ^{a}
Cistus salvifolius	46.9 ^{a}	55.7 ^{ab}	34.6 ^{c}	38.9 ^{a}	40.1 ^{abc}
Cytisus triflorus	36.0 ^{a}	42.6 ^{cd}	26.0 ^{d}	44.8 ^{a}	37.1 ^{bc}
Erica arborea	48.2 ^{a}	53.5 ^{bc}	47.3 ^{ab}	48.4 ^{a}	49.3 ^{ab}
Genista aspalatoides	51.6 ^{a}	64.4 ^{a}	44.3 ^{b}	49.6 ^{a}	51.2 ^{ab}
Myrtus communis	49.0 ^{a}	47.7 ^{bcd}	41.1 ^{bc}	47.0 ^{a}	48.1^{ab}
Phillyrea angustifolia	52.2 ^{a}	50.5 ^{bc}	48.6 ^{ab}	50.4 ^{a}	50.4 ^{ab}
Pistacia lentiscus	50.5 ^{a}	49.8 ^{bcd}	43.6 ^{b}	48.8 ^{a}	48.4 ^{ab}
Quercus suber	49.9 ^{a}	54.5 ^{b}	47.5 ^{ab}	54.1 ^{a}	51.5 ^{ab}
Quercus coccifera	51.1 ^{a}	60.0 ^{ab}	55.2 ^{a}	52.2 ^{a}	53.0 ^{ab}
Smilax aspera	41.0 ^{a}	40.8 ^{cd}	33.4 ^{cd}	46.6 ^{a}	40.5 ^{bc}
Viburnum tinus	41.7 ^{a}	47.9 ^{bcd}	38.7 ^{c}	48.1 ^{a}	43.7 ^{abc}
Calycotum villosa	44.7 ^{a}	nd	40.2 ^{c}	41.2 ^{a}	41.6 ^{bc}
Average	46.9 ^{A}	51.1 ^{A}	41.7 ^{B}	47.2 ^{A}	46.4 *
SE	10.1	4.1	2.8	11.2	--

SE: standard error; nd: not determined; *: global average (all seasons and species); ^{a,b,c}: Means in the same column followed by different letters are significantly different (P< 0.05); ^{A,B}: Means in the same file followed by different letters are significantly different (P< 0.05).

The interaction season-species was significant (P<0.05). Thus, the effect of the season on the dry matter content of the shrubs was variable depending on the species.

Certain species showed a relatively high dry matter content, as *Genista aspalatoides* (64.4%), whereas other species were characterized by a low content, as *Cytisus triflorus* (26%).

Organic matter content

For all the species studied, the organic matter content was not affected by season (P>0.05), and the average content was 95.6% of the dry matter (Table 4).

Despite the lack of effect of the season, the minimum value is recorded in spring (92.8%) and the maximum one, in summer (97.2%).

Table 4. Seasonal variation of organic matter content of 13 shrub species

	Season				
Species	Spring (April -June)	Summer (July-Sept.)	Autumn (Oct.-Dec.)	Winter (Jan.-March)	Average
Arbutus unedo	94.2	96.6	95.5	95.4	95.2
Cistus salvifolius	92.8	95.3	94.4	93.3	93.6
Cytisus triflorus	94.3	94.8	95.4	94.8	94.7
Erica arborea	97.1	97.2	97.1	97.0	97.1
Genista aspalatoides	96.4	97.2	97.5	97.4	97.2
Myrtus communis	95.2	95.6	95.7	96.0	95.7
Phillyrea angustifolia	96.0	96.2	96.2	95.8	95.9
Pistacia lentiscus	95.1	94.5	95.1	95.1	95.0
Quercus suber	96.3	96.6	96.5	96.8	96.5
Quercus coccifera	95.8	96.4	96.6	96.7	96.3
Smilax aspera	95.4	93.4	94.5	94.6	94.7
Viburnum tinus	93.5	94.1	94.3	94.4	94.0
Calycotum villosa	95.0	nd	96.9	96.8	96.2
Average	95.2	95.8	95.8	95.7	95.6 *
SE	1.5	1.5	1.1	1.3	

SE: standard error; nd: not determined; *: global average (all seasons and species).

Total nitrogenous matter content

The global content of total nitrogenous matter was lower than 10% (Table 5). Although there were no significant differences between seasons (P>0.05), this content decreased by 22% from spring to summer, and increased again in autumn. Most of the species showed a lower content than the average. Only *Cytisus triflorus* and *Calycotum villosa* had contents higher than 17% in every season.

Table 5. Seasonal variation of total nitrogenous matter content in 13 shrub species

Species	Season				
	Spring (April -June)	Summer (July-Sept.)	Autumn (Oct.-Dec.)	Winter (Jan.-March)	Average
Arbutus unedo	7.2 ^{b}	5.5 ^{b}	7.0 ^{b}	6.7 ^{b}	6.8 ^{d}
Cistus salvifolius	9.3 ^{b}	6.2 ^{b}	9.7 ^{b}	10 ^{b}	9.4 ^{c}
Cytisus triflorus	20.8 ^{a}	17.2 ^{a}	20.6 ^{a}	22.7 ^{a}	21.0 ^{a}
Erica arborea	7.8 ^{b}	6.2 ^{b}	6.9 ^{b}	9.0 ^{b}	8.2 ^{cd}
Genista aspalatoides	10 ^{b}	7.3 ^{b}	7.9 ^{b}	8.3 ^{b}	8.5 ^{cd}
Myrtus communis	7.5 ^{b}	4.8 ^{b}	6.7 ^{b}	7.1 ^{b}	7.0 ^{cd}
Phillyrea angustifolia	6.9 ^{b}	6.8 ^{b}	6.5 ^{b}	7.2 ^{b}	7.0 ^{cd}
Pistacia lentiscus	8.5 ^{b}	7.1 ^{b}	7.3 ^{b}	7.6 ^{b}	7.8 ^{cd}
Quercus suber	9.6 ^{b}	8.2 ^{b}	9.7 ^{b}	8.0 ^{b}	9.5 ^{c}
Quercus coccifera	9.2 ^{b}	6.8 ^{b}	7.6 ^{b}	7.8 ^{b}	8.1 ^{cd}
Smilax aspera	7.4 ^{b}	6.2 ^{b}	7.0 ^{b}	7.6 ^{b}	7.2 ^{cd}
Viburnum tinus	7.9 ^{b}	5.7 ^{b}	6.6 ^{b}	6.9 ^{b}	7.0 ^{cd}
Calycotum villosa	16.9 ^{a}	nd	20.4 ^{a}	19.1 ^{a}	19.1 ^{b}
Average	9.4 ^{A}	7.3 ^{A}	9.5 ^{A}	9.6 ^{A}	9.2 *
SE	1.7	0.7	2.0	1.6	

SE: standard error; nd: not determined; *: global average (all seasons and species); ^{a,b,c}: Means in the same column followed by different letters are significantly different (P< 0.05); ^{A}: Means in the same file followed by the same letter are not significantly different (P> 0.05).

Total fibre content (NDF)

The total fibre content is shown in Table 6. On the whole, the total fibre content (or NDF: neutral-detergent fibre) represents almost half the dry matter (48.7%). This content is significantly affected by the season. The highest concentration is recorded in summer, in *Genista aspalatoides* (72.2%), and in autumn, in *Quercus coccifera* (69.4%).

