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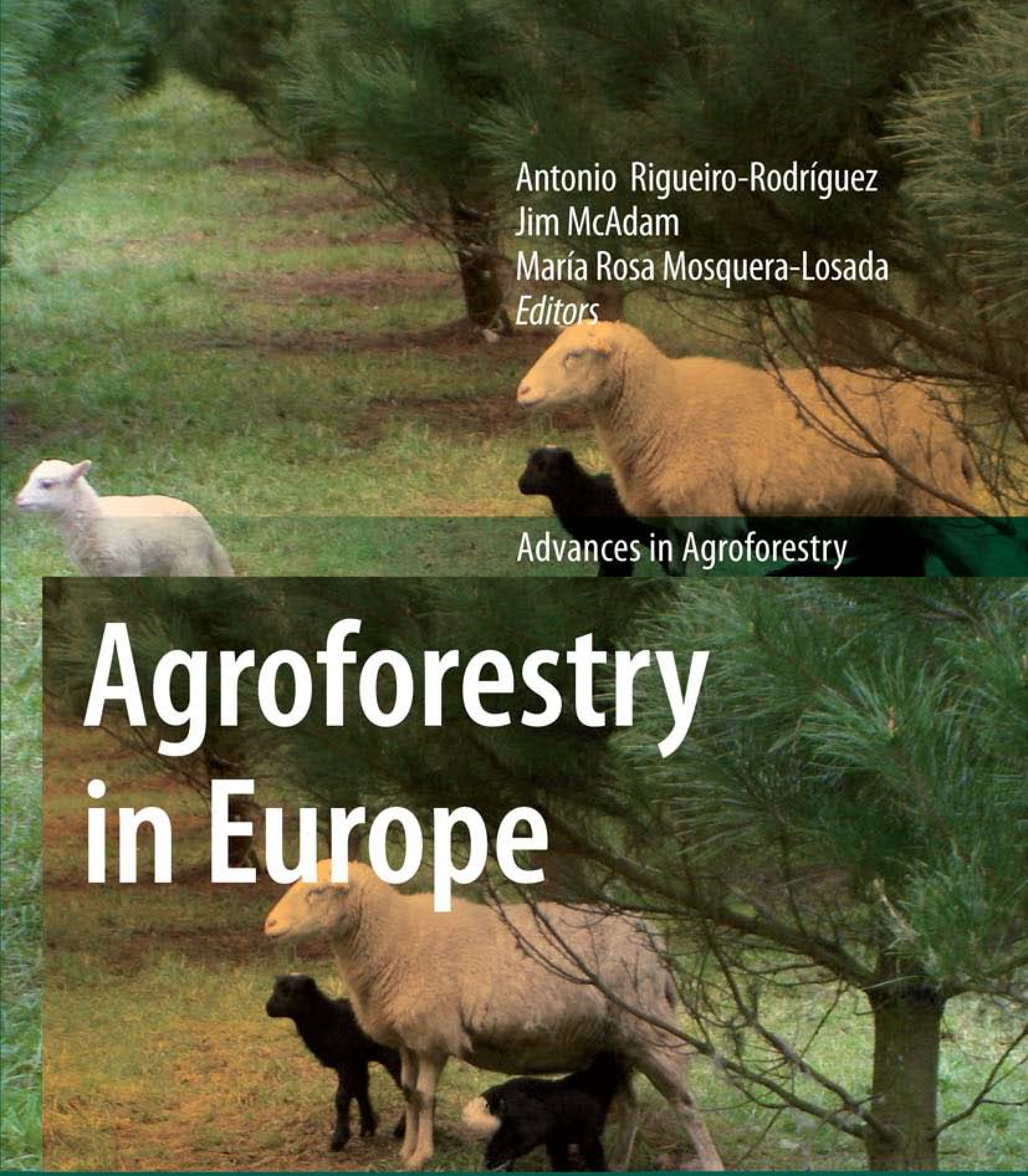

Advances in Agroforestry

Agroforestry in Europe

Current Status and Future Prospects

Springer

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Advances in Agroforestry

Volume 6

Series Editor:
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Aims and Scope

Agroforestry, the purposeful growing of trees and crops in interacting combinations, began to attain prominence in the late 1970s, when the international scientific community embraced its potentials in the tropics and recognized it as a practice in search of science. During the 1990s, the relevance of agroforestry for solving problems related to deterioration of family farms, increased soil erosion, surface and ground water pollution, and decreased biodiversity was recognized in the industrialized nations too. Thus, agroforestry is now receiving increasing attention as a sustainable land-management option the world over because of its ecological, economic, and social attributes. Consequently, the knowledge-base of agroforestry is being expanded at a rapid rate as illustrated by the increasing number and quality of scientific publications of various forms on different aspects of agroforestry.

Making full and efficient use of this upsurge in scientific agroforestry is both a challenge and an opportunity to the agroforestry scientific community. In order to help prepare themselves better for facing the challenge and seizing the opportunity, agoroforestry scientists need access to synthesized information on multi-dimensional aspects of scientific agroforesty.

The aim of this new book-series, *Advances in Agroforestry*, is to offer state-of-the art synthesis of research results and evaluations relating to different aspects of agroforestry. Its scope is broad enough to encompass any and all aspects of agroforestry research and development. Contributions are welcome as well as solicited from competent authors on any aspect of agroforestry. Volumes in the series will consist of reference books, subject-specific monographs, peer-reviewed publications out of conferences, comprehensive evaluations of specific projects, and other book-length compilations of scientific and professional merit and relevance to the science and practice of agroforestry worldwide.

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Foreword

Agroforestry has come of age during the past three decades. The age-old practice of growing trees and crops and sometimes animals in interacting combinations – that has been ignored in the single-commodity-oriented agricultural and forestry development paradigms – has been brought into the realm of modern land-use. Today agroforestry is well on its way to becoming a specialized science at a level similar to those of crop science and forestry science.

To most land-use experts, however, agroforestry has a tropical connotation. They consider agroforestry as something that can and can only be identified with the tropics. That is a wrong perception. While it is true that the tropics, compared to the temperate regions, have a wider array of agroforestry systems and hold greater promise for potential agroforestry interventions, it is also true that agroforestry has several opportunities in the temperate regions too. Indeed, the role of agroforestry is now recognized in Europe as exemplified by this book, North America, and elsewhere in the temperate zone. Current interest in ecosystem management in industrialized countries strongly suggests that there is a need to embrace and apply agroforestry principles to help mitigate the environmental problems caused or exacerbated by commercial agricultural and forestry production enterprises. If we are to meet the society's needs and aspirations for forest-derived goods and services, we must find ways of augmenting traditional forestry by gleaning some portion of these benefits from agricultural lands where agroforestry can be practiced. In many places, the only opportunity to provide increased forest-based benefits, such as wildlife habitat or forested riparian systems, is through the increased use of agroforestry on agricultural lands. The publication of this book is very timely. As the editors say, the European Union has recognized the economic, ecological, and social advantages of agroforestry in its rural development policy; but the implementation of the policy is adversely affected by the lack of adequate information on the subject. The need for such a book is obvious.

I want to say how much I appreciate the enormous amount of work involved in bringing together such a volume. The state of agroforestry in Europe and literature on it being at early stages of development, it must have been a daunting task for the authors to piece together the information they have so painstakingly gathered for their chapters. I congratulate all the authors and the editors for such a wonderful job. Undoubtedly, this is a significant contribution to agroforestry literature worldwide and a great service to the fledgling field of European agroforestry.

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P. K. Ramachandran Nair
September 2008

Preface

While recent EU Rural Development policy clearly recognizes the economic, ecological, and social advantages of agroforestry systems, to date the implementation of such systems has been poor so far throughout most of Europe. In light of this, this collection of peer-reviewed papers brings together some of the most important current research in European agroforestry, and evaluates the current scope and future potential of agroforestry across the EU.

This volume contains a selection of papers covering the most recent research, embracing the wide range of geographical zones and crops and livestock systems found in Europe. While the majority of Europe's agroforestry practices are currently focused in the Mediterranean, this volume draws together examples from a wide range of countries – including France, Germany, Greece, Hungary, Ireland, Italy, Portugal, Slovenia, Spain, Switzerland, the Netherlands and the UK. The book also covers a range of agroforestry types, including silvopasture – Europe's predominant form of agroforestry – silvoarable, forest farming and multipurpose trees, but also explains some other practices like improved fallow and riparian buffer strips. Through these examples the book also discusses the potential roles for these traditional land management systems in addressing both environmental issues such as carbon sequestration, water quality, biodiversity conservation, desertification, soil preservation ecosystem services and socioeconomic issues such as rural population stabilization.

Augmented by detailed reviews of the main elements of European agroforestry and the issues that face it, this timely collection of research papers provides a valuable reference for advanced students and researchers, administrators and policy makers interested in a wide range of issues around land use, rural development, natural resource management, landscape ecology and conservation across Europe, and for those interested in agroforestry – including practitioners, researchers and extension organizations – worldwide.

This book is structured in four main parts: the Introduction, the European Mediterranean Agroforestry systems, the European Atlantic Agroforestry systems and the European Continental, Pannonian and Alpine Agroforestry systems. At the end of the book a chapter related to future directions is provided.

The **Introduction** part give the reader a general perspective on the development of agroforestry practices and systems in Europe in fourth chapters. It is important to highlight that there has been no previous attempt in describing agroforestry in pan-European level although there are some books and other publications dealing with specific aspects of the main agroforestry practices implemented, e.g. silvopasture. The first chapter of the book introduces the reader to the description of the main agroforestry practices found in Europe: silvoarable, forest farming, riparian buffer strips, silvopasture, improved fallow and multipurpose trees. The current situation of the main components of agroforestry systems, i.e. tree and agricultural (including pasture and livestock), are briefly described to give the reader an initial balanced perspective on the status of European agroforestry systems and practices at a farm level. The second chapter reviews different types of classifications and functions of current agroforestry systems in Europe according to their components, spatial and temporal arrangements, functions, agroecological zone and socio-economic aspects, focusing on silvopastoral and silvoarable practices, the main types of agroforestry practiced in Europe. The third chapter of this part of the book is related to the future perspective for the use of these agroforestry systems at a farm level, based on their productive and ecological advantages. The fourth and final chapter of this part of the book deals with a social study conducted at 14 locations in seven countries within the European Union, to evaluate the degree of knowledge about agroforestry practices and the potential benefits and disadvantages that they can bring to farmers.

Part II dealing **European Mediterranean Agroforestry systems** has 10 chapters (Chapters 5 to 14). These chapters provide descriptions and development of agroforestry systems in the densely populated countries of the Mediterranean areas and examine how the economics of agroforestry systems in Europe has changed over time due to the different social conditions of the farmers. The countries/regions to which the chapters relate include Greece (Chapter 5), the transitional Atlantic-Mediterranean area of Western Europe (Chapter 6) and the four autonomous regions of the Mediterranean part of Spain: Cataluña, Murcia, Extremadura and Andalusia (Chapters 7 to 10). These have very different rural social structure, physical mountain geography and Mediterranean climate sub-classification types. While dehesa, the most widespread agroforestry system of southern Europe is the focus of Chapter 7. Chapter 8 deals with the forest grazing type of agroforestry practice in Cataluña. Chapter 9 presents studies on agroforestry practices in a river basin and along an altitudinal and precipitation gradient from 0 to 2,000 m asl and from 300 to 1,000 mm year^{-1}, respectively, in southern Spain. Various aspects of silvopasture are included in detail in the next two chapters (10 and 11). Chapter 12 deals with the main types of agroforestry practices in the Mediterranean and Alpine biogeographic regions of Italy. This chapter also evaluates the connection between them through traditional and current management. A socioeconomic study of cork oak agroforestry systems is the subject of Chapter 13. The part concludes with Chapter 14 that deals with forest farming, explaining the history of truffle production within the main European countries and presenting a synthesis of the best practices to reach high truffle productivity.

The next book part (Part III) deals with the **European Atlantic Agroforestry systems** in three chapters. This biogeographic region is characterized by having a history of clear-cut separation between forest and agricultural land, at all levels including education, farming systems and policy. Allocation of the most productive areas to agricultural production, often at the expense of forest, has been an important feature of the land-use policy in the region. Thus, agroforestry systems are neither widespread nor properly implemented in this part of Europe. In the recent years, some important afforestation schemes have been carried out in this zone, even though some parts have the lowest proportion of forestland in Europe. The first paper of this part of the book (Chapter 15) describes a methodology used to locate the dominant trees distributed throughout Europe and demonstrates the advantages of applying stratification to estimate a complex land use resource, using the different ecological conditions found in the region. Chapter 16 deals with the development over time and description of current agroforestry practices in the Netherlands, while the opportunities for introducing silvopastoral and silvoarable systems in Ireland, one of the least forested areas of Europe, is the focus of Chapter 17. The chapters in this part clearly bring out the point that the main driving force behind the introduction of such systems in the region is the promotion of floral and faunal biodiversity and other aspects of environmental sustainability that are adversely impacted by agriculture.

The final part of the book deals with **European Continental, Pannonian and Alpine Agroforestry systems** in four chapters and explains that the main aims of implementing agroforestry systems in these areas are to exploit the environmental and crop protection functions offered by trees. The implementation of agroforestry practices in Germany is described in Chapter 18, whereas Chapter 19 describes the Alpine regions silvopastoral systems in Switzerland, where, unlike in the Mediterranean areas, supplementary food for livestock is obtained during summer time. Chapter 20 presents the Slovenian perspectives on agroforestry covering not only Alpine and Continental areas, but also Mediterranean areas and even some areas with Atlantic climatic characteristics. The final chapter of this part (Chapter 21) describes the specific characteristics of silvopastoral and silvoarable agroforestry practiced in the Pannonian region and explains how implementation practices such as hedgerows is very important in dealing with the special climatic characteristics of wind and snow in the region.

This book concludes with a synthesis (Chapter 22) of the information presented in the various chapters emphasizing the major challenges as well as opportunities of agroforestry in Europe.

We hope that this collection of research papers, augmented by detailed reviews of the main elements of European agroforestry and the issues facing it, will be a valuable reference source for advanced students and researchers, administrators and policy makers interested in a wide range of issues around land use, rural development, natural resource management, landscape ecology, and conservation across Europe, and for those interested in agroforestry – including practitioners, researchers and extension organizations – worldwide.

We thank all authors of individual chapters for their excellent contributions as well as splendid cooperation in dealing with repeated revisions of their manuscripts. Each chapter was peer-reviewed; the reviewers did a superb job in enhancing the

content and presentation quality of the respective chapters. Finally, a special word of appreciation to Professor P.K. Nair, the book-series editor, for suggesting the idea for such a book, and following it through its completion with consistent encouragement and valuable directives thought the process.

Rigueiro-Rodríguez A
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Chapter 1
Definitions and Components of Agroforestry Practices in Europe

M.R. Mosquera-Losada[1]*, J.H. McAdam[2], R. Romero-Franco[1], J.J. Santiago-Freijanes[1], and A. Rigueiro-Rodríguez[1]

Abstract Agroforestry systems are traditional land use systems that were and are used in Europe. They can be defined as those land use systems which involve two main components – trees/shrubs and an agricultural crop (which could also be pasture) and are artificially managed. Agroforestry systems can be implemented at a temporal and spatial scale for a land owner, who can use different agroforestry practices. Since human interaction with the environment in Europe is very important and has occurred for a long time there are different types of agroforestry practices in Europe that are described in this chapter and named, silvoarable, forest farming, riparian buffer strips, silvopasture, improved fallow and multipurpose trees. A brief description of the main agroforestry practice components, i.e. trees and agriculture (including pasture and livestock) in Europe will give an overview of the current and potential situation in Europe for the use of these systems.

Keywords Silvorable, forest farming, riparian buffer strips, silvopasture, improved fallow, multipurpose trees

Definitions of Agroforestry

Agroforestry can be defined as sustainable way of land management which integrates both agricultural and forestry practices on the same land management base. Agroforestry system practices have been defined by different authors (Nair 1993) as practices which involve "the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land". The International Centre for Research in Agroforestry (ICRAF) and the World agrofor-

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estry Centre (WAC) define the term agroforestry as “a dynamic, ecologically based natural resources management system that, through the integration of trees in farmland and rangeland, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels” and “A land-use system in which woody perennials (trees, shrubs, palms, bamboos) are deliberately used on the same land management unit as agricultural crops (woody or not), animals or both, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components”, respectively. Finally the AFTA (Association for Temperate Agroforestry) (1997) in USA also defines Agroforestry systems as “an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock”.

Hence agroforestry systems should involve two main components: trees/shrubs and an agricultural crop (which could also be pasture). All types of agroforestry systems integrate people as part of the system as they are artificial systems to a higher (i.e. domestic animals) or lower degree (i.e. wild animals in natural or national parks), where one component can be promoted over the other, or both at the same time trying to reach equilibrium between the different components. The promotion of one component over the other can be modified as the tree develops. Man, through traditional experience and practice or new knowledge, should promote the positive interactions between the two components, by an initial knowledge-based selection of the tree species and later by adequate management, mainly of the agricultural crop. Silvicultural practices applied during the main, stable years of the tree stand life could be implemented through the enhancement of the synergies of the tree and the crop (mainly related to thinning and pruning practices). However, the definitions are not clear if the shrubby or the tree component should be an indistinct component. For the purpose of this book agroforestry systems include shrubs as a main component of the woody vegetation.

Classification of Agroforestry Practices

Following the definitions given by AFTA (1997) and Alavalapati and Nair (2001) there are currently five basic types of agroforestry practices in temperate areas: windbreaks, alley cropping, silvopasture, riparian buffers and forest farming. This classification is mostly based on the main practices developed in America. Although the situation is different in Europe, this classification is still valid, but, it should be slightly changed and increased in scope (Table 1.1): silvoarable agroforestry, forest farming, riparian buffer strips, silvopasture, improved fallow and multipurpose trees. European farmers have had a longer history of interaction with forests than American farmers. This interaction, coupled with the significant range of climates and microclimates has led to the evolution of many combinations of agroforestry practices in Europe. Most of the types of agroforestry practices described around the world were present in different parts of Europe at different levels of intensity,

Table 1.1 Agroforestry practices in Europe (Modified from Association for Temperate Agroforestry (AFTA) 1997); Alavalapati and Nair 2001; Nair 1994; Alavalapati et al. 2004)

Agroforestry practice	Brief description
Silvoarable agroforestry	Widely spaced trees inter-cropped with annual or perennial crops. It comprises alley cropping, scattered trees and line belts
Forest farming	Forested areas used for production or harvest of natural standing specialty crops for medicinal, ornamental or culinary uses
Riparian buffer strips	Strips of perennial vegetation (tree/shrub/grass) natural or planted between croplands/pastures and water sources such as streams, lakes, wetlands, and ponds to protect water quality
Improved fallow	Fast growing, preferably leguminous woody species planted during the fallow phase of shifting cultivation; the woody species improve soil fertility and may yield economic products
Multipurpose trees	Fruit and other trees randomly or systematically planted in cropland or pasture for the purpose of providing fruit, fuelwood, fodder and timber, among other services, on farms and rangelands
Silvopasture	Combining trees with forage and animal production. It comprises forest or woodland grazing and open forest trees

and overlapping both temporally and spatially depending of the livelihoods and needs of European citizens. There was an notable decline in the implementation of agroforestry practices in Europe in the 20th century, when agriculture was intensified, specialised and promoted. Most extended agroforestry practices nowadays in Europe are silvopasture and silvoarable practices (Agroforestry Forum 2007).

Silvoarable Practices

Silvoarable practices were defined by Eichhorn et al. (2006) as widely spaced trees inter-cropped with annual or perennial crops. The main characteristic of this kind of agroforestry practice is determined by the agricultural component, which is harvested every year or every few years in the case of energy crops. It is very important that trees are widely distributed across the land to facilitate the movement of machinery through the plots to reduce harvesting costs. This is also enhanced through the position of the trees in rows or surrounding the plots, when light interception is reduced and allows maximum light to the crop (Mosquera-Losada et al. 2005). The range and implementation of the most common silvoarable practices currently used in Europe are described in Chapter 2. They include (1) *alley cropping*, i.e. trees planted in single or grouped rows within agricultural or horticultural fields with crops growth in the wide alleys between the tree rows, (2) *scattered trees* at low density (not in rows) with an annual cropping pattern. Silvoarable systems can include annual crops like maize, wheat, oats, sunflower, vegetables or fodder production (to make silage or hay), but also perennial crops which are harvested every few years (e.g. energy crops) and (3) line belts such as hedgerows, shelterbelts, windbreaks and forest belts. Belts are tree rows distributed around farms and, together with the riparian agroforestry systems are classified as "trees outside the forest" in European statistics (MCPE 2003). Nowadays, it can be included those tree formations planted at the sides of roadways or railways to separate them from agricultural land and which protect, at the same time, agricultural lands and artificial paths from strong wind and blown snow (Takács and Frank 2008). Hedgerows are usually made of trees or thorny shrubs which are cut and shaped in order to interweave the branches and create "walls" to separate agricultural crop areas from grasslands (Herzog 2000). The use of this kind of agroforestry practice reached its maximum around the 18th century and then started to decline. It is estimated that since 1969 between 40% to 80% of the European hedgerows have disappeared or degenerated due to the reallocation of agricultural holdings to create larger field plots (Herzog 2000). The main types of hedgerows are seen in Brittany (*bocages*), Normandy, Ireland, the Knicks and Walhecken in Germany, but they are not usually seen in the southern part of Europe. Shelterbelts, windbreaks and forest belts are usually aimed to protect crops growing in their lee (Takács and Frank 2008).

Forest Farming

Forest farming includes forested areas used for production or harvest of natural or cultivated speciality crops for medicinal, ornamental or culinary uses. There are many examples of this type of agroforestry practice in Europe like medicinal plants, mushrooms, truffles, berries, honey and decorative foliage as described by MCPFE (2003). This represents around 27% of the share of the total non-wood forest products from forest and other wooded land across 27 countries of Europe. The other non-wood forest products are game (30%) which is a kind of silvopasture, Christmas trees (24%), nuts (7%) and cork (11%). Mushrooms, including truffles, are the most important non-wood forest specialty crop in Europe. As a resource after game and Christmas trees, their use has been recorded in 15 out of 27 European countries (including Spain), followed by fruit and berries which were recorded in 17 countries. Medicinal plants are also important in 9 out of 27 European countries (including Spain). It is important to highlight that harvesting of these plants is usually uncontrolled, which makes it very difficult to manage sustainably the system and reduces its potential profitability. Mushrooms, medicinal plants and berries appear to be dominated by personal use, and their harvesting is not clearly regulated and can result in crop damage.