Table 6. Seasonal variation of NDF content in 13 shrub species

Species	Season				Average
	Spring (April -June)	Summer (July -Sept.)	Autumn (Oct. -Dec.)	Winter (Jan -March)	
Arbutus unedo	32.6 [bc]	49.4 [c]	50.2 [c]	32.3 [c]	40.4 [c]
Cistus salvifolius	25.8 [bc]	57.7 [b]	45.1 [cd]	30.9 [c]	40.2 [c]
Cytisus triflorus	46.8 [ab]	53.2 [bc]	62.9 [a]	51.9 [a]	54.6 [ab]
Erica arborea	47.6 [ab]	56.9 [bc]	59.5 [b]	41.9 [abc]	50.2 [ab]
Genista aspalatoides	48.0 [ab]	72.7 [a]	59.5 [b]	54.7 [a]	57.8 [a]
Myrtus communis	34.4 [abc]	52.2 [bc]	45.1 [cd]	37.4 [bc]	41.2 [c]
Phillyrea angustifolia	40.3 [abc]	51.0 [bc]	49.4 [cd]	44.7 [ab]	46.1 [bc]
Pistacia lentiscus	38.3 [abc]	51.9 [bc]	51.3 [bc]	36.6 [bc]	44.6 [bc]
Quercus suber	53.1 [a]	52.2 [bc]	66.7 [ab]	51.6 [a]	55.2 [ab]
Quercus coccifera	48.4 [ab]	59.1 [b]	69.4 [a]	54.3 [a]	56.7 [a]
Smilax aspera	52.9 [a]	57.8 [b]	59.5 [ab]	51.3 [a]	55.1 [ab]
Viburnum tinus	36.2 [abc]	45.2 [c]	42.6 [cd]	36.5 [bc]	39.1 [c]
Calycotum villosa	42.0 [abc]	nd	60.0 [ab]	43.3 [abc]	48.0 [abc]
Average	42.4 [B]	55.2 [A]	55.5 [A]	42.1 [B]	48.7 *
SE	7.5	3.0	3.5	5.7	

SE: standard error; nd: not determined; *: global average (all seasons and species); [a,b,c]: Means in the same column followed by different letters are significantly different ($P< 0.05$); [A,B]: Means in the same file followed by different letters are significantly different ($P< 0.05$).

In spring and winter, most of the species studied have total fibre contents lower than the average. Regardless of the season, *Quercus suber* and *Smilax aspera* have contents higher than 50%, whereas in *Viburnum tinus* this value is lower than the average.

Lignocellulose content (ADF)

The global average (considering all the species and seasons together) of lignocellulose content (or ADF: acid-detergent fibre) was 31.3% of the dry matter (Table 7).

Table 7. Seasonal variation of ADF content of 13 shrub species

	Season				
Species	Spring (April -June)	Summer (July-Sept.)	Autumn (Oct.-Dec.)	Winter (Jan -March)	Average
Arbutus unedo	25.0 ^{a}	32.9 ^{d}	31.9 ^{d}	21.8 ^{a}	25.2 ^{c}
Cistus salvifolius	18.0 ^{a}	31.9 ^{d}	30.0 ^{d}	22.7 ^{a}	23.6 ^{c}
Cytisus triflorus	28.8 ^{a}	26.0 ^{e}	30.7 ^{d}	36.1 ^{bc}	31.1 ^{c}
Erica arborea	35.7 ^{a}	39.4 ^{c}	40.1^{b}	32.8 ^{abc}	35.4 ^{ab}
Genista aspalatoides	37.4 ^{ab}	49.5 ^{a}	40.7 ^{b}	42.3 ^{bc}	41.6 ^{a}
Myrtus communis	24.1^{a}	28.7 ^{de}	28.6 ^{de}	23.6 ^{ab}	23.9 ^{c}
Phillyrea angustifolia	29.0 ^{a}	45.3 ^{b}	32.9 ^{cd}	33.2 ^{abc}	33.1 ^{bc}
Pistacia lentiscus	26.1 ^{a}	45.8 ^{b}	34.6 ^{cd}	28.6 ^{ab}	30.6 ^{bc}
Quercus suber	37.8 ^{ab}	32.8 ^{de}	41.6 ^{b}	37.8 ^{bc}	37.7 ^{ab}
Quercus coccifera	33.9 ^{a}	39.0 ^{c}	44.1^{ab}	37.5 ^{bc}	37.1 ^{ab}
Smilax aspera	25.5 ^{a}	36.2 ^{c}	40.5 ^{b}	37.5 ^{bc}	37.8 ^{ab}
Viburnum tinus	26.5 ^{a}	29.2 ^{de}	24.9 ^{e}	26.5 ^{ab}	26.6 ^{c}
Calycotum villosa	29.7 ^{a}	nd	36.0 ^{c}	27.6 ^{ab}	29.4 ^{bc}
Average	29.1 ^{B}	36.4 ^{A}	35.1^{AB}	30.4 ^{AB}	31.3 *
SE	8.0	1.6	1.5	4.7	

SE: standard error; nd: not determined; *: global average (all seasons and species); ^{a,b,c}: Means in the same column followed by different letters are significantly different (P< 0.05); ^{A,B}: Means in the same file followed by different letters are significantly different (P< 0.05).

There are significant differences (P<0.05) between spring (29.1%) and summer (36.4%) contents, while in autumn and winter the concentrations are intermediate and do not differ statistically (P>0.05). Regardless of the season, *Myrtus communis* and *Viburnum tinus* show a lower ADF content than the average. The lowest ADF content is recorded in *Cistus salvifolius* (18%) in spring, whereas the highest content is found in *Genista aspalatoides*, *Phillyrea angustifolia,* and *Pistacia lentiscus* in summer.

Lignin content (ADL: acid-detergent lignin)

Considering all the species and seasons together, the global ADL content reaches 17.4% of the dry matter (Table 8), differing significantly between the seasons (P<0.05).

Table 8. Seasonal variation of ADL content of 13 shrub species

	Season				
Species	Spring (April-June)	Summer (July -Sept)	Autumn (Oct.-Dec)	Winter (Jan -March)	Average
Arbutus unedo	7.5 [bc]	23.3 [bc]	19.8 [b]	11.3 [bc]	14.5 [bc]
Cistus salvifolius	6.1 [bc]	18.6 [cd]	14.1 [cd]	8.0 [bc]	9.9 [c]
Cytisus triflorus	12.8 [abc]	14.4 [d]	13.4 [cd]	14.4 [ab]	13.7 [bc]
Erica arborea	24.2 [ab]	38.2 [a]	32.4 [a]	21.6 [a]	25.5 [a]
Genista aspalatoides	13.3 [abc]	20.3 [c]	14.8 [cd]	14.7 [ab]	15.2 [bc]
Myrtus communis	9.5 [bc]	20.4 [c]	13.2 [cd]	10.3 [bc]	11.5 [c]
Phillyrea angustifolia	15.5 [abc]	29.7 [bc]	17.6 [bc]	18.7 [ab]	18.7 [b]
Pistacia lentiscus	16.0 [abc]	25.9 [bc]	20.9 [b]	18.3 [ab]	18.7 [b]
Quercus suber	16.5 [abc]	16.5 [cd]	18.1 [bc]	23.0 [ab]	19.1 [b]
Quercus coccifera	14.5 [abc]	15.4 [d]	18.9 [bc]	18.6 [ab]	16.6 [bc]
Smilax aspera	20.1 [ab]	16.7 [cd]	19.6 [bc]	18.3 [ab]	19.0 [b]
Viburnum tinus	15.1 [abc]	22.7 [bc]	15.3 [cd]	16.2 [ab]	16.5 [bc]
Calycotum villosa	10.4 [bc]	nd	12.1 [cd]	11.9 [bc]	11.3 [c]
Average	14.8 [B]	21.3 [A]	17.7 [AB]	15.6 [B]	17.4 *
SE	4.9	2.0	1.7	4.7	

SE: standard error; nd: not determined; *: global average (all seasons and species); [a,b,c]: Means in the same column followed by different letters are significantly different ($P < 0.05$); [A,B]: Means in the same file followed by different letters are significantly different ($P < 0.05$).