The main types of wild mushrooms harvested in European countries are ectomycorrhizal fungi developed in natural forests and plantations. Mushroom production can be associated with those broadleaved ecosystems (e.g. Atlantic and Mediterranean oaks, chestnuts) and also pine stands. Production is mostly in autumn, although, in some areas, spring production is important. Mushroom annual production is variable, and depending very much on intra-annual climate conditions, but there are years in which the economic importance of this product is higher than other forest products in some areas. Mushroom production could be between 15 and 100 kg ha^{-1} $year^{-1}$. There are several dozen species of edible wild mushrooms that can be harvested in Europe and which have economic importance like *Amanita caesarea* (Scop.: Fr.) Grév., *Boletus edulis* Bull.: Fr. and other species of the same group like *Lactarius deliciousus* L.: Fr., *Cantharellus cibarius* Fr., *Hydnum repandum* L. ex Fr., *Tricholoma portentosuum* (Fr.) Quélet, *Morchella* spp., *Cantharellus tuberiformis* Fr. etc. Some crop and silvicultural techniques can enhance fungus production like clearance, pruning, thinning, fertilization or summer irrigation (Fernández and Rodríguez 2000). Truffle is an important crop and its history and recent advances in agroforestry are described in this book (Reyna-Domench and García-Barreda 2008).

Medicinal plants are an important economic resource for many countries (FAO 1995, 1997). The WHO estimates that around 80% of the world population use medicine plants for therapeutical uses. Around 25% of the commercial medicines used by the pharmaceutical industry are prepared with components which come directly from plant species, and the other 25% come from plants derived and modified in pharmaceutical laboratories (De Silva 1997). Europe is the main place in the world where medicinal and commercial transactions take place. This market is worth around 6.7 billions dollars annually (Laird and Pierce 2002). Germany is the main European medicinal plant market which is worth around 1.2 billion dollars and has commercialized between 500 and 600 plant species (Lewington 1992). The total European medicinal plant market involves around 2,000 species, between 1,200 and 1,300 of these are native species, the rest are imported. Most (80%) medicinal plant production has been commercialized in five European countries: Germany, France, Italy, Spain and United Kingdom. Annual European exports are around 70,000 t, approximately 20% going to the North American market (Lewington 1992).

Harvesting of wild medicinal plant populations is still very important worldwide, especially in countries like Albania, Bulgaria, Hungary and Spain. From all the autochthonous species commercialized in the European markets, around 90% come from wild populations, representing between 20,000 and 30,000 t per year. By country, it is estimated that between 30–50% of aromatic and medicinal plants commercialized in Hungary come from wild collection, 50–70% in Germany, 75–80% in Bulgaria and almost 100% in Albania (Lange and Schippmann 1997; Lange 1998). Particular species or groups of plant species collected are *Adonis vernalis* L., *Arctostaphyllos uva-ursi* (L.) Sprengel, *Arnica montana* L., *Cetraria islandica* (L.) Ach. Cast., *Drosera anglica* Hayne, *Drosera intermedia* Hudson, *Drosera rotundifolia* L., *Gentiana lutea* L., *Glycirrhiza glabra* L., *Menyanthes trifoliata* L., *Origanum* spp., *Paeonia* spp., *Primula* spp., *Ruscus aculeatus* L., *Sideritis*, spp. and *Thymus* spp. The intensive and unsustainable management of a lot of European populations of medicinal and aromatic plants has prompted the European Union to supervise commercial transactions with these types of products. An official list of plants to be regulated has been drawn up (Annex D of the EU Council Regulation No. 338/97 on “the protection of species of wild fauna and flora by trade" regulation). Also the annexes of the Community Directive about the use of habitats, flora and fauna includes some of the medicinal plants under threat and therefore the member states should use policy measures to promote better management to avoid this scenario. Some of these plants are already included in the "Red lists" and in books of endangered flora of the different countries and 24 species are endangered at a European scale (Walter and Gillet 1998). For these reasons it is very important that the future market for aromatic and medicinal plants should be based on cultivation rather than wild collection. Around 130–140 species are already cultivated, but most are in an experimental phase or grown in small areas only. Only *Carum carvi* L., *Foeniculum vulgare* Mill., *Lavandula* spp. and *Papaver somniferum* L. are cultivated in extensive areas.

Riparian Buffer Strips

Riparian buffer strips of perennial vegetation (tree/shrub/grass) are planted between croplands/pastures and water sources such as streams, lakes, wetlands, and ponds to protect water quality. In Europe they are usually located along streams or rivers and are often remnants of former river plains forest with willows (*Salix* spp.) alder (*Alnus glutinosa* (L.) Gaertn.) and a variety of hardwood trees (*Fraxinus excelsior* L., *Ulmus* spp. *Acer* spp., *Quercus robur* L.). They protect water bodies against sedimentation, soil erosion on adjacent agricultural lands, but of more current importance, against nitrate contamination. A Ministerial Conference on the Protection of Forests in Europe (MCPE 2003) considers tree forest riparian strips and line forests (hedgerows, shelterbelts, windbelts) as coming under the definition of trees outside forests. This kind of agroforestry (Long and Nair 1999) can be seen in different parts of the world. Most riparian forests (natural and plantations) are of high economic, ecological and landscape importance due to the modification and improvement of the landscape, the high wood quality of some of the component tree species attract a good price (*Populus* spp., *Alnus glutinosa*, *Alnus cordata* (Loisel.) Duby, *Fraxinus excelsior*, *Fraxinus angustifolia* Vahl, *Betula pubescens* Ehrh., *Betula alba* L., *Ulmus glabra* Huds, *Ulmus minor* Mill., *Celtis australis* L., *Acer pseudoplatanus* L., *Quercus robur*) and because they have been used as food for livestock. Mushrooms and medicinal plants are also produced in this kind of ecosystem. From an ecological point of view, they regulate light and temperature of the rivers, acting as green filters, which reduces the eutrophication processes, help stabilise river banks, act as food and cover for aquatic fauna and amphibian. They are communities of high biodiversity acting as corridors for flora and fauna.

Improved Fallow

Improved fallow is defined as fast growing, preferably leguminous woody species planted during the fallow phase of shifting cultivation; the woody species improve soil fertility and may yield economic products. This kind of agroforestry system was used in the recent past in some parts of Europe. It can be said that until the use of fertilizers became widespread, there was a very close connection between forestry and agricultural land in Europe. The importance of agricultural land in a built-up area and the degree of fertility was linked to the area of forest it has (with a temporal and spatial perspective), with the exception of coastal areas, where the shells of molluscs and crustacean as well as algae were used to improve soil fertility. Until the end of the 1960s, *Ulex europaeus* L., *Cytisus striatus* (Hill) Rothm. and *Genista florida* L. (leguminous woody species) were sown to be harvested for compost in stables (they were used as a bed for animals, horse feed and wood production), and after 10–20 years rotation the same soil was used to grow wheat or rye. This was very labour demanding and, due to the high salary costs, is currently not profitable. If mechanised, this system could be used for organic farming. In the same way, in Galicia, long rotations of cereals and legume shrubs like *Cytisus striatus* were used for firewood and, when it was present on the land, a natural grass stratum was produced and used by livestock. This practice has been completely replaced in recent years by artificial fertilization and liming of those acid soils.

Multipurpose Trees

Multipurpose trees can be fruit and/or other trees randomly or systematically planted in cropland or pasture for the purpose of providing fruit (both for human and animal consumption), fuelwood, fodder and timber, among other services, on farms and rangelands. Leaves and fruits from some of the European species such as *Castanea sativa* Mill., *Fraxinus* spp., *Betula* spp. and *Quercus* spp. were used in the past to feed animals and help overcome feed shortage periods. The importance of fruit-trees distributed throughout agricultural land can be seen by the different names of this kind of practice has in Europe like "*Streuobst*" in Germany, "*près vergers*" in France, "fruit-tree meadows" and "orchards" in English. Despite the lack of information of this kind of system in most of European countries, there are around 1 million hectares of Streuobst in 11 European countries (Herzog 2000). In Spain and Portugal multipurpose trees are usually a practice linked to the most traditional agroforestry system in Europe called "*dehesa*", where acorn production of trees like *Quercus ilex* L. and *Quercus suber* L. was used in the past and still is, to feed animals like pigs. Acorn production from this agroforestry practice (multipurpose tree) is very important to sustain the system because it provides a cheap feed resource for animals when fodder such as grass is not available (Cañellas et al. 2007). In those years when summers are especially dry and pasture availability is reduced for a very long period of time, to overcome pasture shortage, trees are pruned to feed animals and enhance fructification, and thus are a sort of food "storage", as branches can be pruned when an especially dry summer appears. Multipurpose or fodder trees and shrubs are very important to feed animals during shortage periods in most of the Mediterranean area (Dupraz 1999). This practice was also used in the past to feed humans in the humid part of Spain, where *Castanea sativa* Miller fruit was the basic human daily carbohydrate resource until a disease (ink illness – caused by the fungus *Phytophtora cambivora* (Petri) Buis, *Phytophtora cinnamomi* Rands)) destroyed most of the trees in the lowlands and in the areas prone to high humidity, which causes that this species was replaced by the potato as the main carbohydrate human resource. This practice has decreased since the mid 19th century. Chestnut woodlands are considered nowadays to have high economic importance due to their high quality wood and fruits. This explains the establishment of recent plantations over the past few decades with hybrids of *Castanea sativa* and *Castanea crenata* Sieb. & Zucc. (from Japan), which are interspersed with varieties of high quality fruit (big, easy peeling and with low number of partition walls). In some Atlantic areas (north-west Spain) some of the traditional agroforestry practices are recovering, like pigs grazing in these chestnut woodlands, and feeding on the fruits (*montanera*) during the fattening period, this is mainly done in this area with the autochthonous Galician pig breed (Celtic breed). A new disease (caused by *Chryphonectria parasitica* (Murril) Barr. & Anderson) is rapidly spreading through the European chestnut woodlands and is even affecting the ink-resistant hybrids. Some vaccines have recently developed for some of the types of the disease and currently research is been conducted to find some resistant ecotypes or breeds. Special cultural treatments like pruning and injections can reduce the spread of the disease because the common mode of entry of the pathogen is to infect the tree through an injury (Bounous et al. 2001).

Silvopasture

Silvopasture is the combination of trees with forage and livestock production. They can include (a) <u>forest or woodland</u> grazing when forestry production is promoted (high density stands, natural forests) mainly associated with wild or local or autochthonous rustic breeds of animals and (b) <u>open forest trees</u> (low density stand, recently afforested or reforested areas) which could have wild or domestic animals. Silvopasture is one of the main types of agroforestry practices used in the past and currently in Europe and can be found in all the biogeographic regions of Europe, such as Alpine (Mayer 2005), Atlantic (McAdam 2005; Rigueiro-Rodríguez et al. 2005), Boreal (Hytönen 1995), Continental (Boron 2005), Mediterranean (Eichhorn et al. 2006) and Pannonian (Takács and Frank 2008). This agroforestry practice is characterised by having an extra component, the grazing or browsing animal, in comparison with the other agroforestry practices, so it can include natural parks (mainly for preserving nature, and with an important social use, but managed by man) that can be found all over Europe, but also farms with domestic animals, i.e. the reindeer farms, *dehesas* or *montados*, associated with the Boreal and Mediterranean areas, respectively. Heterogeneity created by the presence of animals at an appropriate stocking rate has been recognised as an important tool in the preservation of biodiversity (Hytönen 1995; Mosquera-Losada et al. 2005; Martínez-Jauregui 2007) as can also be found throughout this book (Buttler et al. 2008).

European Components of Agroforestry Systems

Agroforestry systems can be exclusively formed by either one or a combination of agroforestry practices (the most common situation) and practised at the same time or at different times during the year on any one farm. Agroforestry practices can also be combined in a temporal (transhumance – Helle 1995; Bunce et al. 2008; Pardini 2007) and at a spatial (Mosquera-Losada et al. 2005; Moreno and Pulido 2008; Moreno et al. 2007) scale. The main combinations of most of these practices used nowadays in Europe can be seen in the second chapter of this book, and they are mainly found in two categories: silvoarable and silvopastoral areas. There are two main components of agroforestry practices (trees and crops) and their current status will be briefly described in this chapter. Also a brief description of livestock component in Europe is described, due to the high importance of silvopasture in Europe.

The productivity of both, tree and agricultural components as well as the interactions between them, depends on the edaphoclimatic conditions where they are implemented. Agroforestry systems can be developed together with forestry and agronomic systems to enhance productive, social and environmental goods from the broader European landscape.

Following the EEA (European Environment Agency) (2003) maps, 11 biogeographic regions can be described in Europe (Fig. 1.1), which together with the nineteen different soil types (Jones et al. 2005) define the vegetation types of Europe on a broad scale. In this book the agroforestry systems of the Alpine, Atlantic, Continental, Mediterranean and Pannonian biogeographic regions will be evaluated from an ecological, productive and social perspective. Statistics based on biogeographic regions are difficult to extract as most of them involve different regions of different countries, and usually data are only given on a country basis.

Tree Component

Fourteen forest types have been recently defined in the whole European continent (EEA 2003) and two of these – boreal and hemiboreal forest (45% of the forestland in Europe) – are very important. Others like coniferous forest of the Mediterranean, Anatolian and Macaronesian regions (7%), plantations and self sown exotic species (7%), Alpine coniferous forest (6%), mesophytic deciduous forest (6%), thermophilous deciduous forest (6%), birch or aspen forest (6%), beech forest (5%), montane beech forest (4%), broadleaved evergreen forest (4%)

	Biogeographic region	Main threats to biodiversity
	Arctic region	Climate change may change conditions for plant and animal communities Ozone depletion
	Boreal region	Intensive forestry practices Exploitation for hydroelectric power Freshwater acidification
	Atlantic region	High degree of habitat fragmentation by transport and urban infrastructures Intensive agriculture Eutrophication with massive algal blooms Invasive alien species
	Continental	High degree of habitat fragmentation by transport and urban infrastructures Industry and mining Atmospheric pollution Intensive agriculture Intensive use of rivers
	Alpine (Alps, Pyrenees, Carpathians, Dinaric Alps, Balkans and Rhodopes, Scandes, Urals and Caucasia).	Climate change may change conditions for plant and animal communities Transport infrastructures Tourism Dams
	Pannonian	Intensification of agriculture Drainage of wetlands Irrigation combined with evaporation leads to salinisation and alkalisation Eutrophication of large lakes Mining industry with heavy metals pollution of some rivers
	Mediterranean	The world's most important tourism destination High pressures from urbanisation in coastal areas Intensification of agriculture in plains, land-abandonment in mid-mountains Desertification in some areas Invasive alien species
	Macaronesian (Includes Azores, Madeira, Canaries islands)	Invasive alien species Tourism Forest fires and uncontrolled tree-felling Intensification of agriculture with large greenhouses
	Steppic	Intensification of agriculture, e.g. abandonment of nomadic pastoral activities Desertification Large mining and industrial settlements, with pollution problems
	Black Sea	Intensification of agriculture: irrigation, salinisation Waterlogging Tourism
	Anatolian	Intensification of agriculture : conversion of steppes into arable lands, irrigation, drainage of wetlands, overgrazing Building of dams

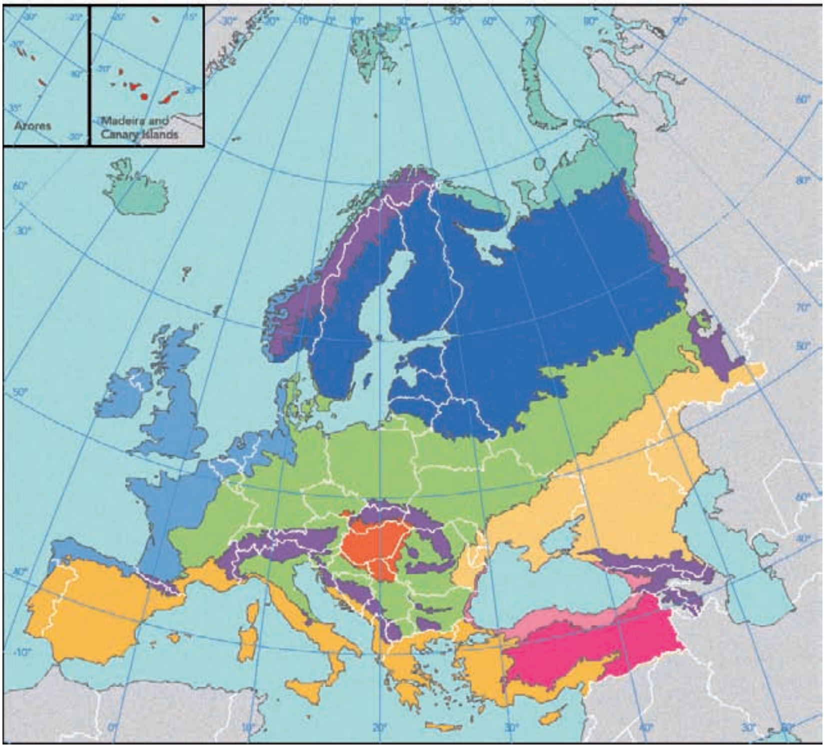

Fig. 1.1 Biogeographic regions of Europe (EEA 2003)

are less represented but in total occupy 51% of the European area. There are three types of very scarce forest – acidophilus oak and oak-birch forest (1%), non riverine alder and in a smaller proportion, flood plain forest (1% including riparian and fluvial forests) and mire and swamp forest (1%). Köble and Seufert (2001) mapped 115 forest species in the EU and found that there are 36 tree species with coverage over 0.2% representing 95% of the European forest area. Only two tree species occupy more than 50% of the European area (EU-30), which are *Pinus sylvestris* L. (31%) and *Picea abies* (L.) H. Karst. (21%). The following main European tree species (EU-30) include *Fagus sylvatica* L. (7%), *Betula pubescens* (5%), several tree species with a percentage between 2% and 3% like *Quercus robur*, *Pinus pinaster* Aiton, *Betula pendula* Roth, *Quercus petraea* (Matt.) Liebl., *Q. ilex*, between 1% and 2% *P. nigra* J.F. Arnold, *Abies alba* Mill., *Q. pubescens* Wild., *P. halepensis* Mill., *Castanea sativa*, *Q. cerris* L., being between 0.5–1% others like *Carpinus betulus* L., *Eucalyptus* sp., *Q. suber*, *Larix decidua* Mill., *P. sitchensis* (Bong.) Carr., *Q. pyrenaica* Willd., *Populus tremula* L., *Fraxinus excelsior*, *Q. frainetto* Ten., *Robinia pseudoacacia* L., *P. menziesii* and, finally, between 0.2 and 0.5 *Alnus glutinosa*, *Acer platanoides* L., *Ostrya carpinifolia* Scop., *Pinus pinea* L., *Quercus faginea* Lam., *Quercus coccifera* L., *Abies cephalonica* Loudon, *Tilia cordata* Mill., *Quercus rotundifolia* Lam. and *Pinus contorta* Dougl. ex Loud. Most of these species are or were related to agroforestry practices in Europe.

Coniferous boreal forests, mainly formed by *Pinus sylvestris* and *Picea abies*, used to have agroforestry practices related to forest farming (mushroom collection, medicinal plant collection, small fruits and woods) and silvopasture (reindeer farming). However agroforestry practices in the rest of the area are scarce with the exception of the Mediterranean and southern Atlantic areas. Tree species linked to silvoarable practices are *Quercus* spp., *Juglans* spp., *Populus* spp., *Prunus* spp., *Eucalyptus* spp., *Castanea sativa*, *Pinus* spp. Tree species like *Populus* spp., *Alnus* spp., *Betula* spp., *Acer* spp. and *Fraxinus* spp. are more linked to riparian buffer strip practices and *Quercus* spp., *Fraxinus* spp., *Castanea* spp., *Eucalyptus* spp. and *Pinus* spp. are more linked to silvopastoral practices. Truffles are farmed from forests with *Q. ilex*, *Q. robur* and *Q. coccifera* species, mushroom production to *Quercus* spp., *Castanea* spp., *Fagus* spp., *Abies* spp., *Pinus* spp. and *Picea* spp.), small fruit production is linked to *Quercus* spp., *Fagus* spp., *Pinus* spp., *Abies* spp., *Picea* spp. and *Betula* spp.). The main multipurpose trees belong to the genera *Robinia*, *Morus*, *Quercus* spp., *Fraxinus*, *Betula*, *Castanea*, *Pinus*, especially *Pinus pinea* and *Castanea sativa* for direct human consumption.

Depending on biogeographic and edaphic characteristics, tree species could be very broadly European distributed (e.g. *Quercus petraea*, *Pinus sylvestris*) or occupy a very small area (e.g. *Pinus pinaster* or *Quercus ilex*) of the continent. There are also some species introduced to Europe as they have a high growth rate, e.g. *Eucalyptus globulus* Labill., *Pseudotsuga menziesii* (Mirb.) Franco, *Pinus radiata* D. Don, *Quercus rubra* L.. Silviculture recommended for most of the tree species is to plant them at a high density leaving less opportunity for the ingression of other non-wood products and manage them in a profitable and intensive way. However, there are no available statistics for use beyond timber production for these species at a European scale which makes it very difficult to know the degree of implementation of agroforestry practices or the real amount of silvopasture practiced in Europe. There is a lack of knowledge regarding the non-wood product use per region, but as mentioned before, this could include medicinal plants, mushrooms, crop production under trees or grazing (either with domestic or wild animals). This makes very difficult to know the degree of implementation of these systems and how agroforestry system use is changing over time. However, some indirect estimates can be made if tree cover is taken into account because when tree cover is low, light is allowed to reach the soil and the productivity of other products different from wood is enhanced. From FRA (2005) data from Europe on forest land and other wooded land (OWL) distribution it can be seen that OWL, which will include the lower density of woodland stands, defined as land either with a tree crown cover or equivalent stocking level of 5–10% of trees able to reach a height of 5 m at maturity in situ; or a crown cover (or equivalent stocking level) of more than 10% of trees not able to reach a height of 5 m at maturity in situ (e.g. dwarf or stunted trees) and shrub or bush cover, is mostly found in the Mediterranean biogeographic region of Europe, where agroforestry practices are most important (Fig. 1.2) (Etienne 1996). However, agroforestry practices are also present in other areas like Boreal (Yrjölä 2002), Atlantic (Rigueiro-Rodríguez et al. 2005) and Alpine areas where silvopasture, in terms of woodland pasture depends on altitude (Gillet and Gallandat 1996).