The highest contents are recorded in summer (38.2% in *Erica arborea*) and the lowest ones, in spring (6.1% in *Cistus salvifolius*). With all species taken together, the average lignin content increases by 44% from spring to summer, and subsequently decreases to attain a concentration statistically similar to that of autumn (17.7%), but different to those of winter (15.6%) and spring (14.8%). The species showing the highest lignin content are, in order of importance, *Erica arborea*, *Smilax aspera*, *Quercus suber*, *Phillyrea angustifolia,* and *Pistacia lentiscus*.

Conclusions

The parietal composition of the shrubs of the maquis varies during the year. NDF, ADF, and ADL contents are relatively high and tend to increase in summer. Regarding the total nitrogenous matter, it tends to decrease from spring to summer. This content is relatively low (less than 10%), with the exception of legumes, *Calycotum villosa* and *Cytisus triflorus*, which have contents similar to those of lucerne. When total nitrogenous matter content is lower than 70 g kg^{-1} DM there is a marked decrease of ingestion. Furthermore, this matter is poorly digested in the rumen because, on one hand, the important fraction of nitrogen linked to the fibres and, on the other hand, the presence of phenolic compounds. The 13 shrub species studied have a high total phenolic content (more than 100g gallic acid-equivalent kg^{-1} DM), which causes a strong inhibitory action on the cellulolythic activity (results not shown). This might negatively affect the digestibility of shrubs. In any case, and despite their chemical composition, the diversity of shrub species and the presence of certain legume species allow us to consider that the shrubs of the maquis have a relatively stable nutritive value during the year.

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Use by young sheep of a mixture of a shrub-based silage fodder

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Introduction

The improvement of pasturelands through the planting of fodder shrubs has been widely developed in Tunisia during the last decades, mainly in the arid areas. Fodder shrubs, namely *Acacia cyanophylla*, *Atriplex nummularia,* and *Cactus inerme* (*Opuntia ficus indica* var. *inermis*), have been planted on about 600,000 ha. These shrubs contribute to the preservation of the ecosystems and increase food resources for small ruminants during dry periods. However, different factors can limit the direct use of shrubs by animals. During the spring and summer, *Acacia cyanophylla* is not available to animals, because the phyllodes are dry and lignified. During the rainy season, the herbaceous species abound in the pastureland and the shrub consumption is rather low, if compared with the biomass produced. Few studies regarding shrub conservation by silage have been published. This technique would allow an increase in the palatability of shrubs and of consumption level and use by the animals as compared to fresh or dry product (El Shaer 2000). The main goal of this work is to study the possibility of stocking *Acacia cyanophylla* and other shrubs: *Atriplex nummularia* and *Cactus inerme*, by using the silage technique, and the effect of the so-treated product on ingestion level, digestibility, and growth of young sheep in comparison to a classic diet based on hay from a vetch-oat mixture.

Material and methods

This study was carried out in El Madfoun Station, located in the centre of Tunisia. *Acacia cyanophylla* occupies 650 ha and is used primarily for wood production. The Station is located in a semi-arid bioclimatic area, with an average annual rainfall of about 330 mm.

Silage of the shrub mixture

The silage was made from a mixture of leaves and tender branches of *Acacia cyanophylla* and *Atriplex nummularia*, and from pads of two year-old *Cactus inerme*, in equivalent proportions, based on the crude matter (1/1/1). The silage capacity was 4.5 t (4 m x 2.9 m x 0.4 m).

The leaves and green branches of *Acacia cyanophylla* and *Atriplex nummularia* are minced with the help of a plant grinder, whereas the cactus pads are chopped into little pieces about 3 cm-long. These products are mixed and stored in silage. Water is added during the filling up of the silage, in order to adjust the dry matter content to about 25%. When the process is finished, the product is packed down and covered with plastic, in order to maintain an anaerobic environment. The silage is opened 60 days after being made.

Diets

Two diets were formulated, the first one (trial) based on the shrub mixture silage (R1) and the second one (R2) (control), based on hay from vetch-oat. Both are supplemented with a commercial concentrate for sheep.

R1: Shrub mixture silage *ad libitum* + 300 g concentrate

R2: Vetch-oat hay + 300 g concentrate.

The concentrate composition is 45% barley, 40% wheat bran, 10% soya meal, and 5% mineral complement with vitamins. Food is supplied twice a day (at 9.00 and 16.00). Water is constantly available for the animals.

Animals

Sixteen, 6 month-old 'barbarine'-race lambs, with an average live weight of 21.3 kg were used for the study. The animals were housed in individual cages and distributed at random into two groups of 8 lambs each, receiving the trial and the control diet respectively.

Measurements and analysis

The quantity of food supplied and rejected was weighed every day for all animals of both groups. The in vivo digestibility of both diets was measured by total collection of faeces (Demarquilly and Boissau 1976). These measurementswere taken for 4 animals per group during two one-week periods, separated by a rest week. The animals previously underwent a two-week diet-adaptation period. In order to study the growth of the animals, they were weighed every 10 days. The weighing was carried out before the morning feeding, always under the same conditions.

The chemical analyses were carried out on distributed and rejected samples and faecal matter. Dry matter (DM), mineral matter (MM), crude proteins (CP), crude cellulose (CC), and phosphorus (P) were analysed using the AOAC methods (AOAC 1975). ADF (acid-detergent fibre) and ADL (acid-detergent lignin) analyses were carried out by the method described by Van Soest and Wine (1967). Digestibility results were statistically analysed by GLM method (SAS 1985). Consumption and growth results were analysed by two-way ANOVA.

Results and discussion

Table 1 shows the results regarding the chemical composition of the different feeds. These results show a high variation between the chemical composition of the fresh shrubs, the shrub mixture silage, and the vetch-oat hay. The dry matter level of silage is comparable to that of plants prior to the silage procedure. This is related to the nature of the fodder used and to the water added during the silage process. The calcium and phosphorus levels are relatively high in the fodder shrubs (*Acacia cyanophylla*, *Opuntia ficus indica* var. *inermis* and *Atriplex nummularia*), higher before conservation (26.4% and 0.97%) than in the silage (19.5% and 0.71%). The decrease might be related to the loss of mineral elements in the silage juice. This decrease is less intense than that observed by Michalet Doreau and Demarquilly (1981) in grass silages. In addition, the level of crude proteins of the silage (9.05%) is comparable to that before conservation (9.33%). This result is similar to that obtained by Demarquilly and Andrieu (1988) in conventional fodders. The level of crude cellulose is relatively high in the silage, if compared to that of the fresh plants (the difference is 4.3%). This result is consistent with those reported by Demarquilly (1980), and Michalet-Doreau and Demarquilly (1981) in other fodder species. The silage pH is 4.24, which allows classifying the product as ‘standard silage’, taking into account its dry matter content (Dulphy and Demarquilly 1981).

The daily-consumed amount of the different fodder constituents is expressed in Table 2. During the experimental time, the lambs having received the shrub mixture silage have consumed less dry matter than the lambs fed with vetch-oat hay as basic ration. In addition, the ingestion level differs significantly between the diets ($P<0.05$). The ingestion level is higher than that observed by Degen et al. (1997) in sheep and goats fed with acacia as sole basic ration. This can be explained by the positive effect of the concentrate added to poor fodder, reported by some authors. In addition, the concentrate proportion has been relatively low in the diets studied: the ratio of concentrate/fodder was about 0.4.

Table 1. Chemical composition of shrubs before and after conservation by silage, and of vetch-oat hay. DM: dry matter (%); OM: organic matter (g kg^{-1}); CP: crude proteins (g kg^{-1}); CC: crude cellulose (g kg^{-1}); ADF: acid-detergent fibre (g kg^{-1}); ADL: acid-detergent lignin (g kg^{-1}); P: phosphorus (g kg^{-1}); Ca: calcium (g kg^{-1})

Species	DM	OM	CP	CC	ADF	ADL	P	Ca
Acacia cyanophylla	40.2	910.3	134.3	209.5	336.5	122.5	1.24	20.8
Opuntia ficus indica var. inermis	10.7	774.7	34.5	125.4	175.6	71.6	0.43	49.3
Atriplex nummularia	41.9	755.7	111.0	300.8	376.0	90.2	1.24	9.3
Shrub mixture silage	29.9	851.1	90.5	255.0	453.4	184.6	0.71	19.5
Vetch-Oat hay	87.8	911.0	39.3	320.5	481.4	78.4	1.32	1.30

The results concerning the in vivo digestibility of the different diets are shown in Table 3. The hay-based diet shows a high digestibility, significantly different from that of the shrub silage ($P<0.05$). In addition, the dry matter, organic matter, crude protein, and ADF digestibility coefficients are inversely correlated to the lignification degree of the diet, expressed through ADF and ADL rates.

Table 2. Average quantity of dry matter ingested from different diets. IDM: ingested dry matter; IOM: ingested organic matter; ICP: ingested crude proteins; ICC: ingested crude cellulose; IADF: ingested acid-detergent fibre

	Shrub silage	Vetch-oat hay
IDM (g j^{-1})	684.4 ± 192.3 b	1016.5 ± 115.3 a
IOM (g j^{-1})	592.7 ± 166.8 b	935.5 ± 102.8 a
ICP (g j^{-1})	67.7 ± 1.2 a	44.0 ± 3.8 c
ADFI (g j^{-1})	29.3 ± 88.3 b	47.3 ± 58.3a

Dry matter and organic matter digestibility are 63.3% and 65.7% respectively, in the case of the hay, and 49.4% and 48.7%, in the case of the shrub mixture silage. As seen, the lowest values are those of the silage. This is probably related to the high concentration of condensed and hydrosoluble tannins found in *Acacia cyanophylla*, which has a negative effect on the digestive use of the diet constituents, namely proteins. Makkar et al. (1989) have observed that the low digestibility of shrubs can be ascribed to a high ADF level in the cell and to a low fixation level in the cell walls of the rumen microorganisms.

Crude protein digestibility is significantly higher ($P<0.05$) in the hay diet, as compared to the shrub silage (50.8% vs. 35.43%). This difference is probably due, once again, to the effect of the tannins, namely those of *Acacia cyanophylla*. Some authors have reported that crude protein digestibility decreases as tannin content in feed increases (Singh and Menke 1986; Kumar and Vaithiyanathan 1990; Koukoura and Nastis 1994; Degen et al. 1995). Tannins immobilize proteins, mainly those proteins of endogenous origin, forming a complex less accessible to the microbial and enzymatic digestion agents (Menke and Leinmüller 1991). As a consequence, the faecal excretion of NDF (neutral-detergent fibre)-associated nitrogen increases and the protein digestibility decreases (Reed et al. 1990; Ben Salem et al. 1995).

The digestibility of the lignocellulose fraction (DADF) of the silage-containing diet is very low as compared to that of the hay-based diet. Reed et al. (1990) have reported negative values for lignin digestibility. In fact, a higher proportion of fibre is digested in the hay-based diet as compared to the shrub silage diet. This could be related to the fact that the shrub silage contains a higher quantity of lignocellulose and a lower quantity of cellulose and hemicellulose than the hay. In addition, the higher tannin content of *Acacia* interferes with the digestibility of the cell wall (Reed 1986; Reed et al. 1990; Hemdane 1994; Ben Salem et al. 1995; Degen et al. 1995).

The results in Table 4 show that the animals fed with the shrub mixture silage have a lower ADG (average daily gain) than those fed with hay (66.8 g day^{-1} vs. 108.0 g day^{-1}). This result is consistent with the ingestion level and the digestibility of the diets studied. The animals that have consumed the highest quantities and shown the highest digestibility have had the highest growth level.

Table 3. Digestibility of the diets studied. Means with different letters differ significantly (P<0.05). DMD: dry matter digestibility; OMD: organic matter digestibility; CPD: crude protein digestibility; ADFD: ADF digestibility

	Shrub silage + concentrate n=8	Hay + concentrate n=8
DMD (%)	49.3 ±1.9 b	63.3 ±1.8 a
OMD (%)	48.7 ±1.1 b	65.6 ±1.9 a
CPD (%)	35.4 ±1.2 b	50.8 ±2.4a
ADFD (%)	1.8 ±0.8 b	62.2 ±2.7a

The daily growth of lambs in this experiement was rather moderated, which can be related to the low nutritive value of the diets and the low level of ingestion. Nevertheless, these diets have allowed fulfilment of the growth needs of the lambs. The weight and growth rate of lambs fed with shrub mixture silage are lower than those of lambs fed with hay. In fact, the animals fed with silage have needed a period of transition and adaptation to the diet, and have shown a growth delay, whereas the hay-fed animals have received the standard diet after weaning. These results are consistent with those reported by Ryan (1990), who has observed that young animals subjected to diet restriction show a growth delay after refeeding.

The results concerning ingestion and nutritive value of shrub silages differ from those obtained by Shaer (2000), who observed a positive effect of shrub silage on goat performances. These differences could be related to differences concerning the period of use of the shrubs and the animal species. The goats could be able to take better advantage of this kind of feed.