The tree component will have a major effect on understory production as it affects the amount of light reaching the ground. Trees most suitable for agroforestry will be those species which have low branch density are self-pruning and have good leaves distribution. The two first of these characteristics will have a significant effect on final wood quality. It is also advisable to use trees with a deep rooting capacity which will avoid competition with crops or pasture. Tree type affects understory production, e.g. trees with leaves, which fall every year, are more suitable than evergreen trees, as light is allowed to entry in the system when radiant energy input is low (autumn and winter), but also because of the higher soil nutrient

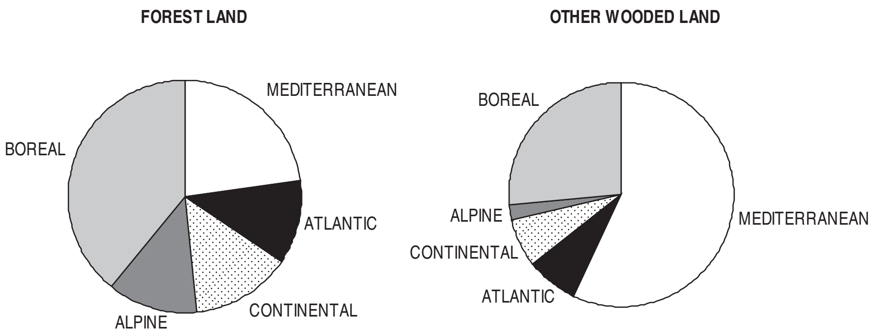

Fig. 1.2 Forest land and other wooded land distribution per biogeographic region of Europe (FRA 2005)

enrichment. The fewer the branches trees have, the more light can enter the system, e.g. compare *Betula alba* or *Populus* spp. with *Pseudotsuga menziesii*.

Silvicultural practices can also help manipulate tree component products as well as understory production. As tree density and distribution as well as tree age will affect understory production tree management is very important (Mosquera-Losada et al. 2005). So, if an agroforestry system is established several aspects should be taken into account. (1) Genetic improvement and quality selection: The low recommended tree density for agroforestry establishment removes the option of successive thinnings to select final trees. (2) Pruning and thinning silvicultural practices are important as it reduces tree-understory competition. (3) The use of mulching or plastic to reduce the initial competition with weeds or sowing pasture should be implemented to reduce initial tree-understory competition. (4) Tree protection should be a major silvicultural practice.

Tree regeneration, particularly in silvopastoral systems (where stock will graze the young seedlings) is one of the main issues in implementing agroforestry practices. There are different types of tree protectors, such as those using metallic or plastic mesh fixed to the soil with wire or wood sticks buried in the soil to retain the mesh or those already commercially available (Tubex 2007). INRA studies have shown that these tubes can, also reduce low branching, initial tree mortality and enhance initial tree growth in some tree species (Tubex 2007). In any case, stocking rate should be low enough to avoid damage, as usually, animals will preferentially graze the herbage component. However, animal preferences depend on animal type. Animals like goats prefer woody vegetation, are not suited to silvopastoral systems with young trees and should be avoided. In any case, and as most of the European forests are planted with seedlings of the same age in the same piece of land, grazing can be avoided by fencing over the first few years, as the potential for tree damage reduces as the trees age. Agroforestry practices other than silvopasture can be used to avoid this problem.

Agricultural Component

One of the main aspects of the agricultural component of the agroforestry systems, with or without trees, is the total and seasonal distribution of rainfall as well as the soil type which will determine the total and seasonal understory productivity, as long as light inputs are not greatly reduced (Mosquera-Losada and González-Rodríguez 1999).

Agriculture, either for pasture or crops, is the main European land use (Fig. 1.3) for most of the biogeographic regions with the exception of Alpine (18%) and Boreal (45%) biogeographic regions which are dominated by forest (EEA 2006). Arable crops dominate the steppic (71%) and pannonian biogeographic regions (54%), pasture and a mosaic of crops are more important in the Atlantic (33%) and Continental (25%) biogeographic regions. However, it has to be taken into account that there is an important use of land for agriculture in the forest area, where trees are scarce or at low density and there is a level of pasture production which sustains

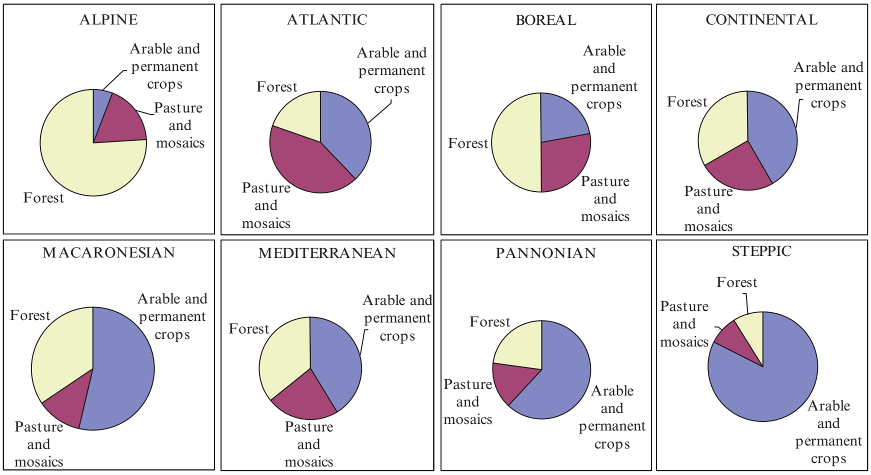

Fig. 1.3 Forest, pasture and mosaics of arable and permanent crops expressed as proportion per biogeographic region (EEA 2006)

livestock production (silvopasture). This happens in the Mediterranean area of Europe or in the Boreal region. However, statistics on agroforestry practices on arable land are usually rare in Europe, in spite of the benefits from an ecological point of view that they can offer (Dupraz et al. 2005). Main arable crops in EU are cereals (wheat, barley, grain maize and durum wheat), followed by Oilseeds (rape, sunflower) and green fodder (EU 2005). Most of these crops are produced in an intensive way and trees or shrubs are rarely associated with them, so silvoarable agroforestry practices presence in Europe is very scarce (Eichhorn et al. 2006). Silvoarable practices should be based on reducing competition between the tree and crop component (e.g. reducing light, nutrient and water competition), this should be done by adequate dispersal and density of trees in arable plots (Dupraz et al. 2005; Mosquera-Losada et al. 2005). Arable crops can be linked to agroforestry practices like riparian buffer strips, silvoarable (including line belts), or in the past improved fallow because these practices would deliver productive, environmental and social benefits as can be seen in Chapter 3 of this book. The other important agricultural land use in the EU is pasture, and there is a long tradition of using trees as part of the grassland systems, like reindeer husbandry in boreal countries, hedgerows in Continental or Atlantic countries or multipurpose trees in Mediterranean and Macaronesian biogeographic regions. A description of how these practices are linked to agroforestry systems can be seen in Chapter 2.

Livestock Component

Silvopasture is the main agroforestry practice used in Europe, hence, the types of animals and the most recent changes in this sector are important from an agroforestry point of view. Pastures are most common in the Atlantic countries (Fig. 1.3) as well as in the Mediterranean countries where OWL areas are very important for livestock maintenance. For this reason the possible implementation of silvopasture in these areas will be discussed.

The main type of livestock in Europe (EU-15) are bovines (50%) followed by pigs (25%), poultry (13%), sheep (9%), equidae (1.5%), and goats (0.9%) (Vidal 2002). There are clear preferences between the numbers of holdings in the different European countries. Bovines are more commonly found in Atlantic areas and goats and sheep in Mediterranean areas (Vidal 2002). This can be explained by the predominance of herbaceous pastures in the Atlantic area compared with the shrubland use in the Mediterranean area. Bovine dominance is based on dairy cows, which are usually intensively managed and create contamination problems, mainly related to nitrate leaching. Dairy cow numbers in the EU have been reducing since 1984 due to the increase in productivity of the dairy sector and the successive reduction in quotas. This reduction has benefited other types of bovines and also sheep number, which are based on more extensive systems, where silvopasture could be better implemented. Agricultural intensification of grassland has decreased significantly all over Europe (EEA 1999). This extensification (EU 2006) will reduce the profitability per unit of land, and this could be reversed by the introduction of trees at a density which will not reduce pasture or forage production to any great extent.

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Chapter 2
Classifications and Functions of Agroforestry Systems in Europe

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Abstract Agroforestry systems have often been neglected in Europe because administrative structures within many national governments have considered that only agriculture or forestry are legitimate within their remit. This has resulted in the loss of agroforestry systems in European countries and an impoverishment of the benefits that they provide. This paper argues that agroforestry systems are a complex interaction of agricultural and forestry elements which can be classified according to their components, spatial and temporal arrangement, agro-ecological zone, and socio-economic aspects. A further breakdown can be made on the basis of ecosystem functions, and their associated goods and services. The ecosystem functions of agroforestry systems can be grouped under production (the creation of biomass), habitat (the delivery of biodiversity), regulation (maintenance of essential processes and life support systems) and culture (cultural heritage, landscape enhancement and recreation). The importance of the multi-functionality of agroforestry systems in terms of their management input and the range of their outputs is stressed and it is proposed that land use decisions should be made within the broader ecosystems perspective so that greater social well-being can be derived from rural areas in Europe.

Keywords Silvopastoral systems, silvoarable systems, multi-functionality, ecosystem services

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Introduction

This paper seeks to give an overview of the principal features and functions of agroforestry systems in Europe. Such land management practices incorporating combinations of trees and agriculture have been a key historical element of the European landscape. However, they have often been ignored or undervalued as many administrative organisations segregate land use and financial support into simplistic terms such as “farming” or “forestry” and do not fully recognise the broad interface area.

However, the increasing pressure on land in Europe, and in fact worldwide, requires new ways of thinking about land management. In addition to providing food, timber, fibre and biomass feedstock, land is required to provide habitats for both wildlife and humans, as well as sites for recreation. Moreover, there is an increasing realisation of the importance of land management in providing regulating services such as well-distributed supplies of high quality water and the sequestration of carbon (Gordon et al. 2005; Millenium Ecosystem Assessment 2005; Nair et al. 2007). Whilst Eichhorn et al. (2006) and Mosquera-Losada et al. (2005) have broadly summarised the position for silvoarable and silvopastoral systems respectively in Europe, this paper seeks to summarise the wide range of ecosystem functions, goods and services of European agroforestry practices.

Classification of Agroforestry Systems

There are numerous definitions of agroforestry. These range from “growing trees on farms” (Young 1997) to more technical definitions, such as that by Sommariba (1992) who defines agroforestry as a form of multiple cropping which satisfies three basic conditions:

1. There are at least two species that interact biologically.
2. At least one of the species is a woody perennial.
3. At least one of the plant species is managed for forage, annual or perennial crop production.

Beyond such definitions, it is possible to categorise particular types of agroforestry. Such classifications are most useful if they are easily understood, readily handled, and provide a practical framework for synthesis and analysis. In the early 1980s, ICRAF completed an inventory of agroforestry systems in the tropics and subtropics (Nair 1985). Sinclair (1999a) used the same database to update the classification, focusing on agroforestry practices rather than agroforestry systems. Across these classifications, agroforestry practices are categorised according either to (i) components, (ii) predominant land use, (iii) spatial and temporal structure, (iv) agroecological zone, (v) socio-economic status, or (vi) function (Table 2.1).

Nair (1990) suggests that the first stage of classification should be on the basis of the components, but any subsequent classification should be based on the purpose.

Table 2.1 Classification of agroforestry systems based on their components, spatial and temporal arrangement, function, agro-ecological zone, and socio-economic aspects (Modified from Nair 1990, 1993; Young 1997)

Classification method	Example categories	Major area of application
(i) Components	**Agrisilviculture**: crop and trees, of which Silvoarable comprises arable crops with trees **Silvopastoral**: pasture/animals and trees **Agrosilvopastoral**:crops, pasture/animals and trees **Other**:multipurpose tree lots, beekeeping with trees, aquaculture with trees	
(ii) Predominant land use	**Primarily agriculture** **Primarily forestry**	Administration
(iii) Spatial and temporal arrangement	**Spatial** Mixed dense (e.g., home gardens) Mixed sparse (e.g., most systems of trees in pasture) Strip planting (e.g., most systems involving agricultural machinery) Boundary (trees on edges of plots and fields) **In time** Coincident separate	Particularly useful in research on plant management for optimising interactions
(iv) Agroecological	Humid, arid mountainous	Land use planning
(v) Socio-economic	Commercial, intermediate, subsistence	Socio-economic analysis of agroforestry potential
(vi) Function	**Productive functions** Food, fodder, biofuel, wood, other products **Habitat functions** Biodiversity **Regulating functions** Shelterbelt, soil and water conservation, shade **Cultural functions** Recreation and landscape	Developing projects for exploiting agroforestry potential

The initial part of this paper reviews briefly the first five classification methods before concentrating on the classification of systems in terms of their functions.

Components

The first stage of most agroforestry system classifications is to define the system in terms of its components of management at a farm scale (Sinclair 1999a). In addition

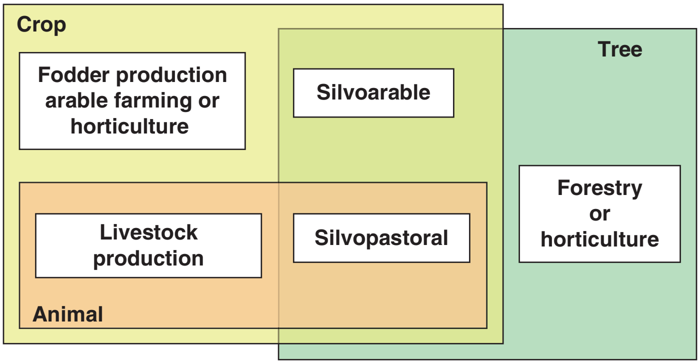

Fig. 2.1 Schematic diagram showing definitions of land use on the basis of the use of either crops, animals and trees

to a manager, the three potential components in an agroforestry system are the woody perennial, the agricultural or horticultural crop, and the animal. Hence, there are two basic forms of agroforestry at a farm scale. These are silvoarable (tree + crop) and silvopastoral systems (tree + fodder crop + animal) (Fig. 2.1). In theory, it is also possible to have an "agrosilvopastoral" system that combines an annual crop with a silvopastoral system, but the arable and livestock components are usually temporally and spatially distinct. Within this classification, farm forestry, where trees are planted in small blocks, may be classified as a forestry or woodland system.

Predominant Land-Use

Sinclair (1999b) suggests that the second criterion of agroforestry system classification is the predominant use of the land where the practice takes place. The land may be predominantly forestry with some agricultural use (e.g. forest grazing) or agricultural with the introduction of trees (e.g. a parkland system). Hence, within silvopasture systems, some classifications distinguish between trees in livestock systems and livestock in woodland systems (Etienne et al. 1996; Olea et al. 2005). For example, silvopastoral systems can be created by either respacing an established woodland or forest, or by planting trees into established pasture. Across most of Europe, forest grazing has almost disappeared due to population pressure, shift in EU policy on farming support, and the disappearance of traditional transhumance patterns (Dupraz and Newman 1997; Finck et al. 2005). However, some examples of wooded pasture remain, such as in the Jura Mountains in Switzerland (Gillet and Garlandat 1986). In practice, although classifying systems on the basis of predominant land use can be useful for administrative purposes, agroforestry can occur at any point along the continuum (Fig. 2.2).

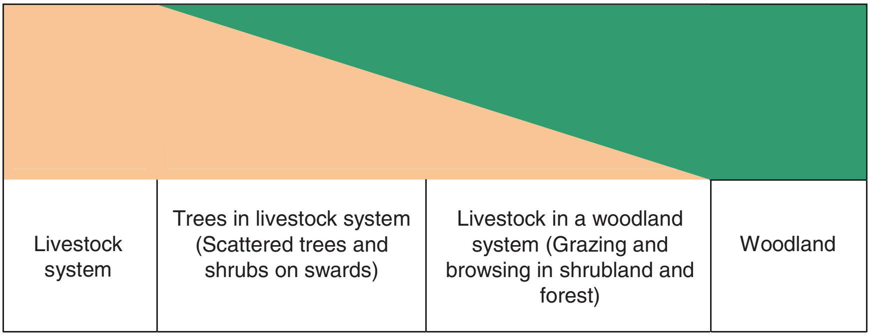

Fig. 2.2 Continuum of agroforestry systems from a principally livestock to a woodland system

Spatial and Temporal Arrangement

Agroforestry systems can also be classified according to the spatial and temporal arrangement of the trees and crops (Nair 1985). The spatial arrangement of the trees can be mixed (dense or sparse) or zoned (lines in the centre of fields or boundary planting). Examples of spatially mixed systems in Europe include the scattered and dispersed arrangement of oak trees in the *dehesas* of Spain or Portugal, and parkland systems in the UK. Examples of zoned systems include the planting of olive in 5–10 m rows with cropped areas in between, and the use of shelterbelts for livestock in Northern Europe.

In terms of the temporal arrangement, silvoarable systems such as the *pré-vergers* or poplar systems of Italy and France are sometimes intercropped with annual crops or perennial fodder crops only during the initial part of the tree rotation. In contrast, in widely spaced trees systems such as olive tree associations in Italy, intercrops can be grown indefinitely. This is because light or water competition from the trees does not reduce crop yields below an economic threshold (Moreno et al. 2007).

Agroecological Zone

Another method of classifying systems is according to the agroecological zone. For example, Nair (1985) and Young (1997) classified tropical and sub-tropical agroforestry systems according to whether they occurred in humid and sub-humid lowland, dry regions, or highlands. Within Europe, it is possible to identify broad agroecological zones (Metzger et al. 2005), and these can be useful in distinguishing agroforestry systems within a Mediterranean agroecological zone from those practiced elsewhere. Hence, Mediterranean systems are often limited by the availability of water (Moreno et al. 2007) whilst in Northern Europe, most the crop component of agroforestry systems may be constrained by relatively low levels light (Mosquera-Losada et al. 2005).

Socio-economic Classification

Another method of categorising systems is according to a socio-economic classification, such as the scale of production or the level of input and management. For example, it is possible to distinguish between commercial and subsistence systems. In some examples, socio-economic circumstances may be closely related to the agro-ecological area. For example, Graves et al. (2007a) highlight the differences in the benefits and constraints of silvoarable systems perceived by farmers in Mediterranean and Northern parts of Europe.

Function

The last method for classifying agroforestry systems is according to their ecosystem functions, and this provides the framework for the rest of the paper. Traditional thinking on land management, as often practised by agriculturalists and foresters, has often focussed on the productive function of land use systems. Nair (1993) when classifying agroforestry systems also recognised their protective functions. More recently, research and analysis such as the Millennium Ecosystem Assessment (2005) has further highlighted and expanded our appreciation of the very wide range of functions that natural and managed ecosystems provide (Hindmarch et al. 2006). De Groot et al. (2002) described the four primary functions of ecosystems as production, habitat, regulation, and information functions (Table 2.2). The production function refers to the creation of biomass which can provide goods such as food, raw materials, and energy resources for human consumption. The habitat function is associated with the contribution of natural ecosystems to conservation or biological and genetic diversity. The regulation function has been defined as the capacity of an ecosystem to control essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes, and the cultural or information function describes the provisioning of opportunities for reflection, spiritual enrichment, cognitive development and recreation. The rest of this paper considers European agroforestry systems in terms of the goods and services that arise from these four functions.

Production Functions

There is likely to be more than one product from most agroforestry systems. These derive from the productive function of the tree, the crop and, in silvopastoral systems, the output from the animal component. These are considered in turn.

Table 2.2 Generalised functions, goods and services of agroforestry ecosystems

Functions	Description of function	Example goods and services
Production	Creation of biomass	Trees: fruits, oil, nuts, timber, firewood, cork and fodder Crops: grain and seed production, soft fruits and vegetables, biofuel and fodder Animals: meat
Habitat	Provision of habitat for conservation and maintenance of biological diversity	Habitat diversity Species diversity Shelter for animals Mechanical support
Regulation	Maintenance of essential ecological processes and life support systems	Soil and water conservation Reduced nutrient leaching Reduced fire risk Carbon sequestration
Cultural	Opportunities for reflection, cognitive development and recreation	Cultural heritage Landscape enhancement Recreation

Productive Functions of Tree Component

It is possible to classify agroforestry systems according to the product obtained from the trees (Eichhorn et al. 2006). The products of the tree components of European agroforestry systems include (i) fruit, oil and nuts, (ii) timber, (iii) fuelwood, (iv) cork, and (v) fodder. Generally as one moves from northern to southern Europe, the range of tree products tends to broaden. For example, timber is often the main product in northern Europe, the provision of coppice and browse can become important in mid Europe, and the full range of products is evident in the south.

Fruit, Oil and Nuts for Human Consumption

Agroforestry systems based on fruit, oil and nut trees remain widespread in Europe. Olives trees, producing olives either for direct consumption or pressed for oil, cover extensive parts of southern Europe. Eichhorn et al. (2006) reported that the area of silvoarable systems with olive trees (*Olea europaea* L.) in Greece and central Italy were 650,000 ha and 20,000 ha respectively. They also reported smaller areas in Spain (15,000 ha) and France (3,000 ha).

There are also numerous extant silvoarable systems based around fruit trees such as almond (*Prunus dulcis* (Miller), fig (*Ficus carcia* L.), peach (*Prunus persica* (L.), walnut (*Juglans regia* L.), apple (*Malus* spp.), and pear (*Pyrus communis* L.) (Eichhorn et al. 2006). In France, an important agroforestry practice is the *pré-verger* system comprising areas of grazed low-density fruit tree plantations which may include intercropped arable crops in the initial years. The *Streuobst* system in central Europe consists of similar associations, although the trees are generally found "dispersed on croplands, meadows and pastures in a rather irregular association" (Lucke et al. 1992 as quoted by Eichhorn et al. 2006). Herzog (1998) reports that the density of common fruit trees in the *Streuobst* systems is about 20–100 trees ha^{-1}. The *pomaradas* system in northern Spain is similar to Streuobst, with scattered fruit trees grown in association with cereals or vegetables. However, as with the pré-vergers and Streuobst system, the area of *pomaradas* has declined greatly in the recent past (Eichhorn et al. 2006). In southern Europe, agroforestry systems including fruit and olive trees often include grape vines. Such systems are called *piantata* in Italy and *joualle* in southern France. Systems combining olive trees with grape vines are also found in Spain (46,600 ha), and Greece, and Eichhorn et al. (2006) reports that inter-cropped vineyards still cover 153,000 ha in Sicily. Eichhorn et al. (2006) also reports on a range of agroforestry systems integrating fruit trees with vegetable production in northern Spain, southern France, Italy, Greece, and parts of Germany.

Timber

Agroforestry systems have been classified according to whether they produce conifer, broadleaved or coppiced wood (Olea et al. 2005). In parts of northern Europe as well as northern Spain where tree cover is high, forest grazing (in conifers) is the most common form of agroforestry. In this part of Europe, the development of silvoarable systems intended specifically to produce high-quality timber from cropped land is relatively recent (Dupraz et al. 2005).

Eichhorn et al. (2006) report that silvoarable systems based on the use of fast-growing hybrid poplar (*Populus* spp.) with cereal crops was pioneered in northern Italy. In these systems the poplars may be harvested after ten years and intercropped with cereals and soybean for the first two years. Planting timber trees at low densities in either pasture or arable land can increase timber increment per tree in comparison with dense forestry stands. This can reduce the length of time it takes for an individual tree to reach a harvestable size, be it for the use of ash in Northern Ireland for hurley stick production, or for the use of poplar for matchstick or veneer production (Burgess et al. 2005). In southern France, one of the most profitable tree species for inclusion within a silvoarable system appears to be walnut (*Juglans* spp.) (Graves et al. 2007b) (Fig. 2.3). Over a limited area, other trees used for timber production in agroforestry systems include black locust (*Robinia pseudoacacia* L.), wild cherry (*Prunus avium*), oak (*Quercus* spp.), and common ash (*Fraxinus excelsior* L.). Rigueiro-Rodríguez et al.(1998, 2005) describe the use of *Eucalyptus globulus* Labill. compared to *Pinus pinaster* Ait. and *Pinus sylvestris* L. at a high density to produce paper and timber-derived products.

Firewood

As trees in agroforestry systems need to be pruned to improve their form for fruit or timber production, or to allow light through to the intercrop or understorey,

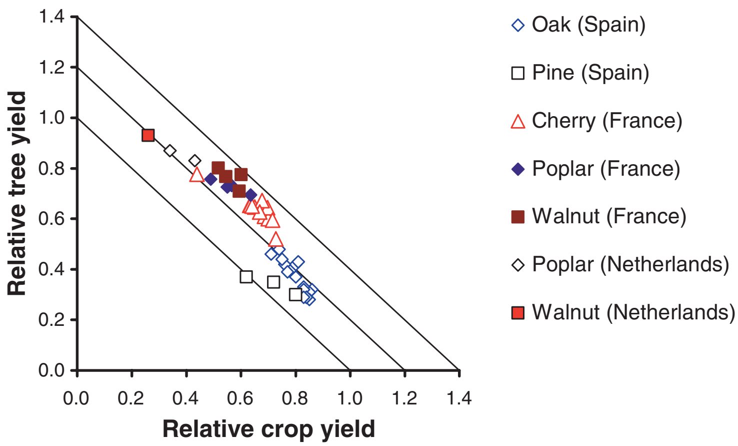

Fig. 2.3 Predicted interactions between relative tree yield and crop yield within selected agroforestry systems (Graves et al. 2007b)

firewood is a potential product from most trees. However, the use of trees in agroforestry for firewood and charcoal production is probably most widespread in Spain and Portugal, where oak trees are pruned to increase the permeability of the tree canopy to light and to enhance acorn production to feed animals. In Spain for example, farmers out-source the work of pruning oaks to contractors, who accept the lopped branches in lieu of payment. These are sold for firewood or charcoal. Oak tree associations cover large areas of Spain (2.3 million hectares), Greece (1.47 million hectares), Portugal (0.87 million hectares), and to a lesser extent Italy (0.18 million hectares) (Eichhorn et al. 2006). Tree densities typically range from between 10 and 40 trees ha^{-1} in Spain and Portugal to between 10 and 100 trees ha^{-1} in Italy and Greece. These systems may be several thousand years old and generally consist of scattered trees, giving the landscape a savannah-like appearance.

Cork

Cork from the bark of cork oak (*Quercus suber* L.) is an important tree product in Portugal and Spain and most of the world's cork oak land (2.3 million hectares) lies in Portugal (33%) and Spain (22%) (APCOR 2007). About 340,000 t of cork are produced annually with Portugal (54%) and Spain (26%) producing most of this (APCOR 2007). The annual global value of internationally traded cork products was approximately €1.4 billion in 2005 and the majority of this was due to exports from Portugal (€€838 million) and Spain (€113 million) (INE 2005). Wine stoppers are worth approximately 70% of the global value of cork products (APCOR 2007). However, there is great concern that the substantial areas of cork oak landscapes could be lost if plastic wine stoppers and screw caps replace cork wine stoppers in the wine trade (World Wildlife Fund 2006). There is some evidence to suggest that cork oak agroforestry could be replaced by holm oak (*Quercus ilex* L.) agroforestry, because holm oaks produce high quality acorns that are especially important in the economics of Iberian pig production (Gaspar et al. 2007). Other studies suggest degradation of cork oak agroforestry might occur as a result of complete abandonment of the land, excessive intensification of livestock production or the conversion of the land to other uses (World Wildlife Fund 2006).

Fodder

The leaves and fruit of trees in agroforestry systems are commonly used as animal fodder in Mediterranean Europe, where they can supplement grass supply during periods of shortage. For example, in the *dehesas* of Spain or *montados* of Portugal, acorns from holm oaks are consumed by foraging livestock and holm oak branches may also be lopped and left on the ground as winter browse. Fig trees in Crete and the Aegean Islands, walnut trees in Italy and the mountains of Greece, and carob trees in Sicily and Crete are also used to provide fodder (Eichhorn et al. 2006). During the summer in mountainous and north-western parts of Spain, leaves from pruned ash, willow and birch trees can also provide a better source of fodder than herbaceous crops during drought periods (Mosquera-Losada et al. 2004), as well as periods of winter forage shortage. Tree management to increase forage value through coppicing, has been evaluated in other temperate areas (Snyder et al. 2007).

Productive Functions of the Crop Component

Grain and Seeds

Cereals such as wheat, maize, and oats are a common feature of silvoarable systems in both northern and Mediterranean areas. Whilst in olive agroforestry systems, where trees are small and slow-growing, intercropping can continue to be an important component of the system for many years, in other systems, canopy development eventually makes it uneconomic to grow the cereal crop. In the dehesa systems of Spain and Portugal, the cultivation of oat or wheat is usually associated with the most fertile part of the farm, and often the areas are rotated to improve pasture quality in the years subsequent to the cultivation of the crop. An additional seed producing crop is sunflower which is sometimes grown with poplar in Italy, and with oak in Greece and Spain.

Vegetables, Soft Fruit and Grapes

Vegetables are grown in olive associations in Italy, fruit tree associations in Greece and Spain, and with carob trees in Crete. Eichhorn et al. (2006) report that irrigated vegetables, grown alongside fruit trees, is a highly profitable system in the Languedoc-Roussillon region of France. Soft fruit such as strawberries (*Fragaria* spp.) are associated with olive trees in Greece and fruit trees in France, and bush fruits (*Ribes* spp.) such as currants and gooseberries are associated with mixed fruit trees in Spain. As noted earlier, grape vines are grown with a number of tree species in Mediterranean Europe.

Biomass Feedstock

Across Europe, there is increasing interest in the use of agricultural crops as a biomass feedstock, either for the production of biogas, bioethanol or biodiesel. Biomass feedstock crops include those currently used for food production, but also alternative crops such as miscanthus and switchgrass. Of particular interest is the capacity of agroforestry systems to increase biomass production per hectare, relative to monoculture agricultural or forestry systems, because of the increased capture of light and water through complementary growth patterns of tree and crop components.

Fodder

Most silvopastoral systems include an understorey grass or leguminous "crop" which provides animal fodder. In countries such as Italy, Greece, Spain and Portugal fodder legumes or grasses also form a common component of the crop rotation of a silvoarable system. The herbaceous species used within temperate European silvopastoral systems have been reviewed by Mosquera-Losada et al. (2005). Depending mainly on the tree cover and the relative costs, the herbaceous layer will be natural or established, (Mosquera-Losada et al. 2005). In traditional forest grazing systems in northern Europe, the herbaceous component is usually indigenous and growth is often limited by the evergreen coniferous trees. In such areas stock such as reindeer may gain nutrition from both the herbaceous sward and lichens. Naturally occurring herb layers have evolved over time in ancient systems such as dehesa and *Montado* (Olea et al. 2005) and in systems where pigs, poultry and other stock are grazed in forests (Brownlow et al. 2000). In the Atlantic biogeographic region of Europe, sowing is associated with low tree cover or young stands. Grassland development is usually seriously limited when tree cover is above 55% (Dodd et al. 1972; Sibbald 1994; Rodríguez-Barreira 2007).

Productive Functions of the Animal Component

The principal productive output from the animal component of agroforestry systems is usually meat. Depending on the particular situation, cattle, sheep, pigs, poultry and wild animals can all satisfactorily graze with minimum need for tree protection (Sánchez 2005). However if the tree density is too high, herbage quality (Peri et al. 2007; Rozados-Lorenzo et al. 2007) and productivity (Mosquera-Losada et al. 2005) will not be sufficient to support high densities of grazing animals with high energy requirements for adequate growth.

Tree-pasture systems can be either created or managed using existing trees; in such cases, provided the trees are large enough, herbivores such as cattle, and pigs can be used. The dehesa system in Spain and Portugal has evolved using either cattle, pigs or, in some cases, sheep under trees such as *Quercus ilex* (Olea et al. 2005). In the Atlantic part of Galicia, agroforestry systems with horses can be found, as well as with sheep, pigs or cattle.

Alternatives to grazing livestock have been reviewed by Brownlow et al. (2000) who examined managed forests grazed intensively with pigs (Brownlow 1994) and poultry production under tree cover. In the UK there are three groups of poultry/tree practitioners: (i) large independent, commercial poultry specialists, (ii) corporate poultry producers who have been encouraged for contract reasons to plant trees, and (iii) smallholders. In all cases, trees create a greater range for the birds, enhance the landscape and improve shelter. Turkeys, ducks, and geese have also been successfully incorporated into agroforestry systems (Brownlow et al. 2000).

Habitat Functions

Because trees are larger, live longer and have a greater variety of tissues and structure than herbaceous plants they can provide a habit for a wide range of organisms (Burgess 1999). Moreover agroforestry systems can enhance the habitat function of an ecosystem because the interactions of the tree, animal, and crop components create complexity and environmental heterogeneity (Martínez-Jauregui et al. 2006; Martínez-Jauregui 2007; McAdam 2000; Rois et al. 2006). For example, mature dehesa is considered to be the most biodiverse mand-made landscape in Europe, as the combination of trees and herbaceous cover provide a habitat for a large variety of insects, birds and other fauna and flora (Moreno and Pulido 2007). Other habitat services include the use of trees to provide shade and shelter for animals, and the provision of direct mechanical support for understorey crops such as vines. The principal underlying aspects related to the habitat function of agroforestry systems will be presented in more detail in Chapter 3.

Regulating Functions

Agroforestry can improve the capacity of land to provide a range of regulating services such as soil, water and nutrient conservation, protection from fire, and carbon sequestration. For example Palma et al. (2007) have analysed the potential of silvoarable systems, relative to arable systems, to sequester carbon and to control soil erosion and nitrate leaching. Rigueiro-Rodríguez et al. (2005) also discuss the potential of silvopastoral systems to reduce fire risk. These and other regulating services will be explained in depth in Chapter 3.

Cultural Functions

Potential cultural services provided by agroforestry systems include the maintenance of local cultural heritage, creation of recreation opportunities, and enhancement of the landscape. The delivery of conservation, amenity, recreational and environmental services by funding farmers and landowners is seen as a key element of the EU subsidy policy (McAdam 2005). However, it is probably in this area, that researchers have been slowest to identify the benefits of agroforestry.

Cultural and Heritage Value

Traditional agroforestry systems are an important part of the culture and heritage of many European areas, and in such areas they are viewed as systems that need to be preserved and sustainably managed (Isted 2005). In the UK, whilst lowland wood-pasture and parkland, and wet woodlands are priority habitats in terms of their biodiversity, they are also of historic and cultural importance. Many large estates in the British Isles had forests planted for their aesthetic and recreational values. Invariably these were to improve the living environment for the owner who would be a person of substantial influence in society, who could influence policy and cultural development and would usually employ many people who would also absorb the same ideas and views. In this way a cultural landscape evolves and one that encompasses the concept of “parkland” where widely spaced, and sometimes ornamental, trees are allowed to grow to full maturity (Isted 2005). Some agri-environment schemes now seek to maintain, enhance, and replant such parkland areas through sensitive land management and a programme of replacement tree planting (Countryside Management Scheme, Department of Agriculture and Rural Development, Northern Ireland, unpublished explanatory booklet).

Vera (2000) has reviewed the cultural significance of grazed woodlands and forests in eastern and western Europe and cited numerous examples of forest types where their multifunctionality has been a key element in their cultural value. In Greece, Ispikoudis and Sioliou (2005) found that cultural aspects of silvopastoral systems were rarely mentioned in the literature. They concluded that an important factor influencing silvopastoral landscapes is the cultural attitude of the occupants. Societies view and perceive landscapes in ways which reflect cultural attitudes, spiritual beliefs and resource values. They also point out that lifestyles like nomadism (or transhumance-mentioned by several papers in this volume) and traditional techniques like pollarding are closely linked with these silvopastoral landscapes which represent these traditional lifestyles but they are also imbued with cultural, symbolic and even religious value. There is also substantial evidence for the cultural value of, for example dehesa systems (Moreno and Pulido 2007).

Recreation

There are opportunities for both farmers and the general public to benefit from the recreation opportunities created by agroforestry systems. For farmers there may be opportunities for hunting or an income from rural tourism, and the general public may gain health benefits from enjoying and appreciating an agroforestry environment. For example, in the UK bird watching is the most popular form of recreation and more people are members of bird conservation organizations than any other. The benefits of agroforestry in attracting birds to rural landscapes are discussed further in Chapter 3. The opportunities provided by agroforestry in Italy for recreation are described further in this book in Chapter 12 (Pardini 2007).

Landscape

For many people, crop and tree monocultures can create unappealing monotonous landscapes, whereas the integration of trees with agriculture can increase the heterogeneity (Bell 2000) and the attractiveness of the landscape. For example the dehesa is associated with an increase in the amenity value of the landscape and is also seen to be historically and culturally significant. The cultural landscapes created by silvopastoralism can also contribute to financial opportunities in the form of ecotourism (Pardini et al. 2002; Pardini 2005).

Multifunctional Agroforestry Management

The tree, animal, and crop components of agroforestry systems interact with each other and can create a high degree of complexity and environmental heterogeneity (Palma et al. 2006). The key to agroforestry management is to optimise the benefits from the system, and this requires special skills and considerations (McAdam and Sibbald 2000). Sinclair et al. (2000) have highlighted the importance of setting objectives for agroforestry systems and managing the systems accordingly, to achieve these objectives.

Sinclair (1999b) and Sinclair et al. (2000) have reviewed two types of interactions and how they relate to resource capture, biodiversity, succession, and scale. In silvopastoral systems, there is a direct interaction where the animal eats the pasture, deposits dung and urine on it and tramps the soil (Buttler et al. 2007). The presence of the tree also creates indirect interactions. It shades the pasture, deposits leaves on it, absorbs nutrients escaping below the pasture (Nair and Kalmbacher 2006), aerates the soil, attracts biodiversity, and affects the grazing behaviour and movements of the sheep. Such factors and their interrelationships need to be taken into consideration when developing guidelines for sward and stock management (McAdam and Sibbald 2000). When the human management component is brought into the analysis, along with the outputs attitudes and expectations, multifunctional management becomes a much more complex issue. McAdam et al. (1999) and Sibbald (1999) reviewed the rationale behind agroforestry (largely as practiced in the British Isles) being viewed as a sustainable land use option, and concluded that agroforestry can make a positive impact on sustainable rural development, in comparison with conventional farm woodlands, because of the employment created by multi-functional systems.

Complementarity of Resource Use

Silvoarable systems integrate the use of crop and trees on the same land management unit, such that there are ecological and economic interactions between them. A major benefit of silvoarable systems is the diversification of products, combining long- and short-term components, and the increased productivity, often measured using the land equivalent ratio. This arises from complementary use of resources, especially light and water (Graves et al. 2007b) but also nutrients (Nwaigbo et al. 1995). The potential economic benefits of silvopastoral and silvoarable systems have been demonstrated by Crabtree et al. (1997), McAdam et al. (1999), Thomas and Willis (2000), Etienne (2005), Fernández-Núñez et al. (2007) and Graves et al. (2007b).

Tree Protection

Tree protection is a major issue when animals are combined with trees (Nixon et al. 1992; Beaton and Hislop 2000) and generally costs of protection against large herbivores such as pigs, horses, and cattle preclude their use, at least in the early stages of a silvopastoral system. McAdam (1991) investigated a range of combinations of plastic tree shelters and posts and these were incorporated into silvopastoral sites established in Northern Ireland as part of the UK National Network Silvopastoral Experiment (Sibbald et al. 2001). In these trials, ash, sycamore, larch and scots pine were successfully protected against sheep for five to six years after establishment. Subsequently, as tree stem diameter increased, the shelters were no longer suitable and a secondary tree protection incorporating plastic netting was adopted. Thirteen years after planting, trees were large enough to allow cattle to be safely used as grazing herbivores in the lowland site in Northern Ireland at Loughgall. Hence the animal component of a silvopastoral system can change as the site matures, with species options increasing in the post-establishment phase. Tree protection requirements depend on animal and tree species. For example, herbivores such as horses and cattle will not usually eat species like *Eucalyptus globulus* or *Pinus pinaster*. By contrast goats and pigs can cause substantial damage, even to large trees (Rigueiro-Rodríguez et al. 2005). However, this effect depends on stocking rate, as animals do not usually browse trees if alternative fodder is available.

Mechanisation

Management of some agroforestry systems may be less efficient, because machine operations are impeded, in order to prevent damage to the machinery or trees. While trees are small and provided they have been planted in rows, normal pasture management operations such as rolling, topping, fertilising, or weed spraying can be satisfactorily carried out in silvopastoral systems. As the trees mature, these operations become more difficult, and yet at the same time may become more necessary, as the trees impact more on the sward. In this case the pasture management decision may influence tree management, and thinning or heavy crown pruning may be implemented. Small, highly mobile four-wheel motorcycle-drawn implements produced, with attachments for mowing, fertilising, and spraying pasture are now produced. These, although ideally suited to silvopastoral systems, are less suited to other farm operations, and may represent a significant investment for the farmer.

Training for Multifunctional Management

If multifunctional agroforestry systems are to be correctly managed there is a need to ensure that managers have the necessary skills and training to optimise the outputs from the system. It is our opinion that there is inadequate skills provision and training available at a European level. There is also minimal provision of tertiary level education in universities to produce people who will have the necessary understanding and vision to carry forward research and development to exploit the potential of multifunctional agroforestry systems. This is a serious omission which needs to be addressed at a European level.

Agroforestry and European Policy

European policy has traditionally been based on production. For example, land use in Europe is classified as being either agriculture or forestry, and Common Agricultural Policy has therefore tended to encourage the removal of scattered trees, particularly from arable land (Lawson et al. 2005). The ecosystems approach suggests that there is need for a more integrated approach to land management. At present agricultural land within the European Union must be kept in "good agricultural and environmental condition". In the future the focus may be on the provision of a broad range of ecosystem services. Such a change would encourage the creation of more mixed cropping systems. In Spain and Portugal, the cultural and environmental importance of agroforestry systems has been recognised. In both these countries, oak trees in dehesas and *montados* are protected by national policy, and at a European level, various directives and initiatives have sought to enhance such areas through social and environmental programmes (Shakesby et al. 2002; Pereira and Pires da Fonseca 2003; Gaspar et al. 2007; Pleininger 2007).

In the new European Rural Development Regulation (Commission of the European Union 2005) agroforestry is specifically mentioned (in Article 44) as receiving special support. However, in some countries there is uncertainty over whether areas of agroforestry remain eligible for Single Farm Payments. For example, some guidelines focus on agroforestry in terms of the continuing use of agriculture within the tree canopy, whilst others focus on specific definitions related to the number of trees per hectare. These issues are currently being debated, particularly by those wishing to promote agroforestry systems in Europe at a broader scale and in as wide a range of scenarios as possible.

Conclusion

Natural capital provides a variety of benefits to human beings in the form of ecosystem functions. Ecosystem functions include production, regulation, habitat, and cultural functions and these provide a variety of ecosystem goods and services, from which human society derives environmental, social, and economic value. Agroforestry systems can help to improve the ecosystem functions of natural capital, especially relative to arable monocultures, and thus improve the range and quality of ecosystem goods and services from which human society derives environmental, social, and economic benefits. Unfortunately, as a rule, the wider functions of natural capital are rarely considered in national or European agricultural policy, and the agricultural landscape has increasingly specialised in the production function of natural capital, tending towards crop monocultures, with the result that the other ecosystem functions and the environmental, social, and economic value that they provide, have been degraded. Perceiving and evaluating agroforestry systems in terms of ecosystem functions, goods, and services, rather than in terms of a specific tree density, could in the long-term prove to be a useful way forwards, and could draw out the relative merits of different land use systems. This would help to ensure that the considerable social and environmental benefits derived from European agroforestry are not lost simply because inadequate definitions of agroforestry cause farmers to remove trees from agricultural landscapes to maximise the economic benefits from national and European agricultural support regimes, such as the Common Agricultural Policy.

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Chapter 3
Agroforestry Systems in Europe: Productive, Ecological and Social Perspectives

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Abstract Agroforestry is a land use type which embodies agricultural and forestry elements in systems which fall between the current European definitions of exclusively forestry and agriculture. If properly implemented, they can help overcome some of the production, environmental and social problems that EU governments currently face. Agroforestry practices are extensively applied in tropical countries and promoted by international institutions. However, the degree of implementation in Europe is low and almost exclusively confined to marginal areas where the advantages of this type of land management are needed for sustainability in the short term. The main productive advantages of agroforestry systems are linked to better use of resources in a spatial and temporal scale which, at the same time, can enhance environmental benefits through reduction in nutrient losses from agricultural land, increasing carbon sequestration, enhancing biodiversity, reducing soil losses and helping manage fire risk in specific areas. The advantages of agroforestry systems can confer important social benefits at a farm level, in the different biogeographic regions of Europe and at the same time benefit the general public. These aspects will be discussed in this chapter.

Keywords Profitability, carbon, nutrient cycling, fires, biodiversity, land use, rural turism

Introduction

The importance of agroforestry systems at a global scale are highlighted in Agenda 21 of the Rio Convention, where agroforestry systems, and therefore agroforestry practices (Nair 1993; Mosquera-Losada et al. 2008), are mentioned as a sustainable

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land management option. They help fulfil the objectives described by UNCED (1992) in the Agenda 21 in chapters 11 (combating deforestation), 12 (managing fragile ecosystems: combating desertification and drought), 13 (managing fragile ecosystems: sustainable mountain development), 14 (promoting sustainable agriculture and rural development) and 15 (conservation of biological diversity) of this important global action plan (UNCED 1992). However, there was no policy in place at a European Union level to promote this kind of land system management on a widespread scale until 15 September 2005, when a Council Regulation on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) was released. This established that "measures targeting the sustainable use of forestry land through the establishment of agroforestry systems on agricultural land" should be taken. The mechanism is currently being implemented at a regional scale through subsidies, but how much this land use management will extend as a result of the implementation of this new regulation is still unknown. However, previous European policy support for afforestation of agricultural lands or organic farming has proved to be a success.