Table 4. Weight and daily average gain (DAG) of lambs fed with different diets. Means with different letters differ significantly (P<0.05)

	shrub silage + concentrate	Hay + concentrate
Initial weight (kg)	21.9 ± 1.2 a	21.8 ± 1.3 a
DAG (g day^{-1})	66.7 ± 58.5 b	108.0 ± 23.4 a
Final weight (kg)	24.7 ± 1.6 b	26.3 ± 1.7 a

Conclusions

The conservation by silage of fodder shrubs is possible, and allows the improvement, by shrub planting, of pastureland exploitation. Silage involves changes in the chemical composition of plants. The ingestion level and digestibility of the shrub mixture silage are lower than those of vetch-oat hay, involving a lower growth rate in the first case. In conclusion, the shrub silage cannot be the sole base feed for the young sheep; it must be combined with supplementary feed, apart from concentrate.

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Long-term effects of total forest protection on sandarac conservation and agro-pastoral practices of forest users in Tunisia's Boukornine mountains

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Introduction

Sandarac (*Tetraclinis articulata* Vahl. Masters) trees offer an excellent red wood whose physical and mechanical properties make them transformable into luxurious furniture, cabinetry, doors, and windows that are highly desirable (Bajon 1974). This wood species was prized by the Romans who used it extensively in construction because of its impregnation with a rot-proof resin that constantly gives off a pleasant odour (Ibanaz et al. 1989). From this specific resin, gums are extracted for the purpose of producing nail varnish and many other pharmaceutical products (Seigue 1985). Despite sandarac's inherently slow growth rate, the species has been successfully used in re-forestation programs in arid zones where few other tree species would survive, particularly in Israel's Negev desert (Tenbergen et al. 1995). In Spain, sandarac is used as an ornamental species to improve tree landscapes thanks to its pyramidal shape, quite similar to that of the fir tree which remains in high demand for Christmas celebrations (Seigue 1985). In the northern hemisphere, sandarac has a very limited geographical distribution because its natural occurrence is limited to Spain and Malta where the species is classified as highly threatened, and to the North African countries of Algeria, Morocco, and Tunisia, where it has a reduced lifespan (Seigue 1985; Ibanaz et al. 1989). In Tunisia, , sandarac forests cover a total surface area of about 22,000 ha, 18.4% of which are located in the mountains of Boukornine, near Tunis City. The Cap Bon region of Northeast Tunisia hosts the remaining portion (DGF 1995). Most Tunisian forests, including those of sandarac, suffer from a lack of regeneration often attributed to overgrazing (Hamrouni 1992). This is why the country's foresters have always advocated total protection to insure the regeneration of dominant trees. In Boukornine's case, total protection is further justified by the fact that its forest shelters many other endangered plant and animal species like *Cyclamen persicum*, turtles, chameleons, and rare birds that also needed protection from depredations of forest users and their domestic livestock. With this in mind, a National Park was created in the Boukornine mountains, in 1987. The Park's boundaries cover 48% of the region's forests (1940 ha), while the remaining area (2100 ha) was left as an unprotected buffer zone, hence accessible for grazing and wood harvesting by neighbouring forest inhabitants. Since 1987, the status of this protected area was promoted to that of a UNESCO reserve of the world's biosphere, but the effects of imposing a total protection have never been studied, neither upon the evolution of the vegetation dynamics, nor upon the changes induced in the livelihoods of the Park's neighbouring forest populations. While studies dealing with the socio-economic effects of forest protection remain in constant need for an improved involvement of local populations to conservation issues, there is a worldwide lack of studies focusing on the effectiveness of buffer zones around protected areas in achieving the goals assigned to biological conservation (Heinen and Mehta 2000). The objectives of the present paper were, first, to compare Boukornine's protected and unprotected forest stands 15 years after the Park´s creation in regard to the conservation of the sandarac. Second, we aimed at assessing the changes incurred between 1987 (before the Park creation) and 2002 (after the Park creation) in land use and agro-pastoral practices undertaken by the local forest populations living in agglomerations surrounding Boukornine's National Park.

Materials and methods

Study site description

Boukornine's National Park covers 48% of the sandarac forests found in that mountainous region, with an area of 1,940 ha. The park is located at 20 km south of Tunis City, and is comprised between the longitudes of 8.86 and 8.96 ° E, and the latitudes of 40.72 et 40.81 ° N. The study region is part of the Tunisian Dorsale which is a series of mountain ranges that run across the country from the northeast to the southwest. Boukornine is further characterized by a range of altitudes between 10 and 576 m above the sea level. Its annual rainfall average fluctuates between 450 and 550 mm, depending on altitude, with 95% occurring between September and June. The average annual temperature is 16.7 ° C, with extreme values fluctuating between an average of 7 ° C for January's minima and 26.4 ° C for July's maxima. Soils encountered in Boukornine's mountains differ widely in depth and texture, but they all evolved from a calcareous mother rock. Finely textured and deep soils are predominant in valleys and gentle slopes, while coarsely textured and superficial soils are more frequent on breaks and sharp slopes. The extent of humus presence and the accumulation of organic matter closely follow the soil depth gradient. The tree canopy in Boukornine's forests is characterized by the dominance of sandarac and the sporadic presence of a few other species including: Aleppo pine (*Pinus halepensis* Mill.), Stone pine (*P. pinea*. L), Kermes oak (*Quercus coccifera* L.), and wild olive trees (*Olea europea* var. *oleaster* L.). The understory vegetation is much more diverse when compared to breaks and uplands, with a higher exuberance on river banks where soils are deep and water retention capacity is higher. The most prominent species encountered under tree canopies are : *Ampelodesma mauritanica, Asparagus album, Brachypodium ramosum, Calycotome villosa, Carpobrutus edulis, Cenchrus teraranus, Cistus monspelliensis, C. villosa, Cyclamen persicum, Erica multiflora, Festuca coerulescens, Genista tricuspidata, Globularia alypum, Phagnalon rupestre, Rosmarinus officinalis,* and *Stipa parviflora*.

Sampling the tree canopy

In June 2002, the tree canopy was sampled similarly inside and outside the Park using the point-centred quarter method (Cottam and Curtis 1956). Protected and unprotected forests were each covered by 24 representative sampling points equally distributed among lowlands, breaks, and uplands. Distances were measured from the sampling point to the nearest tree occurring in each of four quarters delimited by two cross lines departing from the selected 48 points, with one line running in the north-south direction and the other running from east to west. Distance measurements were transformed into densities with the distinction between total and specific density based on the species nature for each nearest tree occurring in the quarters. All the closest sandarac trees to the sampling point were submitted to measurements of circumference over bark at breast height, using a graduated ribbon. Circumference values were later converted into diameter values. Double readings of total height measured by an extendable perch were also recorded. Similarly, double counts of branching whorls were made to provide age estimates (Spurr and Barnes 1981) for all sampled sandarac trees.