Agroforestry is an ancient agricultural form of forestland management that should be encouraged as it increases productivity in the short, medium and long term (in comparison with forestland), biodiversity (in comparison with agricultural land) and sustainability of land (multiproduction system). Hence it increases productivity of land fulfilling environment and social aspects.

The current chapter tries to explain at a European scale how agroforestry systems can contribute to fulfilling the directives and goals of productive, environmental and social European policy objectives. Agroforestry practices could be implemented in forestland, where silvopasture, multipurpose trees or forest farming agroforestry practices are the most appropriate, or in recently created forestland where agroforestry practices like silvoarable, riparian buffer strips and silvopasture (avoiding tree damage through an appropriate selection of animals and trees (combined or not with the use of protectors, depending on tree age)) could be used.

Agroforestry Productivity in Practice

If we compare the income generated from a forest, agricultural or agroforestry land managed system during a whole cycle of tree development, it can be seen that these profits not only vary because of the type of product obtained (tree and crop), but also because of the period of time when economic benefits are obtained within the different systems (Fig. 3.1).

When an exclusively agricultural system (including livestock systems), is established, initial costs are quickly absorbed, because of the benefit obtained from the crops and animals (wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), milk, wool, meat). Working with an exclusively forestry system, the initial investments are usually related to plant and land preparation but the benefits are obtained

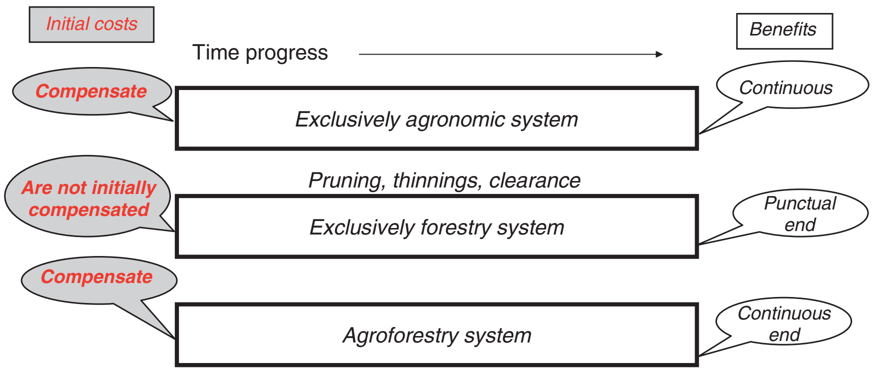

Fig. 3.1 Initial costs and benefits obtained with an exclusively agronomic system, exclusively forestry system and with an agroforestry systems for a stand life (time progress goes from plantation to harvesting) and varies with the type of tree

a long time after planting when some silvicultural operations like commercial thinnings are carried out. This is currently important in the European Union where the degree of afforestation has been substantially increased in the last years, representing around 0.5% or 1 million hectare of the forest area of Europe in the last decade (EEA 2005b) (Fig. 3.2).

Some silvicultural management practices should be carried out between establishment and commercial thinnings in order to reduce tree-understory competition (clearance) or to enhance tree quality (pruning) which increases the establishment and maintenance costs, because no benefits are obtained from these operations. However, when agroforestry practices are established, initial costs are usually more quickly recouped than from exclusively forestry land use. On the other hand, land profit is increased as time progresses and as tree grows compared with exclusively agricultural use.

A comparison of initial investments and establishment costs between forestry, agriculture and agroforestry (Fig. 3.3) was made in the Atlantic area of Spain (Fernández-Núñez et al. 2007). It was found that initial investment was higher for the silvopastoral system compared with the agricultural or forestry system as the initial inputs are higher. Regarding exclusively forestry management operations it has been shown that the cost of silvicultural operations during the life of the stand is very high (45% of the total costs). This is an important issue because so much land is being afforested in the European Union at present. The man-power cost for maintenance is higher in traditional livestock systems (62%) than in agroforestry systems (36%) due to the higher stocking rate in the first case. The economic study over a 30 year period, found that the profitability per hectare is higher with this type of agroforestry system than with exclusively livestock (17%) or forestry (53%) systems. This takes into account that the defined agroforestry system was applied only during the ten first years of the stand biomass.

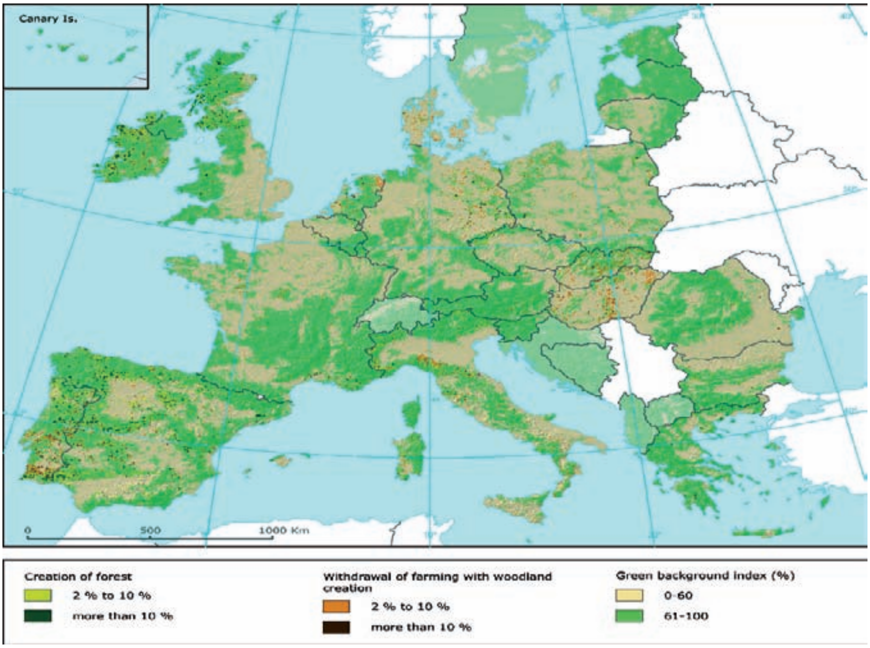

Fig. 3.2 Afforestation in Europe 1990–2000 (EEA 2007)

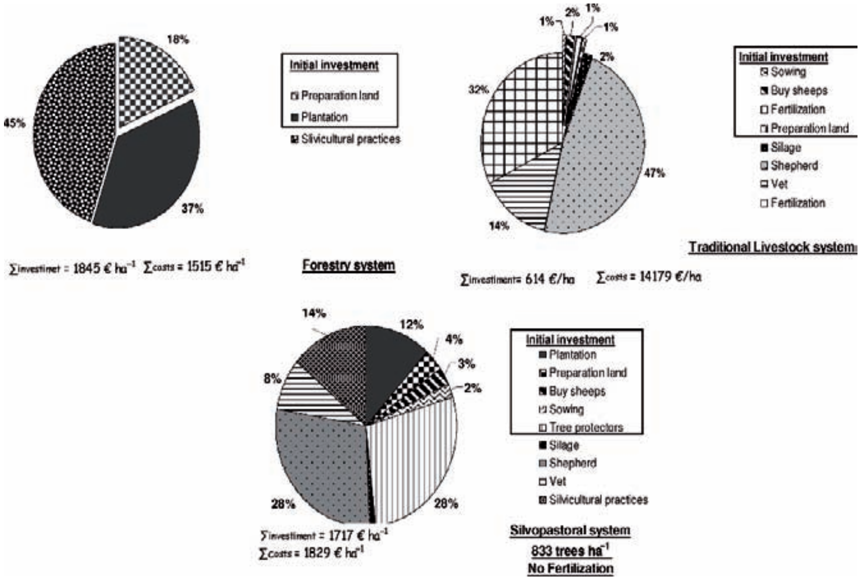

Fig. 3.3 Initial investments and cost of exclusively forestry land, traditional livestock system (without trees) and silvopastoral systems (Fernández-Núñez et al. 2007)

Economic studies carried out in silvopastoral systems in the Atlantic area of Europe indicate that profitability of the tree and pasture components (sheep-farming) depends on tree species and density, and in some cases, the updated net value could be higher than exclusively sheep-farming system, reaching an increment of 15% of Net Present Value if *Fraxinus excelsior* L. is used in the lowlands (Sibbald 1996). These studies did not take into account environmental and ecological benefits derived from these land uses types, which increases profitability of agroforestry systems. When environmental and ecological benefits where evaluated in the NW Spanish study abovementioned, the profitability of the agroforestry systems was even higher (Fernández-Núñez et al. 2007). Social aspects (man-power costs) between different countries also affect the benefits of agroforestry systems (Campos et al. 2007).

Agroforestry productivity depends on the type of tree and tree management in the long term. Tree profitability is usually higher with fast growing species because the time required to obtain a return is shorter compared with slow growing tree species. It is important to highlight that nowadays, it is more widespread silvicultural practice to promote high stock densities at planting as the aim is to increase tree volume per hectare. High quality saw-logs derived from tall trees are more in demand in the European Union (Fig. 3.4). Modern silviculture reduces tree density to concentrate on growth per tree in the short term and make the whole process more mechanised, even though tree volume production per hectare is reduced (Evans 1984). Tree size is increased without tree competition, so modern silvicultural practices to obtain high quality forest products are more compatible with an understorey development that suits silvopastoral or agroforestry practices and land productivity is increased due to the intermediate products obtained (mainly agricultural) and the increase in the output of valuable forest products in a shorter period of time.

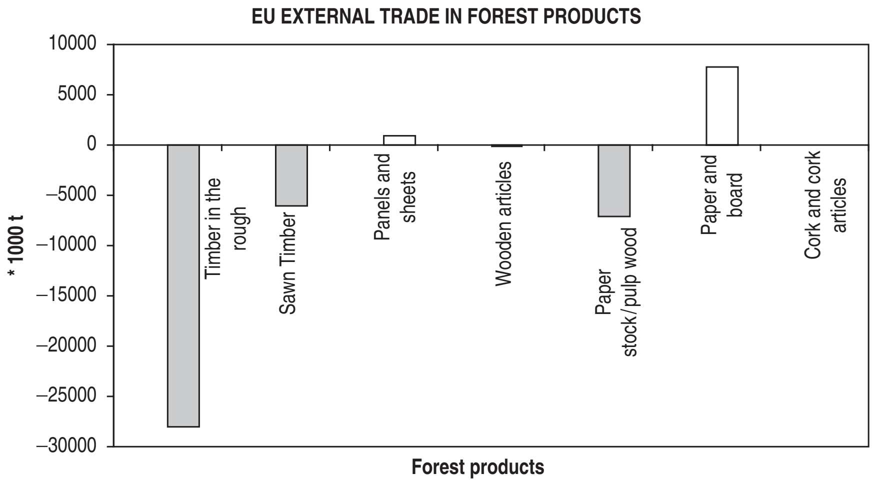

Fig. 3.4 EU external trade in forest products (EU 2002)

As previously mentioned, the tree component will definitely affect potential understorey production due to the modification of light quantity and quality inputs into the system (Mosquera-Losada et al. 2005). Agroforestry practices can be developed under low, moderate or high shade. For example, some medicinal plants, berries and mushrooms are better adapted to shade conditions (Silva-Pando 2006). In contrast, it is known that understorey production is limited by high tree cover (derived from high density in mature stands), mainly related to silvoarable and silvopastoral practices. Tree cover affects pasture and crop production but this depends on tree species. For example understory maximum production is reached with 35% tree cover with *Q. ilex* L., but at 50% with *Q. pubescens* Willd., and grass production in France was found to be lower under *Q. pubescens* (Etienne 2005). Understory pasture production under *Pinus radiata* D. Don is reduced in the Atlantic area when tree cover is over 55% (Rodríguez-Barreira 2007).

Other understorey products (wheat, rye (*Secale cereale* L.), barley, mushrooms, truffles, aromatic and medicinal plants) and livestock-derived products are the other income resources in agroforestry systems. Crop production in agroforestry systems is usually linked to livestock management, to feed animals economically during shortage periods. Other products like mushrooms, truffles, aromatic and medicinal plants are also very important to increase productivity, as their value is much higher than timber or tree products in a lot of cases. Mushroom recollection in Galician forests (north-west Spain), could reach values between 24 and 30 million Euros, based on the price paid to the people who pick the mushrooms. This is from a region with 3 million hectares in total and 2 million hectares of forestland of which 1.4 million out of the 2 million have dense populations of trees. However, the lack of experience with and information on mushroom collection and the indiscriminate harvesting associated with it makes difficult to quantify exactly.

As previously mentioned, one of the most important agroforestry practices in Europe are those involving animal production, mainly in the Mediterranean, Alpine and Boreal biogeographic regions, where tree growth is slow and stand life long. These silvopastoral systems have an important use for livestock feeding (e.g. reindeer in Boreal forests, goats and sheep in Mediterranean countries and protection in Alpine forests). However, these type of agroforestry practices are less important in the continental regions (where crop production is more important and silvoarable practices most prevalent) or Atlantic regions, even though, pastures are the main land use. Differences in the degree of implementation between Atlantic and Mediterranean systems could be explained by the different distribution and production of pasture resources in these areas. This depends on climate parameters like temperature and precipitation. If we compare pasture production in the Atlantic and Mediterranean biogeographic regions, in the first case, pasture production could be around 4 and 15 t ha^{-1} year^{-1}, i.e. between 0.2–2 t DM ha^{-1} year^{-1} in the arid Mediterranean area, but between 5–10 t DM ha^{-1} year^{-1} in the mild Mediterranean area. Seasonality of pasture production is as important for livestock potential and production as total annual production (Fig. 3.5). Generally, pasture production is restricted in summer in the Mediterranean area but not in most of the Atlantic area of Europe. Potential productivity and seasonal pasture distribution has promoted

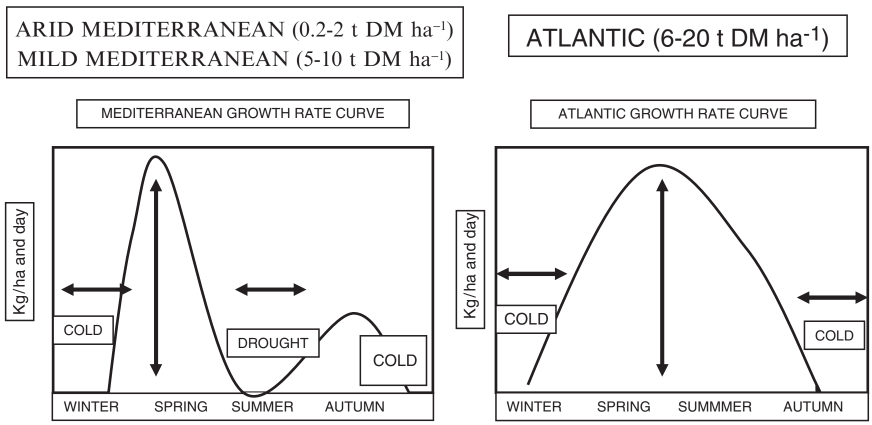

Fig. 3.5 Growth rate curve types in the Atlantic and Mediterranean region of Europe. Vertical lines indicate maximum growth rate and horizontal lines indicate shortage periods

the use of other wooded land to feed animals in the Mediterranean countries. The herbaceous layer is not available for a long period within the year, as annual herbaceous species (the main herbaceous ecological strategy in the Mediterranean countries), go into a seed phase during the summer. During this time, the use of shrubs, tree branches or hay (produced earlier in the year under trees) is the most important and cheap way to fill gaps in pasture production during summer to feed animals. This means that there is a high dependency of livestock on forestry in Mediterranean areas in order to benefit from tree shade advantages (extending grazing season due to the higher persistence of the herbaceous layer under trees at the end of the spring), woodland grazing (which can happen on the same farm or through transhumance), silvoarable systems (to produce hay) and the use of multi-purpose trees (*Q. ilex*, *Q. suber*, *Morus alba* L. (Dupraz 1999; Cañellas et al. 2007)). Forest and OWL (other wooded land) dependence on agriculture in the Atlantic area was very important during the past, as a way of increasing soil fertility. Since fertilization and liming became a widespread agricultural management practices, the value of forest and OWL lands to livestock and other farm uses disappeared. Moreover, in the Atlantic area, trees were considered an obstruction to land mechanization and were harvested to increase the value of the land when land reallocation was made. Nowadays livestock systems in the Atlantic area of Europe do not depend on the forestry area, where silage is made to overcome pasture deficits.

Production advantages of agroforestry systems in the different European environments can also be based on their capacity to produce environmental benefits and the social use of agroforestry systems, such as recreation, landscape enhancement through increased spatial diversity, or high quality food production compared to exclusively agricultural systems. These multiple products from agroforestry systems can be an important income resource for the farm. The value of these has increased in recent years, because of the need for high quality products to have clear certification levels of origin. Recreation could sustain traditional farm management in marginal areas in many cases where some leisure activities such as biking, horse riding, skiing and hunting are more popular in less dense forests. Clear examples of complementary activities linked to farms in Italy are described in this book (Pardini 2008).

Organic farming has been shown to reduce negative impact of agriculture on biodiversity as well as enhance water and soil conservation, although it is not clear if there is a positive effect on the reduction of greenhouse gas emissions (EEA 2005a). Organic farming methods enhance food quality and are compatible with agroforestry systems, which are multipurpose systems and based on better water and soil resource use due to the different components of an agroforestry system (tree and crop). It is important to highlight that organic farming land use has been increased in the recent years at a rapid rate from around 0.25% in 1990 to over 4% of total agricultural area in 2002 (EEA 2005a). Animal welfare is becoming an important issue for the European Union (EU 2006) and is included in the strategic guidelines for rural development for the period 2007 to 2013. Silvopasture is as a type of agroforestry systems which promotes extensive grazing could fulfil the requirements of enhanced animal welfare and organic farming.

One of the most important aspects that could enhance the economic value of the forest and other wooded land is the improvement of environmental and societal benefits that agroforestry systems can deliver, as will be described later in this chapter.

Environmental Benefits

The main environmental benefits which agroforestry systems deliver are the improvement of use of nutrients through the reduction of losses at a farm level (including erosion) but also by the enhancement of carbon sequestration, the reduction of fire risk and biodiversity enhancement. There is an acknowledgment of the importance of woodland grazing to improve biodiversity (Finck et al. 2002; Redecker et al. 2002) and regeneration (Mayer 2005; Smit et al. 2005; McEvoy et al. 2006) in forestry areas if an adequate animal stocking rate is used (Zingg and Kull 2005).

Nutrient Use

The largest water contamination problem in Europe is agriculture management due to the use of herbicides, pesticides and fertilisers (EEA 2003). Nutrient surpluses are an important European issue related to water contamination and eutrophication. The use of pesticides is mostly linked to monocultural cropping systems, which facilitate the multiplication and dispersion of pests. Both, herbicides and pesticides, are less used in agroforestry practices because pest dispersion could be reduced by the tree presence, which also could act as a dispersion barrier. On the other hand, the most extensive systems dealing with agroforestry practices can reduce the dispersion of weeds through physical barriers (hedgerows or belts). But the most useful aspect of reducing water contamination through the use of agroforestry practices is dealing with the uptake of nutrients by the trees that would otherwise contaminate rivers. Main water contamination problems are eutrophication as a result of excess nitrate and phosphorous. The potential contamination from nitrogen is higher than from phosphate, because – it has a more complex cycle (Whitehead 1995) and more opportunities for losses including leaching and atmospheric (N, NO_3, NO, NO_2). These can contribute to eutrophication in an extensive way, contaminating rivers and subterranean waters. The current concentration of nitrate is still above what might be considered to be "background" or natural levels in Europe (EUROWATERNET). The Code of Good Agrarian Practices in Europe in the different regions was mainly created to reduce non-point source contamination by nitrate. Evaluations in 113 regions of Europe were made for nitrogen balance. It was found that there was no nitrogen surplus in 4% of the evaluated regions, and an excess of nitrogen in around 46% of the studied area (EEA 2001).

Nitrogen fertilization is the simplest management practice that the farmer can do to enhance crop production if there are no other crop growth restrictions (hydric, nutrients…). The main nitrogen resources in European continental waters are mineral (European major source) and organic (manure is the second highest source of nitrogen in Europe (Pau-Vall and Vidal 1999)), although it can also come from the atmosphere through fixation. Once nitrogen (or ammonia from manure) is introduced to the soil in a mineral form it has to be used quickly, otherwise it will probably be leached from the system causing contamination. The nitrogen use efficiency (expressed as the relationship between nitrogen added and the nitrogen taken by the crop) depends on the N dose applied and it is reduced as the N dose is increased. For example, in NW Spain, nitrogen efficiency for grassland use is around 41 kg DM pasture per kg N applied if we add 60 kg N ha^{-1} and compare with no fertilization treatment, but it is reduced to 16 kg DM pasture ha^{-1} per kg N applied if 120 kg N ha^{-1} are added. This means that the proportion of nitrate leaching, and therefore the quantity, is enhanced when the dose is increased.

The introduction of trees in an agronomic system, even at a low density, increases the depth and volume of roots exploring the soil. This fact is most important in deeper and arid soils, as the need for water resources promotes tree roots to explore deeper soil areas (Grime et al. 1992). Figure 3.6 shows how the presence of tree roots can reduce contamination through the uptake of the nitrogen not used by the crop. This nitrate can be used by the tree to enhance growth, as was found in a silvoarable system with walnut (Dupraz et al. 2005) and in a dehesa to allow delayed nutrient recycling through the leaves (Moreno-Marcos et al. 2007). It is also important to highlight that forestry practices do not usually include fertilization because of the lack of profitability of this practice, but, in an agroforestry system the tree can benefit from the nitrate unused by the crop.

A study conducted in the EU-15 has shown that pasture is the most important crop of the western (Atlantic biogeographic region) European Countries (Pau-Vall and Vidal 1999), and there is a strong relationship between nitrate contamination

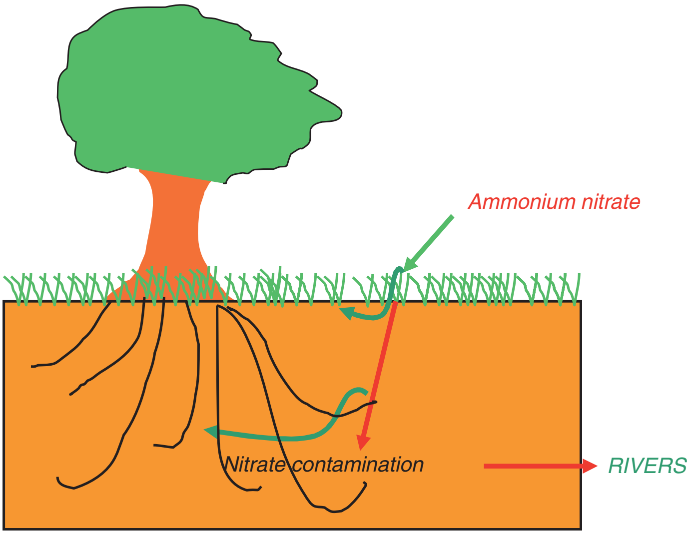

Fig. 3.6 Use of nitrate by tree and pasture roots (green lines) and nitrate leaching (red lines)

and intensive livestock density, where fertilization (manure and inorganic) is widely used to a great extent (Fig. 3.7). In these areas the introduction of trees could reduce nitrate leaching and water quality improved as the different rooting zones of trees and forage crops absorb the nutrients (phosphorus in sandy soils as well as mineral nitrogen, heavy metals…) more completely in the silvopasture than in the tree-less systems. This indicates that a silvopastoral association is better than open pasture in reducing nutrient loss from soil to the surface waters. This fact has been already demonstrated by Lehmann et al. (1999), Nair and Kalmbacher (2005) and Nair et al. (2007) in sandy soils for phosphorous. In some livestock systems, the nutrient loss can be very high, and the efficiency of use very low. For example, efficiencies in N use in intensive dairy systems on sandy soils for the whole farm achieved by skilled farmers are 16%, whereas 36% is technically attainable (Jarvis and Menzi 2004). This efficiency can be increased within an agroforestry system. On the other matter, some types of agroforestry where trees are distributed in lines bordering the pasture plots can also act as belts and riparian buffers in reducing non-point source pollution and thereby improving water quality (Schultz et al. 2004).

Carbon sequestration by forests is an important environmental issue since the Kyoto protocol (article 3.3) was adopted in 1997 (UNFCCC 1998). This referred to the inclusion of removal by sinks resulting from direct human-induced land-use change and forestry activities to meet the Kyoto carbon emissions commitments, by the participating countries over pre-determined periods from 1990. This makes reforestation and afforestation as well as deforestation very important issues for global carbon balance accounting of the different countries The importance of forestry activities on carbon sequestration is based on the higher capacity of trees to

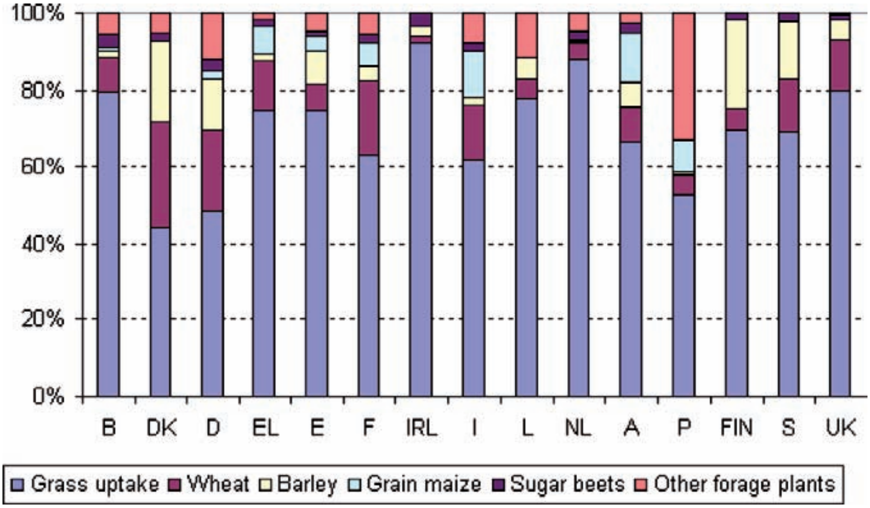

Fig. 3.7 Nitrogen consumption as percentage used by different European crops per EU-15 country (from Pau-Vall and Vidal 1999). B: Belgium, DK: Denmark, D: Germany EL: Greece, E: Estonia, F: France, IRL: Ireland, I: Italy, L: LatviaNL:Netherlands, A: Austria, P: Portugal, FIN: Finland, S: Spain and UK: United Kingdom

absorb CO_2 from atmosphere to incorporate carbon in their own tissues and store them for a long period of time than agricultural crops, for both above and below-ground production. Agroforestry systems could be considered as a low-cost method to sequester carbon in a given soil profile compared with agricultural systems because it has a perennial woody component at the same time as a herbaceous component which enhances roots deep in soil, and increases the potential to sequester carbon. Carbon can be stored for different periods of time from months to years (non woody) and from decades to centuries (woody) in the aerial part of the forest. Belowground carbon can be stored for both long (from centuries to millennia) in the stable soil organic matter pool (organic matter stabilized by clay, chemically recalcitrant carbon and charcoal carbon) in forests. Carbon from surface litter, and crop residues can also be stored for a relatively short time (months to years) or from partially decomposed litter and carbon in macro-aggregate for years to decades as inactive soil organic matter. Simultaneously agroforestry systems can have an indirect effect on C sequestration as they help decrease pressure on natural forests, which are the largest sink of terrestrial C (Montagnini and Nair 2004). It is estimated that at a global scale agroforestry could be potentially established on 585–1275 × 10^6 ha of technically suitable land, storing between 12–228 (median 95) mg C ha under current climate and edaphic conditions (Dixon 1995). The other source of greenhouse gas (GHG) emissions from agriculture is N_2O which can be reduced by minimizing fertiliser use or using nitrogen fertiliser more efficiently as has been previously described. Agroforestry systems are extensive systems with low fertiliser use and more efficient use of fertilisers.

Carbon sequestration by trees depends on different factors like edaphoclimatic conditions, tree species and tree management (density and distribution). All these factors are related to the tree growth rate and therefore the capacity for carbon sequestration, which depends on tree biomass productivity and the rate of CO_2 net assimilation. Tree-crop interactions will directly affect carbon sequestration in agroforestry systems, so those situations in which competition between tree-crop components is important will reduce the capacity of global agroforestry systems to store carbon (reduction of tree and crop production due to hydric stress or nutrient depletion). However, when a synergy in crop-tree productivity is found (tree uptake of nutrients not used by crops) carbon sequestration per unit of land is promoted. Tree species also affects carbon sequestration. Soil sequestration is higher in broadleaves compared to coniferous and deciduous trees (Fernández-Núñez 2007), but also management practices like density and distribution of trees will affect carbon sequestration within agroforestry systems. The percentage of tree canopy cover can vary substantially, and generally as density is increased higher capacity of carbon sequestration is obtained, until tree competition is so high than a depletion of carbon sequestration capacity per unit area can happen. Mature stands have the capacity to storage more carbon than young stands, so the delayed and flexible harvesting of agroforestry trees compared with forestry could initially counteract the higher density of forestry trees in terms of carbon storage. Those tree distributions that promote the homogeneity of root density in soil of an agroforestry system will probably be able to sequester more carbon.

A carbon balance for an agroforestry system has been made in Galicia with real field data (Fig. 3.8) with a fast growing species (*Pinus radiata* D. Don) in a sandy soil. Soil, tree and grass parameters were measured, and after ten years a global balance was obtained taking into account the sheep stocking rate based on pasture production estimates. It can be seen that the *Pinus radiata* agroforestry system has stored around 17.24Mg C ha^{-1} $year^{-1}$. Most carbon is in soil carbon which was sampled in the first 25 cm of the upper layer. Initial soil carbon was around 44 t C ha^{-1}, which is four times less than the value obtained ten years later in this agroforestry system (118.8 Mg C ha^{-1}). Soil carbon comes from tree and pasture root decomposition as well as from tree (leaves) and pasture (unharvested) above ground biomass decomposition. Generally in this system, compared with the exclusively agricultural system, the tree component contributes around 27.5% to the overall balance, without taking into account the incorporation of C to the soil due to tree and root death. These estimates are based on a fast growing species developed in a high quality index site in a region with high tree growth potential and give an idea of the degree of carbon storage possible from this silvopastoral system if it were transformed from agricultural land. The same study was conducted with *Betula alba* L., and it was found that, even if the tree growth rate is smaller, the balance was very similar, due to the higher proportion of soil carbon found with *Betula alba*, which can be explained by the fast degree of incorporation of tree leaves and roots of *Betula* (Fernández-Núñez 2007).

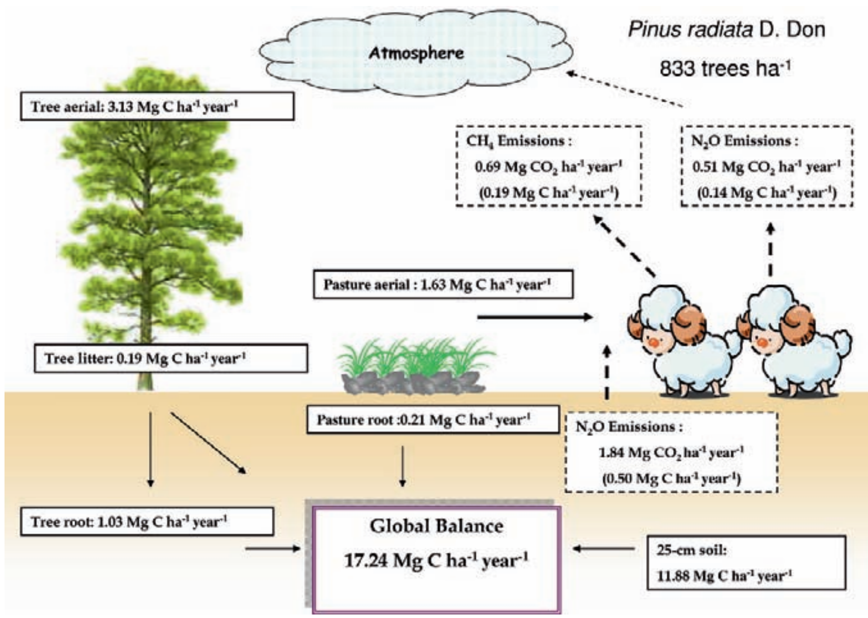

Fig. 3.8 Carbon balance in a ten year old agroforestry system with *Pinus radiata* in Galicia, north-west Spain (Fernández-Núñez 2007)

Fire Risk

Fire is an important problem in those areas of Europe with dry summers. The lack of maintenance of forestland and other wooded land, due to the high costs (clearance and other silvicultural treatments) makes understory growth possible, and fuel accumulation over time very important (Etienne et al. 1996; Bland and Auclair 1999; Rigueiro-Rodríguez et al. 1999, 2005b). Silvopastoral systems represent a good way to reduce fire risk as dry vegetation which can fuel such fires is removed by grazing animals. Fire risk prevention can also help reduce biodiversity and carbon losses at a global scale. Simultaneously silvopastoral systems increase the value of the land (by obtaining high quality animal products) and help preserve traditional practices.

It has also been claimed (Etienne et al. 1996; Robles et al. 2008) that silvopasture can act as a complementary strategy to maintain fuelbreaks in order to avoid soil erosion by creating mechanized fuel breaks. Fire risk reduction impact based on the implementation of silvopastoral systems is different in Mediterranean and Atlantic biogeographic regions. In the Atlantic regions where there is perennial herbaceous vegetation cover, silvopasture should be strategically linked to vegetation change. Once silvopastoral practice is adopted, grazing changes vegetation from shrubland to natural grassland. This is as a result of faeces fertilisation (which encourages herbs rather than shrubs), trampling and the selective grazing of new shrub buds which kill the shrub plants at a medium term (Fig. 3.9). However, drier summers in Mediterranean regions reduce vegetation cover due to the low cover of herbaceous perennial species, so grazing should be based on the reduction of shrub biomass. Some studies have been conducted trying to explain the nutritional value of shrubs as part of the summer or winter diet of animals (Robles et al. 2008). Some aspects related to animal preferences in diets are shown in this book (Martinez 2008), but, recently aspects related the anti-nutritional components of woody vegetation like tannins were evaluated. Tannins are polyphenolic compounds that have become widely recognized as important factors influencing feeding by mammals on woody plants (Robbins et al. 1987; McArthur et al. 1993).They are secondary metabolites that may inhibit digestion of protein and fibre or their astringent taste may cause flavour aversion and adversely affect feed intake. Tannins are present in about the 80% of the woody plants and only in 15% of herbaceous plants (Perry 1994), which enhances herbaceous plant quality in the Atlantic regions, but makes important the election of the adequate animal breeds in the Mediterranean areas to reduce fuel biomass (instead of increasing herbaceous component, which due to annual ecological trait characteristic can produce important erosion problems).

Condensed and hydrolyzable tannins combine with protein to form tannin-protein complexes during mastication and digestion of forage (Hagerman et al.

Fig. 3.9 Fertilization, trampling and selective grazing of new buds of *Ulex europaeus* L. understory made by horses in a *Pinus radiata* D. Don mature stand

1992). Formation of these stable complexes may reduce the amount of digestible protein available for herbivores and digestibility of forage may also be reduced if rumen microflora is negatively influenced by tannins. Many forage species contain significant levels of hydrolyzable and condensed tannins with the potential to reduce dietary quality by reducing protein and dry matter digestibility (Starkey et al. 1999; González-Hernández et al. 2003). Thus, available protein, rather than total protein content, has been reported as the physiologically important parameter relative to animal requirements and metabolic capabilities (Robbins et al. 1987). Digestible protein is likely to be a significant limiting factor, especially if a mix of plants, some with low tannin content, or forbs and grasses, that contain essentially no tannins, are not available for the animals in the forest (Starkey et al. 1999; González-Hernández et al. 2003).

Like other nutritional indicators (González-Hernández and Silva-Pando 1999), tannin content varies with maturity. There is considerable variation among seasons, but tannin content is generally greatest in spring and intermediate in summer, which is the period when the herbaceous layer is not available to stock in Mediterranean areas and they graze proportionately more shrubs. In many species, tannin content of leaves decreases from spring through summer, autumn and winter (Starkey et al. 1999; González-Hernández et al. 2000, 2003). Stems of shrubs, which are important forage resources during winter, contain very low concentrations of tannins (Robbins et al. 1987). Decreased concentrations of tannins and the phenolic glycoside, oregonin, resulted in increased palatability of red alder leaves for cervids in autumn (González-Hernández et al. 2000). Although tannins negatively influence the digestible protein (DP) levels of many forage plants, browsers have adapted to an environment in which many forage species contain tannins with significant capacity to precipitate dietary proteins. They are able to optimize the nutrient availability in seasonal diets by including a mix of species, some with low tannin content. Grasses and selected species of forbs that contain essentially no tannins are important dietary components during spring and summer, when the tannin content increases (Starkey et al. 1999).

There are conflicting claims of beneficial and toxic effects caused by hydrolyzable tannins in various animal species (Jean-Blain 1998; Clifford and Scalbert 2000) and the biological significance of different types of tannins, including their role in nutritional ecology. Studies of red deer diets have found *Calluna vulgaris* L. and *Vaccinium myrtillus* L. appear in higher rates compared to species of *Erica* in the same study area. González-Hernández et al. (2003) reported for these two species 100% of hydrolyzable tannins, whereas in the same study, the *Erica* species had between 68–95% of condensed tannins and only 5–32% of hydrolyzable. Nevertheless, some hydrolyzable tannins may induce severe intoxication in ruminants and in the horse (Jean-Blain 1998). Concentrations of 75–100 g of condensed tannins per kilogram dry matter have depressed voluntary feed intake and rumen carbohydrate digestion as well as rates of body and wool growth in grazing sheep, while values of 30–40 of condensed tannins per kilogram provided nutritional benefits (Barry and McNabb 1999). It is known that condensed tannins also form stable complexes with metal ions and are 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).

Protein-precipitating capacity also varies with forest stand and type. Increased light availability results in increased production of phenolic compounds (Shure and Wilson 1993). Because of differences in canopy coverage, plants growing in clearcut areas are commonly exposed to more sunlight. Understory plants in clearcut areas had greater tannin content than those growing in closed canopy forests in Oregon (Starkey et al. 1999). Because of increases in tannin content associated with reductions in canopy coverage, digestible protein may be limiting for animals inhabiting open areas. Thinning and selective harvesting may provide management tools for timber harvest, increase growth of trees, and an optimum forage resource for animals in the silvopastoral system (Starkey et al. 1999).

Biodiversity

Agroforestry practices promote the maintenance of biodiversity in a direct and indirect way for several reasons. Compared with an extensive agricultural land, the woody component introduces heterogeneity which could favour biodiversity in different ways. Agroforestry practices linked to silvoarable systems or hedgerows sustain those herbaceous species linked to arable practices (like *Silene gallica* L. which is endangered in United Kingdom due to the important transformation of arable lands to pasturelands in the last years), but at the same time the trees create gradients of moisture, light and fertility in both above and belowground components so that many different microbes, fauna (insects, worms…) and plant species adapted to these different microclimates can be developed (Mosquera-Losada et al. 2005). Silvopasture helps maintain the biodiversity level linked to grazing systems with different types of animals, including wild species, and they benefit from the structural heterogeneity created by the trees. Compared with exclusively artificial forests created by afforestation systems more time is usually allowed for the transformation between agricultural and forest land, allowing the natural recolonization of understory species in a more sequential way. The absence of vegetation has been found in some agricultural land in north-west Spain, due to the important fast depletion of pH which produced acidity by the new stand and the heavy rains in the area, which makes agricultural herbaceous species persistence very difficult, that are not replaced by the acidic natural vegetation adapted to the area (Mosquera-Losada et al. 2006). As most of the agronomic land has been occupied by herbaceous species not adapted to very acid conditions due to the long time elapsed since regular liming started, some time is needed to allow the natural, acid -tolerant vegetation to recover.

On the other hand, agroforestry also creates heterogeneity in time, as tree cover is developed, which gives the opportunity for different types of species to be introduced as part of silvoarable and silvopastoral practices. Levels of biodiversity depend on the tree species as their growth, structure and leaf anatomy which will allow different intensity of sun-light to reach the understorey. Different chemical composition and decomposition rates will determine the species assemblages which development in the stand, including birds, arachnids and butterflies (McAdam and McEvoy 2008). In the initial stages of a newly-planted silvopastoral system, the diversity of grass species may stay similar to that of a conventionally-grazed area. In a series of trials in the UK Sibbald et al. (2001) reported that *Lolium* species remained dominant under ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.) and European larch (*Larix decidua* Mill.) until tree canopy cover was in excess of 35%. Tree shade effect on grassland biodiversity was negative in a dense, five years old, *Pinus radiata* D. Don (Mosquera-Losada et al. 2006), being the effect insignificant under birch with the same stand characteristics (Rigueiro-Rodríguez et al. 2005a). By contrast, mature dehesa is considered to be the most biodiverse man-made landscape in Europe, as the combination of trees and herbaceous cover provide a habitat for a large variety of insects, birds and other fauna and flora (Moreno-Marcos and Pulido 2008).

Within silvopastoral systems, an increase in invertebrate species and numbers has been reported when moving from open grassland to agroforestry conditions for carbid beetles in Northern Ireland (Cuthbertson and McAdam 1996) and for four arthropod groups in Scotland (Dennis et al. 1996). Burgess (1999) also reports on the benefits of silvoarable systems, relative to traditional agriculture, in terms of the number of birds and mammals.

European biodiversity in a broad sense is highly related to threatened permanent grassland areas. Pressure on permanent grassland habitats is increasing steadily; these ecosystems play a major, but not always well recognised or understood role for society in terms of the employment they generate, their outputs, the environment they deliver and the contribution they make to sustain a level of biodiversity. The grasslands are key habitats for many species of herbs, grazing animals such as deer and rodents, butterflies and reptiles and many bird species. Sixty percent of the newly afforested area in the EU was formerly permanent pasture or meadows, so it will be necessary to reduce the initial tree density, allowing the establishment of silvopastoral practices which will be more compatible with the previous range of biodiversity (Rois et al. 2006).

Biodiversity promotion due to the implementation of agroforestry practices is also obtained at a landscape level. Biodiversity is also enhanced by silvopastoral systems due to the connection between forest and agricultural habitats, acting as wildlife corridors. This is especially relevant in those areas where the area of forests is very low. Moreover there is an important relationship between biodiversity and traditional practices like transhumance through Europe. It is important to highlight that most of the agroforestry practices in Europe are linked to biodiversity promotion. For example, transhumance in higher forest lands in Alpine areas, which connects lowlands with highlands (Bunce et al. 2005).

Silvopastoral systems can be also used in fragile ecosystems and disadvantaged areas where domestic autochthonous animal breeds are well adapted and therefore their genetic biodiversity value is preserved in a more sustainable and profitable way. Europe is home to a large proportion (almost half) of the world's domestic animal diversity with 3,051 breeds registered in the FAO database (FAO 2004). Grazing livestock (ruminants and equidae) represents 63% of all recorded European breeds. Of the European breeds, almost half are categorised as being at risk of extinction and, unfortunately, the percentage of mammalian breeds in Europe at such a risk increased from 3% to 49% and of bird breeds from 65% to 79% between 1993 and 1997. This declining genetic diversity is due to intensification, large-scale industrialisation of farming and globalisation of world trade in agricultural products and breeding stock, including the consequences the destruction of the traditional farming systems associated with livestock breeds and the development of genetically uniform breeds (Rois et al. 2006).

Soil Conservation

Soil erosion is an important problem for the EU. According to the EEA (2003), about 17% of the total land area of Europe which represents 27 million hectares of European soils has risk of erosion. Most of the European soils are suffering from water erosion (92% of the total affected area) and wind erosion. Soil erosion is a major socio-economic and environmental problem throughout Europe. It reduces the productivity of the land and degrades the performance and the effectiveness of the ecosystems. Erosion is mainly linked to agricultural mismanagement and deforestation (Van Lynden 2000). The phenomenon is more acute in the southern countries, where it often reaches catastrophic dimensions, than in the northern territories because of the difficulty of vegetation to cover the soil due to hydric deficiencies. The effects of soil erosion are expected to get worse, since climate change will modify rainfall regimes in central Europe (Sauerborn et al. 1999). Land abandonment and forest fires, particularly in marginal areas, intensifies soil erosion. According to EEA (2003) erosion is mainly localised in agricultural areas, being very important in the Caucasus and the Mediterranean region, where 50–70% of agricultural land is at moderate to high risk or erosion. In the Mediterranean basin soil losses can be as high as 25 t ha^{-1} $year^{-1}$ (Spain), but reaches 15 t ha^{-1} $year^{-1}$ in France (EEA 2003), being the maximum in Spain 200 t ha^{-1} $year^{-1}$ (Correal et al. 2008). Agroforestry systems, which introduce trees and a perennial controlled understory cover in these countries, will be a good strategy to reduce soil erosion. It is important to highlight that recovery of vegetation cover is very low in these areas due to water restrictions. Recently the southern regions of Spain have tried to reduce fuelbreak maintenance costs by grazing with an adequate stocking rate, as this allow the maintenance of vegetation with low fuel capacity which will help prevent soil erosion caused by the absence of soil vegetation cover, in turn caused by mechanical fuelbreak maintenance (Robles et al. 2008).