Surveying the local forest users

After preliminary field reconnaissance visits, a series of formal and informal work sessions were held between January and April 2002 with the local and regional administrative authorities of the district of Ben Arous, to which the territory of the study region belongs, in order to identify the local forest users retaining historical usage rights according to the Tunisian Forest Code. Complete lists of household heads with access to forest resources and living in eight different agglomerations located in the near vicinity of Boukornine's National Park were obtained. Demographic data showing the total human population size on one hand, and the number of households with forest usage rights on the other hand, were used to select the appropriate proportion of households to be surveyed (Table 1). This proportion varied from a maximum of 100% in small sized dwellings like Douar Ben Jazia and Henchir Khelil, to a minimum of 6% in larger dwellings like Nozha village. For the most heavily populated, November 7^{th} City, a greater proportion (26%) of households relying on forest products for their livelihoods was sampled (Table 1), because of its stretch over a larger geographical area along the boundaries of Boukornine's National Park, in comparison to other dwellings. A uniform explanatory survey was conducted during May and June 2002, with the randomly selected household heads, if not all (Table 1), using a structured questionnaire. Accordingly, individual interviews were held to obtain answers allowing for a comparison between the household situation in 1987 (before the Park's creation) and that in 2002 (after the Park's creation) for land use and agricultural practices, livestock herd size, species composition, and foraging systems. The questions included household size, employment of its members, revenues, and use of forest products for livelihood or commercial purposes, whether legally or illegally. The numbers of each domestic animal species: cattle, sheep, and goats, were expressed in terms of standard livestock units (SLU), using the fallowing equation: 1 SLU = 1 cattle = 5 sheep = 6 goats (Ben Mansoura and Garchi 2000).

Table 1. Size of local populations living in the agglomerations neighbouring Boukornine's National Park from which forest users were identified and surveyed in varying proportions in 2002

Agglomeration	Total size	Size of forest users: Identified	Size of forest users: Surveyed		Household average size (capita)
	< - - - - (Number of households)	- - - - >		< -(%)- >	
Douar Ben Jazia	7	7	7	100	7.6
Henchir Khelil	50	14	14	100	5.6
Borj Abla	23	18	9	50	4.9
May 1st village	220	110	11	10	4.9
Ali Ben Faleh	260	100	10	10	5.4
Hached village	270	160	13	8	5.5
Nozha village	290	140	8	6	4.5
November 7th City	320	72	19	26	5.7
Total or	1440	621	91	-	-
Mean	-	-	-	14	5.2

Statistical analyses

All sampled trees were sorted by species and compared for their numbers and frequencies in protected and unprotected forest stands in order to express the botanical composition of the tree canopy layer. Diameters of sampled sandarac trees were classified into increasing categories from smallest to largest using an increment of 2.5 cm. Small diameter classes were used as an indicator for species regeneration, while larger diameters indicated stand aging (Spurr and Barnes 1980). All tree measurements were also submitted to a one-way analysis of variance. When the Fisher test was significant at the level of $P<0.05$ or less, means were separated using the least significant difference (LSD) (Snedecor and Cochran 1980). Data generated by the socio-economic survey were analyzed using descriptive statistics. Results were expressed in terms of increasing categories, percentages, means, and changes between 1987 and 2002, as appropriate. A matrix of simple correlations was also developed between all variables generated by the socio-economic survey using their initial values as well as their mathematical transformations (Draper and Smith 1966) in an effort to explain their variability through possible linkages between resources available to households and their livelihood activities. All statistical analyses were performed using the Costat software package (Cohort 1986).

Results

Influence of forest protection on the tree canopy

Descriptive statistics showed that sandarac was the dominant tree species in both types of Boukornine forests, but its frequency of occurrence was slightly better in unprotected stands (9.9%) than in protected ones (Table 2). Wild olive was the second species offering a common extent of presence inside and out of the Park, with an equal frequency of 2.1%. The botanical composition of the tree canopy showed, however, a major difference represented by the exclusive presence of two pine species inside the Park, while Kermes oak was encountered solely outside (Table 2). Another major difference included the fact that sandarac trees of the smallest diameter class (0 to 2.5 cm) were three times more frequent in unprotected forest stands (15%), by comparison to protected ones (4.5%) (Table 3). In contrast, the combined proportions of the next two classes of small diameters (2.5 to 7.5 cm) were substantially greater inside the Park's boundaries (76.2%) than outside (65.6%). Similarly, aging sandarac trees belonging to the greatest diameter class (15 to 17.5 cm) were twice more frequent under forest protection than in open access forests, with 2.3 and 1.1% respectively (Table 3).

Table 2. Botanical composition of the overstory canopy in protected and unprotected forests of Boukornine mountains, Tunisia, using the point-centred quarter method (Total N = 48 points x 4 trees / point = 192 trees)

	Protected forest		Unprotected forest	
Species	Number of trees	Frequency (%)	Number of trees	Frequency (%)
Tetraclinis articulata	88	91.7	93	96.9
Olea europea var. *oleaster*	2	2.1	2	2.1
Pinus halepensis	5	5.2	0	0.0
Pinus pinea	1	1.0	0	0.0
Quercus coccifera	0	0.0	1	1.0
Total	96	100	96	100

Table 3. Distribution of sandarac (*Tetraclinis articulata*) trees among different diameter classes in protected and unprotected forests of Boukornine mountains, Tunisia

	Protected forest		Unprotected forest	
Class of breast height diameter (cm)	Number of trees	Frequency (%)	Number of tress	Frequency (%)
0 to 2.5	4	4.5	14	15.0
2.5 to 5	37	42.1	36	38.7
5 to 7.5	30	34.1	25	26.9
7.5 to 10	6	6.8	8	8.6
10 to 12.5	8	9.1	8	8.6
12.5 to 15	1	1.1	1	1.1
15 to 17.5	2	2.3	1	1.1
Total	88	100	93	100

The analysis of variance showed that tree densities were significantly ($P<0.05$) and substantially higher inside the Park than outside, with respectively 2409 and 1362 trees ha^{-1} for total density (Table 4). For sandarac's density, values were slightly lower with 2209 trees ha^{-1} in protected forests and 1319 trees ha^{-1} outside the Park. Average age of the sandarac was also significantly ($P<0.05$) higher in protected forest stands (41.5 years) than in unprotected ones (35.5 years) (Table 4). However, no significant ($P>0.05$) differences between the two sides of the Park's fences existed neither for sandarac's average diameter and height, or for the species growth rates related to these two variables. Nevertheless, sandarac stands dominant height was significantly ($P<0.05$) greater inside the Park (4.83 m) than outside (3.89 m) (Table 4).

Table 4. Comparing protected and unprotected forests in the mountains of Boukornine, Tunisia, for total tree density and Sandarac (*Tetraclinis articulate*) density, age, diameter, total and dominant heights, and growth rates

Measurement	Protected forest	Unprotected forest	$LSD_{0.05}$
Total Density (N ha^{-1})	2409 a	1362 b	742
Sandarac density (n ha^{-1})	2209 a	1319 b	647
Average age (year)	41.5 a	35.5 b	3.7
Average diameter (cm)	5.9 a	5.5 a	N.S.
Diameter growth rate (mm $year^{-1}$)	1.4 a	1.5 a	N.S.
Average total height (m)	3.95 a	3.28 a	N.S.
Height growth rate (cm $year^{-1}$)	9.5 a	9.2 a	N.S.
Dominant height (m)	4.83 a	3.89 b	0.91

[1]Means connected with similar letters in a given line are not significantly (P>0,05) different from each other, according to $LSD_{0,05}$.

Influence of forest protection on the agro-pastoral practices of forest users

The socio-economic survey of forest users showed that the ownership of agricultural lands remained static over time, and no changes in access to agricultural land occurred between 1987 and 2002. However, 61.5% of all households with access rights to forest resources were landless (Table 5). In fact, this average proportion varied widely from a minimum of 20% in Ali

Ben Faleh to 88.9% in Borj Abla. Households with land ownership tallied together 38.5%, out of which 15.4% retained small agricultural properties covering only 1 ha or less (Table 5).