Social Perspectives of Agroforestry Systems

Social benefits of agroforestry systems for owners and people in general are based on their productive and environmental advantages (Fig. 3.10). Multi-output production (mushrooms, wool, meat, medicine, etc.) from a usually non-productive area is

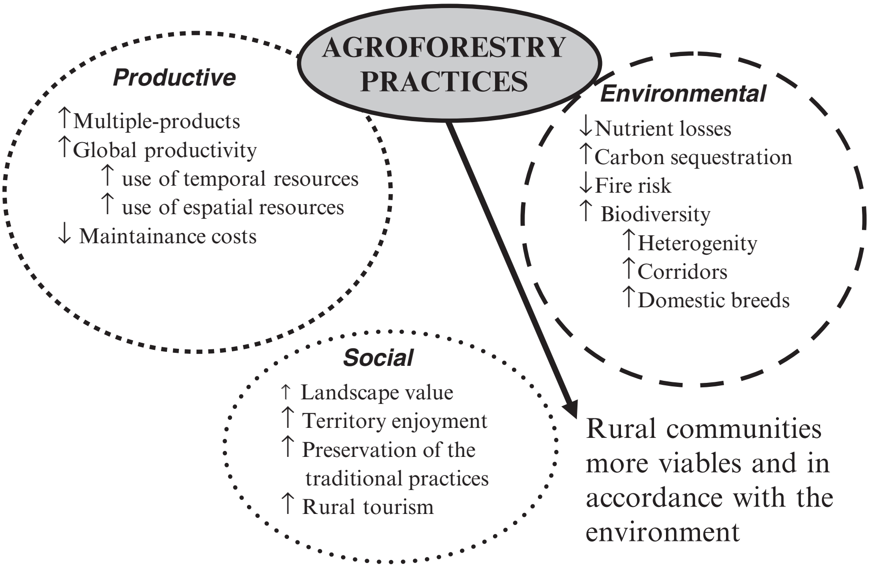

Fig. 3.10 Productive, environmental and social benefits of agroforestry system practices

a major advantage, because it can complement the farm owner's rent and value of his land from afforested areas. Otherwise these would not produce rent until the trees grew to a reasonable size. Overall productivity is increased if an adequate tree-crop is chosen because of the better temporal and spatial resource use. Trees could benefit from the crop fertilization regime as this will deal with the increment of temporal use resources, but, at the same time if silvopastoral practices are applied, animal production based on cheaper and high quality food is enhanced. This would be the case for transhumance from lowlands to forest areas in the highlands, extending the grazing season (dehesa) as the water deficit under the trees is less in Mediterranean areas or due to tree protection in Boreal areas. Better temporal resource use is also based on the use of multipurpose tree species for feeding animals, or the planting of woody perennials (including trees) which have green leaves during the summer (e.g. lines of *Morus alba* L., *Salix* spp., *Fraxinus* spp., etc.). Costs for farmers who are managing both trees and farming systems are less than in forestry areas, because silvicultural operations like clearance are not needed, whereas this would be more important in those European areas with high fire risk. This would reduce the budget allocated to fire control at the same time that forest production is enhanced. From a broad social perspective, agroforestry practices allow a higher enjoyment of the countryside by the general public, because it increases amenity and helps to preserve traditional practices and rural culture. This can also increase farm income if associated with rural tourism and can link this appreciation of the rural countryside with high quality product production (labelled-practice) and organic farming.

In conclusion, if correctly implemented, agroforestry systems could help governments address important European problems such as biodiversity preservation, carbon sequestration, soil preservation, fire risk reduction and water quality improvement.

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Chapter 4
Farmer Perceptions of Silvoarable Systems in Seven European Countries

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Abstract Between 2003 and 2004, 264 face-to-face interviews were undertaken to determine farmers' perceptions of silvoarable agroforestry across 14 sample areas in seven European countries. Across the 14 sample areas, 40% of respondents had heard the term "agroforestry" and 33% then defined it as an association of trees with crops or livestock. By contrast those farmers, who had not heard of the term, were almost as likely to define "agroforestry" as "silviculture" (24%) as an "association of trees and crops or trees and livestock" (25%). Farmers were then shown pictures of silvoarable agroforestry, where trees and arable crops were grown on the same land unit. Farmers in Mediterranean areas felt that the principal benefit of silvoarable systems would be increased farm profitability (37%), whereas farmers in Northern Europe placed greatest value on environmental benefits (28%). When asked to identify the greatest negative attribute, Mediterranean farmers tended to identify intercrop yield decline (31%), whereas farmers in Northern Europe tended to highlight the general complexity of work (21%) and difficulties with mechanisation (17%). When asked to design a silvoarable system for their farm, Mediterranean farmers tended to envisage systems with a higher tree density (100 trees per hectare) than those in Northern Europe (55 trees per hectare). Overall half of all farmers interviewed indicated that they would "attempt" silvoarable

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agroforestry on their farm, ranging from 18% to 90% within the individual sample areas. These results suggest that with appropriate promotion and support, silvoarable agroforestry would become a more common feature of the European landscape.

Keywords Adoption, agroforestry, attitudes, crops, trees, social survey

Introduction

Silvoarable agroforestry can be defined as the integration of trees with arable crops on the same land unit. Such systems can increase productivity and profitability (Graves et al. 2007) and, relative to arable production, provide environment benefits such as control of soil erosion and leaching, increased carbon sequestration and increased landscape biodiversity (Palma et al. 2006, 2007). The European Commission (2004, 2005) states that such systems should be encouraged, because of their "high ecological and social value", and the European Union (EU)'s Rural Development Regulation (1698/2005) allows support to be provided for the establishment of agroforestry systems on agricultural land. However, relatively little is known about how European farmers regard such agroforestry systems. Most research regarding farmers' perceptions of agroforestry has been undertaken in tropical countries where it has sought to understand local practice (Barrance et al. 2003), opportunities for improvement (Dreschel and Rech 1998; Fischler and Wortmann 1999), and the reasons for success or failure (Franzel 1999; Graves et al. 2004).

From August 2001 to January 2005, the Institute National de la Recherche Agronomique (INRA) in France co-ordinated an EU-sponsored project called Silvoarable Agroforestry for Europe (SAFE) (Dupraz et al. 2005). The aim of the SAFE project was "to reduce uncertainties regarding the understanding, knowledge, and functioning of silvoarable systems in Europe". Its objectives included assessment of the production and value of silvoarable systems, the prediction of its potential as a new farming system, and the establishment of guidelines for agroforestry policy.

Overall the project comprised nine activity-based work-packages and one work-package related to project management. One of the work-packages was concerned with the collection of detailed measurements of on-going silvoarable experiments (Burgess et al. 2005, 2006; Moreno et al. 2005, 2007; Paris et al. 2005; Mulia and Dupraz 2006). Four of the work-packages were concerned with development of an appropriate modelling framework and the development, parameterising and testing of two biophysical models of forestry, agroforestry, and arable system called Hi-SAFE and Yield-SAFE (van der Werf et al. 2007). In another work-package, a modelling approach based on the Yield-SAFE model was used to undertake long-term economic simulations of the effects of different systems at a plot-scale (Plot-SAFE) and a landscape-scale (Farm-SAFE) (Graves et al. 2005, 2007). Another work-package used the Plot-SAFE and Farm-SAFE models to determine the effects of the different systems on the environment (Palma et al. 2004, 2007), and an eighth work-package elaborated guidelines for policy implementation of agroforestry in Europe (Lawson et al. 2005).

The remaining work-package was concerned with the collection and collation of information on traditional European silvoarable systems and the assessment of the attitudes of European farmers toward silvoarable agroforestry. The information collated on traditional European silvoarable systems was described by Eichhorn et al. (2006). This paper describes the results for a sample of farmers in 14 areas across seven countries in Europe. The objectives were to determine farmers' current awareness of silvoarable systems, to understand their perception of the potential benefits and constraints, to understand how they would design such a system, and to determine if they would consider implementing such a system.

Method

The survey took place in 14 areas across seven countries in Europe (Table 4.1, Fig. 4.1). Six areas occurred within the Mediterranean environmental zone described by Metzger et al. (2005). The eight remaining areas in Northern Europe

Table 4.1 Brief description of the 14 sample areas

Country	Area	Description of landscape and agricultural practice
UK	Bedfordshire	Relatively flat; intensive arable production; some woodland
Netherlands	Northern Friesland	Flat, open landscape; principally dairy farming and some arable farms with potato, sugar beet or vegetable; few trees and bushes
Netherlands	The Achterhoek	Relatively flat; small and mainly mixed farms; landscape features include hedges, tree lined plots, solitary trees and copse wood bushes; many trees some forests
Germany	Schleswig-Holstein	Flat; large-scale arable farming and large deciduous forests
Germany	Brandenburg	Flat; large-scale arable farming and large coniferous forests
France	Poitou-Charentes	Primarily arable farming focussed on wheat; substantial area of hedges
France	Centre	Research focused on intensive arable area
France	Franche-Comté	Substantial forest cover (43%), agriculture focussed on livestock and pasture
Spain	Castilla y León	Relatively flat; large-scale cereal and sunflower farming; small irrigated plots with alfalfa and beetroot; treeless landscape
Spain	Castilla-La Mancha	Relatively flat; large-scale cereal farming, olive plantations and vineyards; occasionally combination of olive trees with vineyards
Spain	Extremadura	Flat landscape dominated by irrigated cropland with tomatoes, tobacco, corn, and vegetables. Dehesas (silvopastoral system with scattered oak trees) and cereal farms dominate non-irrigated lands
Italy	Northern Italy	Intensive mechanised agriculture
Italy	Central Italy	Extensive agriculture including traditional agroforestry systems
Greece	West Macedonia	Diversified agriculture, presence of scattered trees

Fig. 4.1 Map showing the approximate location of the study areas together with a line indicating the approximate border of the Mediterranean zone

occurred within the Atlantic or continental environmental zones. The areas were selected on the basis of having a significant arable production for that country whilst minimising the distance from the organisations undertaking the research. One exception to this was Franche Comté in France which is well-forested and the principal agricultural system is livestock production (Table 4.1).

In 2003, in each of the areas, a sampling frame (Schofield 1996) of commercially-active farmers was developed. Various avenues were taken for this. In the UK, the sampling frame was developed from a listing of farmers in a local telephone directory; whilst in The Netherlands, a fee was paid to a consulting company to provide the names of potential farmers. In Germany, addresses of farmers were given by regional farmers' union ("Kreisbauernverband") and agricultural schools. In France, the surveyed farmers were identified through the ROSACE database (Réseau d'observation des systèmes d'explotation). In Spain, the farmers were randomly sampled from the list of addresses given by farmer associations (at province level) and the agriculture extension services (at county level). In Italy the interviewed farmers were identified through both institutional contacts with farmer associations, consortia or cooperatives and personal contacts. In West Macedonia, all of the farmers were within the Askio Municipality and each had at least one plot of land contained or bordered by trees. The number of farmers interviewed in each area ranged from 14 to 30 (Table 4.2). The exceptions to this were in Germany where budget constraints meant that between six and ten farmers were interviewed.

In each of the 14 areas, individual face-to-face interviews were undertaken with farmers and farm managers using an interview schedule based on a standardised questionnaire (Neuman 2000; Liagre et al. 2005). The questionnaire comprised

Table 4.2 Number of interviews, mean age of the interviewee, the proportion able to identify a successor, mean farm area, proportion of the farm that was owned by the occupier, the area per worker, and the number of arable crops being grown per farm, for each of 14 sample areas

Area	Number of interviews	Mean age (years)	Proportion identifying a successor (%)	Mean farmed area (ha)	Proportion of area owned (%)	Workers per farm	Area per worker (ha)	Number of arable crops
Bedfordshire, UK	15	45	53	306	64	3.4	106	3.3
Northern Friesland, NL	15	50	20	52	65	1.4	39	3.4
The Achterhoek, NL	14	48	29	61	54	1.5	46	2.6
Schleswig-Holstein, D	6	40	17	392	28	3.4	163	6.2
Brandenburg, D	10	42	20	1,450	60	11.8	65	6.9
Poitou-Charentes, F	22	48	18	115	43	1.4	99	4.0
Centre, France, F	22	39	14	135	27	1.4	104	4.0
Franche-Comté, F	15	44	13	130	41	1.3	99	4.4
Mean		**45**	**23**	**331**	**48**	**3.2**	**90**	**4.4**
Castilla y León, ES	25	50	12	134	66	1.7	83	3.6
Castilla-La Mancha, ES	30	50	50	120	69	3.2	51	2.8
Extremadura, ES	30	45	23	302	81	10.9	80	2.5
Northern Italy, I	20	49	65	35	83	2.1	23	2.6
Central Italy, I	20	50	45	120	76	2.4	44	2.8
West Macedonia, GR	20	52	55	4	90	1.5	1	1.3
Mean		**49**	**42**	**119**	**77**	**3.6**	**47**	**2.6**
Overall mean (n = 14)		**47**	**31**	**240**	**60**	**3.4**	**72**	**3.6**
Total	**264**							

both open and closed format questions and, apart from a change in language, the same questionnaire was used in each country. Each interview comprised four main phases and generally lasted between 30 and 90 minutes according to the interest and availability of the farmer. The quantitative and qualitative data collected during the interviews were entered onto a laptop computer.

The first section of the interview was used to determine (i) background information on the farmer and farm business, and (ii) the farmer's understanding of agroforestry systems. The second section included a demonstration of silvoarable systems using images on the computer so that farmers were aware of the types of silvoarable agroforestry being considered in the SAFE project (Fig. 4.2). The third section aimed to determine the perceived positive and negative aspects of the silvoarable systems shown. The final section aimed to determine how farmers would design a silvoarable system and to determine if, after the interview, they would be interested in establishing a silvoarable agroforestry system.

The data collected during the interviews were analysed using a variety of parametric and non-parametric tests (Liagre et al. 2005). Qualitative data were disaggregated and coded according to thematic content (Strauss and Corbin 1998). They

Fig. 4.2 Examples of the types of silvoarable systems shown to the farmers during the second phase of the interview

were then used to substantiate responses to closed format questions, i.e. triangulation of method (Neuman 2000), introduce new themes and explanations in the analysis.

Results

Sample of Farmers

Across the 14 sample areas, those interviewed included farmers and farm business managers. The mean age of the interviewees was 47 years (Table 4.2); however the mean age per area ranged from 39–40 years in Centre France and Schleswig-Holstein to 52 years in West Macedonia. Across the 14 sample areas, 31% of the farmers were able to identify a successor to the farm, a third indicated there was no successor and a third were unable to specify if there was a successor or not. Whereas over 50% of those interviewed were able to identify a successor in Bedfordshire, Northern Italy, and West Macedonia, less than 20% were able to identify a definite successor in Castilla y León and the three sample areas in France (Table 4.2).

The mean cropped area per farm across the 14 areas was 240 ha. However this area ranged from only 4 ha in West Macedonia in Greece to 1,450 ha in Brandenburg (Table 4.2). Although the mean farm size in Brandenburg was 1,450 ha, the distribution of farm size was bimodal with seven farms each covering less than 700 ha and three farms each covering between 3,000 and 7,000 ha. Across the 14 sample areas, farmers owned a mean level of 60% of the farmed area; the rest was rented. The lowest level of ownership (<45%) was in the three French areas and the highest level was in West Macedonia (90%). The mean number of people employed on each farm was generally between 1 and 4, except in Extremadura and Bradenburg, where the mean number of people employed was between 10 and 12. The area per worker ranged from 164 ha per person in Schleswig-Holstein to about 1 ha per person in West Macedonia.

Trees, Arable Crops and Knowledge of Agroforestry

Across the 14 sample areas, 45% of farmers reported no trees on the cropped area of their farm (Fig. 4.3). The proportion of farms without trees on cropped fields was greatest in Bedfordshire, Northern Friesland, the Achterhoek, France Comté, and Castilla y León. In part this appeared to be a result of farmers wishing to maximise the area for crop production, however even in the UK and Germany, some farmers had kept isolated trees for environmental or landscape value. The frequency of farms with more than 20 trees per hectare was greatest in West Macedonia, Castilla-La Mancha and Extremadura.

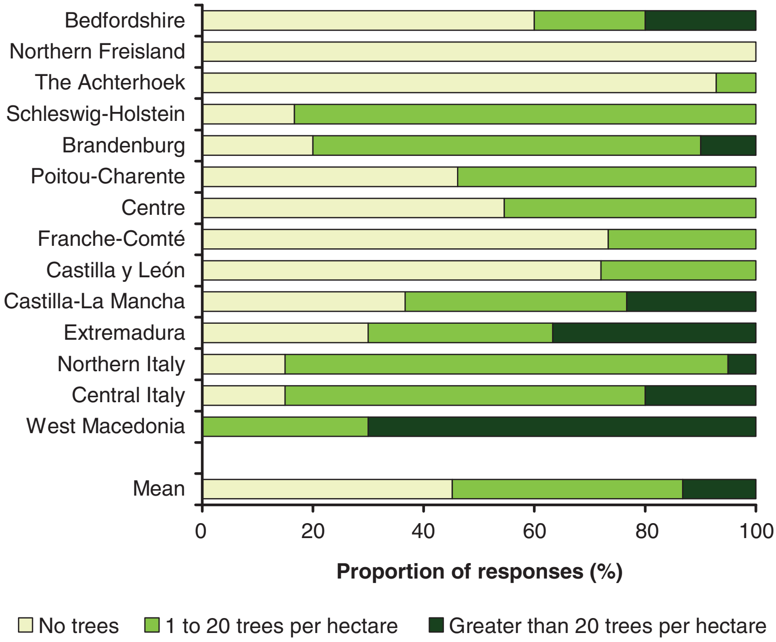

Fig. 4.3 Proportion of interviewees in each of 14 sample areas reporting no trees, 1–20 trees per hectare or over 20 trees per hectare on the cropped area of their farm

Although it was intended that the sample farms should be specialised arable farms, this condition was difficult to achieve. For example, in the Netherlands, it was difficult to find farmers producing crops who did not also have livestock enterprises. In Spain, Italy, and Greece, many of the farms included fruit production. The mean number of arable crops found on the sampled farms ranged from more than six in Germany to less than two in Greece (Table 4.2). Typical arable crops in Northern Europe included wheat, barley, oilseed rape and field beans, whilst those in the Mediterranean included maize and alfalfa.

Across the 14 sample sites, only 40% of farmers claimed to have heard of the term "agroforestry" and were willing to suggest a definition of the term (Table 4.3). In total 33% identified agroforestry as an association of trees with crops or livestock. The four areas – where a higher proportion of farmers related agroforestry to an association between trees and livestock, rather than trees and crops – were Northern Friesland, Castilla y León, Castilla-La Mancha, and Northern Italy (data not shown). Of the remaining 7% who had heard of agroforestry, 4% considered that it was silviculture and 3% considered that it was tree planting on arable land. Of the 54% of farmers, who had not heard of the term "agroforestry" but were willing to suggest a definition, 25% considered that it was silviculture, 24% considered it was an association of trees with livestock or crops, and 5% related it to tree planting on arable land. Overall 6% of farmers did not offer a definition (Table 4.3).

Table 4.3 Proportion of farmers who had heard or had not heard of the term "agroforestry", and the respective proportions who then defined it as "an association between trees and crops or livestock", "silviculture" or "tree planting on arable land" for each of 14 sample areas

Area	n	Had heard of "agroforestry": Association between trees and crops or livestock	Had heard of "agroforestry": Silviculture	Had heard of "agroforestry": Trees planting on arable land	Had not heard of "agroforestry": Association between trees and crops or livestock	Had not heard of "agroforestry": Silviculture	Had not heard of "agroforestry": Tree planting on arable land	Other: Responses including "don't know"
Bedfordshire	15	20	0	27	0	0	0	53
Northern Friesland	15	27	7	0	0	66	0	0
The Achterhoek	14	7	7	7	0	79	0	0
Schleswig Holstein	6	66	17	0	17	0	0	0
Brandenburg	10	50	0	0	30	20	0	0
Poitou-Charentes	22	18	5	0	27	36	9	5
Centre, France	22	14	0	0	9	41	27	9
Franche-Comté	15	20	0	0	40	7	27	6
Mean		**28**	**4**	**4**	**15**	**31**	**8**	**9**
Castilla y León	25	20	0	0	68	12	0	0
Castilla-La Mancha	30	17	7	0	33	40	0	3
Extremadura	30	33	4	0	54	6	3	0
Northern Italy	20	70	0	0	20	10	0	0
Central Italy	20	60	10	5	5	15	0	5
West Macedonia	20	35	0	0	40	25	0	0
Mean		**39**	**3**	**1**	**37**	**18**	**1**	**1**
Overall mean (n = 14)		**33**	**4**	**3**	**24**	**25**	**5**	**6**

Positive Perceptions of Silvoarable Systems

After the farmers had been shown computerised photographs of a range of silvoarable agroforestry (e.g. Fig. 4.2), they were asked to identify possible benefits and constraints of the system. When the positive attributes were ranked across the

Table 4.4 Proportion (%) of respondents in each of 14 sample areas identifying selected characteristics as the most important positive benefit of silvoarable systems

		Positive benefit							
Area	n	Profitability	Environment	None	Diversification	conservation	Patrimony	Subsidy	Other
Bedfordshire	15	27	20	13	7	13	0	7	13
The Achterhoek	14	21	36	0	14	0	7	21	0
Northern Friesland	15	7	20	47	7	0	7	13	0
Schleswig-Holstein	6	17	33	0	0	50	0	0	0
Brandenburg	10	30	30	0	10	0	30	0	0
Poitou Charentes	22	18	32	14	14	5	0	0	18
Centre	22	27	23	5	14	14	9	0	9
Franche Comté	15	13	27	0	20	20	13	0	7
Northern mean		**20**	**28**	**10**	**11**	**13**	**8**	**5**	**6**
Castilla y León	25	52	12	20	0	0	4	0	12
Castilla-La Mancha	30	33	20	17	23	0	0	0	7
Extremadura	30	43	10	3	30	0	3	0	10
Northern Italy	20	35	15	30	15	0	0	0	5
Central Italy	20	30	15	35	15	0	0	0	5
West Macedonia	20	30	10	25	30	0	0	5	0
Mediterranean mean		**37**	**14**	**22**	**19**	**0**	**1**	**1**	**6**
Overall mean (n = 14)		**27**	**22**	**15**	**14**	**7**	**5**	**3**	**6**

14 sites, the most highly ranked positive aspect was increased profitability (27%), followed by environmental benefits (22%) (Table 4.4). Across the 14 sites, 15% of respondents were unable to identify any positive benefit, 14% identified diversification benefits, followed by soil and water conservation (7%), patrimony (5%) and the possibility of obtaining subsidies (3%). The perceived benefits of establishing silvoarable systems varied from Northern to Mediterranean Europe. In Northern Europe only 20% farmers perceived increased profitability to be the principal benefit compared to 37% of farmers in Southern Europe. By contrast 28% of farmers in North Europe considered that the principal benefit would be environmental (including landscape and biodiversity) compared to 14% of farmers at the Mediterranean sample sites (Table 4.4).