Table 5. Extent of availability of agricultural lands to forest users living in different agglomerations neighbouring Boukornine's National Park in either 1987 or 2002, distributed by property size

	Average size of agricultural lands available per household					
Agglomeration	Nil	(< 1 ha)	(1 to 2 ha)	(2 to 5 ha)	(5 to 10 ha)	(>10 ha)
	< Proportion of households with forest usage rights (%) >					
Douar Ben Jazia	57.1	14.3	14.3	0	0	14.3
Henchir Khelil	42.9	35.7	14.3	7.1	0	0
Borj Abla	88.9	0	11.1	0	0	0
May 1st village	54.5	18.2	9.1	9.1	9.1	0
Ali Ben Faleh	20.0	30.0	10.0	20.0	10.0	10.0
Hached village	76.9	0	7.7	7.7	7.7	0
Nozha village	62.5	25.0	12.5	0	0	0
November 7th City	78.9	5.3	5.3	10.5	0	0
Mean	61.5	15.4	9.9	7.7	3.3	2.2

Land property sizes covering between 1 and 2 ha were held by a lower percentate averaging 9.9%, while household properties comprised between 2 and 5 ha belonged to 7.7% of the region's forest users. Larger land properties covering 5 to 10 ha, or more than 10 ha, belonged to the smallest percentage of owners, with 3.3% and 2.2% respectively of all households with access rights to forest resources. However, these two greatest classes of property sizes were less common, as they occurred in only 3 or 2 agglomerations among all dwellings surrounding Boukornine's National Park (Table 5).

Households owning land and engaged in arboriculture and/or vegetable cropping were by far more numerous in 2002, when compared to 1987 (Table 6). Indeed, those practicing fruit tree cultivation rose from 23% in 1987 to 57% in 2002, while the proportion of households engaged in growing vegetables passed from 0 to 20% during the same period. Concomitantly, there was a severe decline in the proportion of households cultivating grain cereals and/or leaving the land bare or under fallow (Table 6). For instance, the percentage of households engaged in cereal grain cropping dropped from 57% in 1987 to only 9% in 2002. A similar decline in land abandonment practice occurred during the same period of time, from 60% to 11% of all households considered (Table 6). Losses in these traditional agricultural practices were replaced, over time, by equal gains in forage cultivation using mainly alfalfa (*Medicago sativa*) or a mixture of A*vena-Vicia* species, in an effort to meet the household's animal forage needs.

Households engaged in raising livestock among the region's forest users increased from an average of 27.5% in 1987 to 42.9% in 2002 (Table 7). All agglomerations were affected by this rising trend over time, except Borj Abla and May 1st villages where the fraction of households herding livestock remained constant, with 33.3% and 27.3% respectively. During the same period, the total livestock population, all animal species combined, declined from 170.7 to 148.5 SLU. In fact, this 13% decline affected only five agglomerations among those surrounding Boukornine's Park. In the remaining three other dwellings of Douar Ben Jazia, Henchir Khelil, and Hached village, there was actually a dramatic increase in total domestic livestock (Table 7). Together, their animal population rose nearly three times from 23.4 SLU in 1987, to 72.6 SLU in 2002. The ratio of livestock accumulation also decreased between 1987 and 2002, but this general declining trend in the average herd size from 6.8 to 3.8 SLU/household did not affect all agglomerations. The two dwellings of Douar Ben Jazia and Henchir Khelil represented the exceptions, as their average herd size in 2002 was more than double what it was in 1987 (Table 7).

All the study region's households retaining forest usage rights and raising livestock recognized that the Park creation in 1987 reduced their traditional grazing space and imposed changes on their foraging strategies.

Greater reliance on grazing crop residues represented the most important change, followed by an increased orientation towards forage cultivation in replacement of cropping grain cereals or leaving the land under fallow. Poor, landless forest users opted for grazing along roadsides and vague terrains in surrounding urban areas, in addition to the accessible buffer zone. Wealthier ones chose to raise livestock in feedlots where commercial rough and concentrate forages are brought from outside the region. The significant ($P<0.05$) positive correlation ($r=0.808$) found between the total livestock population owned by forest users in 2002 and the sum of all agricultural lands available to them (Figure 1a) confirmed the move over time towards increased integration of livestock production with agricultural land uses, other than the forest cover. This finding was further corroborated by another highly significant ($P<0.01$) positive correlation ($r=0.871$) linking the household's average herd size in 2002, to the size of the family's agricultural land (Figure 1b). In both cases, the explanatory variables remained constant between 1987 and 2002, but neither of the two correlations shown in Figure 1 existed when data pertaining to 1987 were analyzed. Among the region's forest users, the disinherited households who owned neither livestock nor land admitted, to varying degrees, to being in constant conflict with the forest administration as shown by the significant ($P<0.05$) correlation ($r=0.816$) linking these two variables (Figure 2a). Another positive correlation ($r=0.960$), very highly significant ($P<0.001$), between forest users' average household size and the proportion of those admitting active engagement in transgressing forest laws (Figure 2b) provided further evidence of a lingering hardship effect driven by the Park's creation on the livelihoods of forest users. Both correlations shown in Figure 2 were elaborated using values assessing forest users' situation in 2002, but they did not exist when past situation values of 1987 were analyzed.

Discussion

Effects of total forest protection on sandarac's conservation

The obtained results showed that open forests were more efficient in ensuring sandarac's conservation, using several criteria such as the species frequency of occurrence in the tree canopy (Table 2), the frequency of sandarac's smallest diameter class as an indicator of the species regeneration and establishment of its saplings (Table 3), tree canopy densities, and aging (Table 4). Thus, continued access of forest users to graze the competing understory vegetation was more beneficial to the species growth and regeneration than total protection. Similar results showing enhanced forest regeneration and improved tree growth in moderately grazed Mediterranean forests were previously reported by numerous authors (Allen and Bartolome 1989; Etienne 1996; Gonzalez-Hernandez and Silva-Pando 1996). Long-term absence of any form of use, including clearing and grazing, caused the accumulation of excessive shading which severely hindered the regeneration of sandarac, a sun loving species (Seigue 1985). Excessive shading due to very heavy canopy densities was also responsible for a greater number of small sandarac diameters (2.5 to 7.5 cm) inside the Park (76.2%), in comparison to open forests (65.6%) (Table 3). Similar findings showing reduced growth in diameter for sandarac, hindrance of the species regeneration, and its ageing under high densities in Jbel Latrache were previously reported by Ben Mansoura and Garchi (2001). Although, unprotected forests in Boukornine out-performed protected ones in achieving sandarac's conservation objectives, densities remain very high in the open forest stands as well. This is demonstrated by the species slow growth in diameter with an average of 1.4 to 1.5 mm $year^{-1}$ (Table 4). In the neighbouring forest of Jbel Latrache, sandarac grew faster with an average value of 3.7 mm $year^{-1}$ thanks to lower densities varying mostly between 82 and 848 trees ha^{-1} (Ben Mansoura and Garchi (2001). Furthermore, the species growth in height was substantially lower in Boukornine (9.2 to 9.5 cm $year^{-1}$) (Table 4), when compared to the neighbouring sandarac forests of Jbel Latrache where stem elongation was also faster with 17.9 cm $year^{-1}$. Although tree height is rather dependent on soil fertility (Spurr and Barnes 1980), the proximity of the two sandarac forests where prevailing climatic and soil conditions are quite similar does not explain the large difference in the species height growth rate. This difference is, therefore, attributed to the excessive densities encountered in Boukornine compared to to Jbel Laache. Excessive canopy closure was previously stigmatized for reduced stem elongation of sun loving species like Aleppo pine (Garchi and Ben Mansoura 999), and sandarac (Seigue 1985). The effect of stand soil fertility on height growth (Spurr and Barnes 1980) was demonstrated in the significantly ($P<0.05$) greater dominant height value which was obtained inside the Park (Table 4). This is because the Park's boundaries were deliberately established to protect the best sandarac stands that existed in the region when protection was imposed in 1987. But, this initial advantage favouring the Park in stand soil fertility was lost over time since no differences existed, in 2002, in sandarac's average total height between protected and unprotected forest stands. The loss of this advantage is explained by excessive canopy closure which also hindered the species stem elongation as argued above. Consequently, intensive clearing is badly needed in both protected and unprotected forest stands of Boukornine in order to promote sandarac's growth and regeneration. Absence of clearing in open forests is explained by its prohibition by the Tunisian Forest Code which allows forest users to extract dead wood only. Heavy tree densities inside the Park, as elsewhere, are often explained by the forest administration's insufficient funds and lack of personnel (Hamrouni 1992). However, shortages in material means to conduct periodic canopy clearing operations seem to affect most developing countries (Wilkie et al. 2001), as well as developed ones (Noss 1996). High tree densities engender greater risks of forest fires and favour their recurrence due to woody fuel accumulation (Etienne1996; Spurr and Barnes 1980), and litter build-up (Peet 1971). Boukornine's protected forests have been prone to such accidental fires and the worst fire ever occurred in the summer of 1999 when a formidable blaze swept over a large surface area of the Park, leaving behind extensive biological damages. Unprotected forest stands were less prone to such accidental fires due to the continuous presence of local inhabitants, always ready to prevent the spread of unpredicted burns.

Effects of total forest protection on agro-pastoral activities of forest users

Local forest users responded to the Park creation by a series of changing attitudes which varied according to the most important resources for their livelihood: land and livestock. In general, the 48% reduction in the traditional forest grazing space due to the Park's creation in 1987 made land more valuable in the region, and this is why no property legal release occurred between 1987 and 2002. Scarcity of land is further demonstrated by the fact that 61.5% of all forest users owned no land, in addition to the fact that the smallest property sizes of 1 ha or less belonged to the largest proportion of land owners with 15.4% (Table 5). Land owners responded to the park's creation by the abandonment of traditional agricultural practices like cultivating cereals and/or leaving the land bare or under fallow (Table 6). Instead of these low profit practices due to their incompatibility with rugged mountainous terrain (Ben Mansoura et al. 2001), they opted for more lucrative cultivations of fruit trees and vegetables, in addition to growing forages. Similar rationalization of land use induced by accrued land scarcity around protected areas was previously reported by Pfeffer et al. (2005). Greater land scarcity for free grazing in forests was also responsible for the substantial increase in the proportion of households engaged in raising livestock from 27.5% in 1987 to 42.9% in 2002 (Table 7). This increasing trend is a reminder of Hardin's (1968) tragedy of the commons where no one would gain by limiting the benefits he derives from the common resource pool. Hardin's (1968) tragedy was more acute in the three agglomerations of Douar Ben Jazia, Henchir Khelil, and Hached villages where the total livestock population increased between 1987 and 2002, despite a general declining trend elsewhere in the region (Table 7). This exceptional rise in total animal numbers was obviously driven by severe land scarcity in these three agglomerations where the proportion of landless households and those owning only 1 ha or less varied between 71.1 and 78.6% (Table 5). Further evidence of continued common resource abuse is provided by the fact that the region's overall reduction in domestic livestock population, between 1987 and 2002, attained only 13% (Table 7), whereas the reduction in the common forest grazing space was much higher as protection was imposed on 48% of the region's forest cover. The disproportionate reduction in livestock population that was induced by the Park's creation confirmed the importance of grazing as a major source of revenue in Tunisian forest regions where this activity generates 18 to 80% of the forest users' annual income (DalyHassen and Ben Mansoura 2005). Changes over time in the ratio of livestock accumulation showed a declining trend in herd size affecting six of the region's agglomerations, confirming the hypothesis advanced by Pfeffer et al. (2005) for increased rationalization of limited resources use around protected areas. But the rise in herd size which occurred in the two villages of Douar Ben Jazia and Hechir Khelil (Table 7) contradicts the latter hypothesis. It is essentially attributed to the severe land scarcity in these two dwellings (Table 5). Livestock accumulation is considered an important indicator of resource abuse, and high ratios of this variable were highly correlated with environmental degradation (Ben Mansoura et al. 2001; Ben Mansoura and Garchi 2000).

Changes in agro-pastoral activities induced by the Park's creation in 1987 led to a greater integration of livestock production with improved agricultural land uses in 2002 (Figure 1). This argument was verified at the level of the region's total resources in land and livestock (Figure 1a), as well as at the level of single households (Figure 1b). In both cases, the most important departures from the fitted curves were due to Douar Ben Jazia and Ali Ben Faleh. In these two instances, livestock production is a popular activity affecting respectively 57.2 and 70% of all households with forest usage rights (Table 7). Simultaneously, land is severely scarce in these two dwellings as demonstrated by high numbers of household who own no land at all or own 1 ha or less, with 71.4% in Douar Ben Jazia and 50% in Ali Ben Faleh (Table 5). The lingering hardship effect induced by the Park's creation on the livelihoods of local inhabitants is further aggravated by the household size (Figure 2a), and the unavailability of both land and livestock resources (Figure 2b). Douar Ben Jazia which had the greatest number of individuals per household in the region (Table 1), showed a record high in the number of forest users being in constant conflict with the forest administration (Figure 2a). The same dwelling also had the highest proportion of those actively engaged in illicit forest activities (Figure 2b), such as poaching and extraction of protected species like turtles and *Cyclamen* flowers for commercial purposes (Ben Mansoura et al. 2001). These findings are in contradiction with the concept of Nepal and Weber (1994) stating that local people will not extract resources from the park anymore, once access to the buffer zone is allowed. In this study, access to the buffer zone did not prevent anthropogenic encroachment inside the park nor did it solve conflicts with the forest administration.

Conclusion

A long-term (1987-2002) total forest protection was detrimental to sandarac's conservation due to the accumulation of excessively high tree densities which hindered the species growth and regeneration. Grazing and removal of dead wood from open forest stands by local inhabitants were more efficient than total protection in achieving sandarac's conservation objectives, thanks to reduced tree densities and lowered competition between the species saplings and the understory vegetation. Intensive clearing remains badly needed in both protected and unprotected forest stands in order to promote sandarac's conservation objectives. Protection of 48% of the region's forest cover induced a land scarcity which led to a more rational use of the neighbouring agricultural lands and a greater integration of livestock production with new agricultural practices favouring forage cultivation instead of traditional cereal cropping or fallowing. Accrued land scarcity after the Park's creation along with the region's forest users' initial poverty status and household size were the driving forces for continued conflicts with the forest administration and the transgression of forest laws, both inside and outside the protected area.

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