Negative Perceptions of Silvoarable Systems

Across the 14 locations, the principal negative perceptions related to silvoarable systems were the negative effect of the trees on intercrop yield (18%), the complexity of the work (17%) and problems with mechanisation (15%) (Table 4.5). Some

Table 4.5 The proportion (%) of respondents in each of 14 sample areas identifying selected characteristics as the most important negative aspect of silvoarable systems

		Negative attribute									
Area	n	Intercrop yield	Work complexity	Mechanization	Project feasibility	Labour required	Status and subsidy	Risk	Environment	None	Other
Bedfordshire	15	20	13	20	20	7	7	13	0	0	0
Northern Friesland	15	13	0	47	0	0	13	7	20	0	0
The Achterhoek	14	14	0	21	36	7	7	7	0	7	0
Schleswig-Holstein	6	0	33	0	0	17	17	0	33	0	0
Brandenburg	10	0	40	20	10	10	0	20	0	0	0
Poitou Charentes	22	5	18	0	9	23	27	14	0	0	5
Centre	22	0	18	0	14	14	23	14	0	0	18
Franche Comté	15	13	47	27	0	0	13	0	0	0	0
Mean		**8**	**21**	**17**	**11**	**10**	**13**	**9**	**7**	**1**	**3**
Castilla y León	25	4	24	16	24	0	16	8	0	8	0
Castilla-La Mancha	30	17	10	10	10	13	10	10	7	7	7
Extremadura	30	30	7	17	10	3	0	23	0	0	10
North Italy	20	35	5	20	0	30	0	5	0	0	5
Central Italy	20	40	5	10	0	10	0	10	0	25	0
West Macedonia	20	60	20	0	15	0	0	0	0	5	0
Mean		**31**	**12**	**12**	**10**	**9**	**4**	**9**	**1**	**7**	**4**
Mean (n = 14)		**18**	**17**	**15**	**11**	**10**	**10**	**9**	**4**	**4**	**3**

farmers citing lower yields mentioned their experience of reduced growth of maize and decreased tuber volume of potatoes in areas next to woodland, which they attributed to competition for light and/or water. The problems with mechanisation were primarily linked to a perception that machine operators would reduce the speed of machine operations to minimise collisions with trees. Some farmers said they had already experienced these kinds of difficulties during machine operations near isolated trees or woodlands. Some indicated that these concerns could lead to contractors charging extra for machine operations or refusing to undertake the work. Farmers also mentioned the need for adequate headlands around such systems which would make silvoarable systems unsuitable for small fields or particular field shapes.

Farmers' perceptions of constraints appeared to vary with region. For example the proportion of farmers in the Mediterranean area of Europe (31%) listing intercrop yield decline as the principal constraint was greater than that in Northern Europe (8%). In those areas, the principal concerns were the complexity of work (21%) and mechanisation (17%). Across the 14 samples, 9% of farmers cited market risk as the principal constraint in such a long-term system. There was a perception that a range of circumstances could unexpectedly lead to a reduction in the value of the trees and some form of insurance or subsidy would be required. There was also concern about the long-term eligibility of the land to EU subsidies and agri-environment support measures, and some saw possible constraints as they rented some or all of their land from a landowner. Across the 14 samples, 4% of farmers considered agroforestry had a negative environmental impact. For example, 20% of farmers in Northern Friesland felt that this was the principal constraint of the system. Some felt the open landscape in that area was part of the cultural heritage and that this would be undermined by the presence of trees. Also in Northern Friesland, others mentioned that trees could have a negative impact on wild birds such as geese which used the open fields and others believed that the lack of shelter reduced the incidence of livestock pests.

Design of a Silvoarable System

In the last part of the survey, farmers were asked to imagine what tree and crop species they might include in a silvoarable system and how such a system might look on their farm. The suggested tree species included walnut (*Juglans* spp.) (26% of responses), poplar (*Populus* spp.) (17%), fruit trees (12%), oak (*Quercus* spp.) (10%), and wild cherry (*Prunus avium* L.) (6%) (Table 4.6). The choice was generally governed by existing practice in the area. For example, because of large local reforestation projects at Castilla y León in Spain, 90% of farmers stated they would want a tree species such as walnut which can produce valuable timber. Where there were few existing trees, such as in Centre in France or in Northern Friesland, farmers found it more difficult to identify a suitable species; in total 18% indicated that they did not know. Generally farmers suggesting walnuts, poplar or wild cherry trees said their choice was governed by wanting a profitable timber product and rapid tree growth. The primary reason that farmers gave for selecting slow-growing trees such as oak was to contribute to the local landscape.

When farmers were asked to suggest the crop species that would form the most appropriate inter-crop, 27% said they would stop cropping altogether and 20% suggested shifting to fodder crops or pasture. Of the 53% who suggest a crop, most said they would continue using their existing crops. The most cited crops included autumn-planted cereals, which were considered suitable because leaf growth during the autumn and winter would minimise light competition with the trees. Similarly, farmers growing spring-planted crops such as sunflower or vegetables said they might change their existing rotation to minimise light competition. Other farmers focussed on the importance of machinery operations. Many felt that farm machinery for cereal and pasture production could be adapted for use in silvoarable systems, whereas some focussed on crops such as maize and alfalfa which required less frequent use of machinery. Some farmers suggested that selecting nitrogen-fixing crops such as alfalfa could provide a nitrogen benefit to the trees. Crops identified by farmers as unsuitable for silvoarable agroforestry included potatoes, sugar beet, tomatoes and pepper. The basis for this included intolerance to shading, susceptibility to weed or pest competition, and difficult and frequent machine operations.

Farmers in Northern Europe tended to envisage systems with wider alleys (mean = 27 m) than in Mediterranean areas (mean = 18 m) (Table 4.6). However the within-row distance between trees was similar for both Northern European and Mediterranean sites (means = 6–7 m). Overall, these dimensions suggested that

Table 4.6 Tree and crop species proposed by farmers and mean dimensions of suggested silvoarable plots in each of the 14 sample areas

Area	n	Tree species cited by more than 20% of farmers	Most cited crop species	Tree row distance (m)	Within row tree distance (m)	Tree density (ha^{-1})	First year crop width (m)
Bedfordshire	15	Poplar and oak	Cereal	28	7	53	24
Northern Friesland	15	–	Pasture	25	7	57	22
The Achterhoek	14	Walnut	Cereal	27	6	59	25
Schleswig-Holstein	6	–	Cereal	29	6	55	27
Brandenburg	10	Wild cherry	Cereal	na	na	na	na
Poitou-Charentes	22	Walnut and poplar	Cereal	23	9	50	20
Centre	22	Walnut	Cereal	27	6	61	24
Franche-Comté	15	Walnut and poplar	Cereal	27	8	50	23
Mean				**27**	**7**	**55**	**24**
Castilla y León	25	Poplar	Cereal	21	5	90	20
Castilla-La Mancha	30	Walnut and fruit tree	Cereal and alfalfa	14	7	105	14
Extremadura	30	Walnut and poplar	Pasture	19	5	103	17
Northern Italy	20	Cherry	Cereal and legumes	18	6	96	15
Central Italy	20	Walnut and fruit tree	Cereal and legumes	24	7	60	21
West Macedonia	20	Walnut, fruit tree, poplar	Beans and vegetables	13	5	146	6
Mean				**18**	**6**	**100**	**16**
Overall mean (n = 14)				**23**	**6**	**76**	**20**

na = no response available

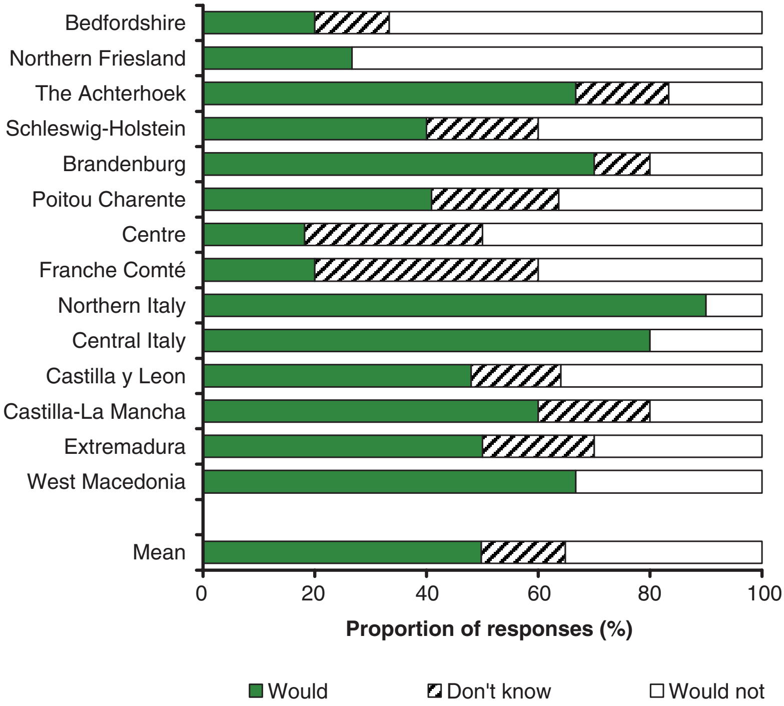

Fig. 4.4 Proportion of interviewees in each of 14 sample sites reporting if they would or would not attempt a silvoarable project

mean tree density for the Northern European sites (55 trees per hectare) was less than that in Mediterranean areas (100 trees per hectare).

Implementation of Silvoarable Agroforestry

In the last part of the survey, the farmers were asked if they were interested in setting up a silvoarable system on their own farm. Across the 14 samples, 50% of farmers indicated that they would consider using such a system (Fig. 4.4). The proportion of farmers giving a positive response ranged from 18–20% in Bedfordshire, Centre and Franche Comté to 90% in Northern Italy. However, this willingness was often conditional on visiting an exiting system or profitability.

Discussion

The results are discussed in terms of knowledge of agroforestry, the benefits and constraints of silvoarable agroforestry, system design and factors constraining the adoption of such systems. The research reported here on silvoarable system is novel in that previous research on farmers' perceptions of agroforestry in temperate areas has tended to focus on riparian strips (Ducros and Watson 2002), hedgerows (Morris et al. 2002), windbreaks (Matthews et al. 1993) or silvopastoral systems (McAdam et al. 1997).

Knowledge of Agroforestry

In the scientific literature, agroforestry is often taken to mean practices where trees are intimately associated with agricultural components at a field scale (Sinclair 1999). However there are papers, e.g. Carvalho et al. (2002), where “agroforestry” seems to refer to the planting of woodland on agricultural land. Across the 14 sites, 33% of the farmers sampled had heard of agroforestry and gave a definition similar to that provided by Sinclair (1999). In fact, most farmers who had heard of the term were able to distinguish “agroforestry” from silviculture and tree planting on arable land. The proportion of farmers – who had both heard of agroforestry and defined it as an association of trees with crops or livestock – was particularly high in Italy (60–70%). This may be a result of the sampled farmers being identified through established contacts rather than random sampling, and the presence of established agroforestry systems (Eichhorn et al. 2006). Pannel (1999) reports that the first condition necessary for adoption of new systems is that farmers must be aware of the system. The results presented here would suggest that the term “agroforestry” remains unfamiliar to a high proportion of European farmers. Moreover of those farmers who had not heard of the term “agroforestry”, a similar proportion guessed that it referred to silviculture (25%) rather than an association between trees and crops and trees and livestock (24%). This finding is significant in that an understanding of agroforestry as an association of trees with crops or livestock does not seem to flow naturally from the term itself. In fact the use of the term “agroforestry”, without an accompanying definition, could potentially lead to greater misunderstanding than the use of more traditional terms such as “grazed woodlands”, “dehesa”, or “parklands”.

Benefits and Constraints of Silvoarable Agroforestry

Across the 14 sample areas, after the farmers had been shown examples of silvoarable agroforestry, they identified that the principal benefit of such a system was likely to be an increase in farm profitability (27%) or environmental benefit (22%). Overall 15% saw no benefit and 14% considered that the greatest benefit was related to diversification. A similar range of motivations was observed by Lawrence and Hardesty (1992) who used a postal questionnaire in Washington State in the USA, to survey employees of the Soil Conservation Service, an extension service, and a group comprising academics, land managers, and owners of natural resource businesses. Overall, Lawrence and Hardesty (1992) report that the principal perceived benefits were land use diversity (25%), enhanced productivity (18%), aesthetics (13%), and income diversity (13%). The focus on environmental benefits, particularly in Northern Europe, also matches the responses of landowners in Florida (USA) as observed by Workman et al. (2003) who found that the four greatest suggested benefits of combining trees with crops and animals related to aesthetics, provision of shade, creation of wildlife habitats, and soil conservation.

Across the 14 locations, the principal constraints identified for silvoarable agroforestry were the negative effects of the trees on intercrop yield (18%), the complexity of the work (17%), and problems with mechanisation (15%). This matches the results of Workman et al. (2003) amongst landowners in Florida (USA) who identified component competition and the expense of management as two of the top four obstacles. The other two major obstacles observed by Workman et al. (2003) were lack of information and a lack of markets. A lack of information and a lack of technical assistance were also identified as key obstacles by respondents in Lawrence and Hardesty's (1992) study in Washington State. The procedure used in the European interviews of describing the silvoarable system within the interview is probably one reason why the proportion of farmers indicating a lack of information or technical assistance was smaller in this study than in the American studies.

Design of System

The farmers sampled in Northern Europe suggested lower tree densities than those in Southern Europe. This is probably a result of the respective width of and type of agricultural machinery in these regions. For example in France and the UK, the width of spray booms was cited as the main criteria for determining the tree row distance. By contrast in some areas of Spain, the width of the tree rows was determined by the width of the combine harvester, as there was minimal use of spray treatments. In addition farmers in Northern locations tended to cite a larger number of crops within the crop rotation and this may also lead to an increased tree row width. For example, it would be important that the tree-row distance is both a multiple of the sprayer and a combine harvester. The choice of the tree row width is critical, because once planted it is fixed unless, for example, a farmer removes alternate lines of trees. Hence some farmers in France specified particularly wide tree row spacing in anticipation of increased spray boom widths within the length of the tree rotation.

It is sometimes proposed that farmers may decrease the width of the alley during the tree rotation. However the farmers surveyed generally indicated that they would use a consistent cropped-alley width for the duration of cropping within the silvoarable system, which was generally perceived to be the same as the rotation for the tree crop. Some farmers were concerned about the possibility of losing agricultural subsidies if they reduced the intercrop area, and one third of farmers said they would continue cropping even if it was unprofitable. Some of those who said they would consider reducing the intercrop area, as the trees grew, mentioned that they could block specific lines within a seed drill. Others said they would establish a fodder or pasture crop, whilst a small proportion said they would maintain bare soil.

Opportunities for Adoption

The proportion of farmers indicating that they would seriously consider adopting silvoarable agroforestry systems ranged from 18–20% in Bedfordshire, Centre and Franche Comté to 90% in Northern Italy. The high value obtained in Northern Italy may in part be a result of the existing practice of such systems in areas such as the Po Valley. These overall results suggest that many farmers are open to the possibility of integrating trees with crops. However, it should be noted that these values do not relate to a firm commitment to plant silvoarable systems, but only that the possibility would be seriously considered. It is also possible that the positive results could have been inflated by the temporary "euphoria" of the interview.

Clearly a decision to consider silvoarable agroforestry is the first step in possible implementation. However before farmers decide to implement such systems they will usually seek further evidence to allow them to make a well-informed decision. Several farmers stated that they would need to see further experimental results in order to understand better how crops grow between trees. Many indicated that they would like to see real sites. Subsequent to the EU project, the French government has agreed to support a number of agroforestry demonstration sites across various French departments to demonstrate the range of systems.

Pannel (1999) indicates that once farmers are aware of a new system, the next three conditions are that than farmers must consider that (1) it can be trialled, (2) that it is worth trialling, and (3) that it meets important objectives such as profit. Farmers are often considered to be "risk-averse" (Antle 1987; Myers 1989) especially if a technology causes fundamental changes in farm management and resource-use and they therefore prefer to trial new technologies before adopting them. The long-term requirements of silvoarable agroforestry mean that it is difficult for an individual farmer to consider trialling the system because of the substantial commitment in terms of land, labour and capital. Across the 14 samples, those farmers interested in considering agroforestry further were keen to understand the economic implications of establishing such systems, for example, investment levels, cash flow evolution and timber prices. Bio-economic models such as Plot-SAFE and Farm-SAFE (Graves et al. 2007) are one possible tool to help demonstrate the potential effect of different market prices on the likely outcomes of different scenarios.

A third point that was often raised by the farmers was the extent to which current EU agriculture and environment regulations penalised mixed cropping systems. Many farmers for example stated that the tree area would need to be eligible for single farm payments. At present it is unclear that this will always be the case as the interpretation of the land management criteria for continued single farm payments can vary with country. In addition some farmers asked that, since there are grants for conventional woodland establishment, was it possible to obtain corresponding grants for agroforestry systems? Although the recent European Regional Development Regulation does allow each EU country to create grants for agroforestry establishment and management, this option may not be taken up in some countries. Pilot-schemes, such as those being trialled in Scotland, can be a useful initial step to see what is possible.

Conclusions

The results from the survey suggest that many farmers are open to the possibility of integrating trees with crops. They also showed that the perceptions of farmers varied with area and according to the environmental and socio-economic contexts. Farmers in Mediterranean areas felt that the principal benefit of silvoarable systems was to improve farm profitability, whereas farmers in Northern Europe highlighted environmental benefits. In terms of negative attributes, farmers in Mediterranean Europe prioritised intercrop yield decline whereas farmers in Northern Europe felt that complexity of work and mechanisation were the most important constraints. Compared to Mediterranean farmers, farmers in Northern Europe envisaged systems with wider alleys and lower tree densities. This difference was associated with the use of larger machinery.

Farmers in Mediterranean areas appeared to be the most likely to establish silvoarable systems on their farms. To some extent these results reflect local agricultural practices or the extent to which trees and tree products are seen as relevant to local economic opportunities. The Southern areas of Europe are where most of the extant silvoarable systems are found, for example, olive associations in Italy or oak associations in Spain and Greece. Olives, fodder and firewood are all valuable products within Southern farming systems. Even so, even in intensive arable production areas in Northern Europe, at least one fifth of the farmers sampled were willing to consider the possibility of a system on their own land. Clearly there is more that is needed from policy, research, demonstration sites, and extension services, if silvoarable agroforestry is to become a significant feature of the European landscape.

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Chapter 5
Traditional Agroforestry Systems and Their Evolution in Greece

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Abstract Agroforestry systems are a traditional land use practice in Greece. They are widely distributed all over the country and constitute important elements of the rural landscape. They include all three types of systems: silvoarable involving trees and crops grown on arable land, silvopastoral involving trees and pasture/animals grown on forest and arable land and agrosilvopastoral involving trees, crops and grazing animals grown on arable land. Trees may be forest species or cultivated trees grown for fruits, naturally regenerating or planted, evergreen or deciduous; crops may be annual or perennial species; and animals may be sheep, goats, cattle, pigs or chicken. The area covered by these systems is estimated to be more than 3 million hectares or 23% of the whole country. All types of systems deliver a great variety of goods and services and constitute a cultural heritage while the role of trees is crucial in sustaining production and improving the environment in rural areas. Despite their great economic, ecological and cultural importance however traditional agroforestry systems have been degraded over the last few decades due to extensification/intensification processes imposed by socio-economic changes. In this paper, after describing the most prominent traditional agroforestry systems and analysing their economic, ecological and cultural roles, their recent evolution is discussed and recommendations are made for their inventory, conservation and sustainable management.

Keywords Classification, cultural aspects, kermes oak, olive tree, valonia oak, walnut systems

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Agroforestry Systems in Greece: Historic Perspective

In Greece, agroforestry dates back to the Neolithic period when forests were opened up by cutting or burning by man in order to accommodate grazing for domesticated livestock resulting in the creation of silvopastoral systems. Grove and Rackham (2001) however claim that open forests of savannah-type were already present naturally in the Mediterranean region during that early period where wild or domesticated animals were grazing. On the other hand, when agriculture was developed and several forests were cleared to be converted into arable land, trees of the original forest were left inside or in the borders of the farm in order to accommodate additional needs of the people for firewood, fruits or foliage for their animals. Those relict trees in farms created the first silvoarable systems.

The deliberate incorporation of trees into farming systems, which constitutes the essence of modern agroforestry science (Nair 1993), started much later when olive and other fruit trees such as sweet chestnut (*Castanea sativa* Mill.) and walnut (*Juglans regia* L.) were introduced into the Greek farming systems (Schultz et al. 1987). According to Sallares (1991), the intercropping of olive trees (*Olea europaea* L.) and cereals or legumes was widespread in Greece during the first millennium BC because it was more productive than monocultures of any of these plants. This practice has been continued ever since with other forest species resulting in the development of a large variety of silvoarable systems. Over the centuries, both silvopastoral and silvoarable systems survived due to their ability to meet the multiple needs of the people thus becoming part or even the dominant feature of the landscape (Ispikoudis et al. 1996).

In the last few decades however most of the traditional agroforestry systems are threatened by degradation either through abandonment or intensification, which leads to their conversion to woodlands and crop monocultures, respectively. This paper presents an analysis and evaluation of agroforestry systems in Greece exploring and discussing at the same time their future evolution.

Structure, Extent and Uses of Agroforestry Systems

Agroforestry Systems Defined

In their attempt to document agroforestry systems of Greece for the first time, Schultz et al. (1987) defined agroforestry as “a general name for land management practices in which trees are grown together with agricultural crops and/or animals”.

In the present work, we have adopted the same definition. A tree is considered as any single-stemmed woody species more than 5 m high. This means that we do not include under agroforestry systems the shrublands where the woody species are multi-stemmed (shrubs or shrubby trees) and usually less than 5 m high. As crops we consider any herbaceous species as well as vines, which are cultivated in the understory or between trees (intercropping). As animals we mainly consider ruminants such as sheep, goats and cattle, but we do not exclude other domestic animals as well (pigs, horses, chickens, etc). All these animal species may be fed or directly graze in the understory on artificially established forage crops or, most commonly, on natural vegetation (pasture), herbaceous or woody (shrubby) species.

Classification of Agroforestry Systems

Schultz et al. (1987) separated agroforestry systems of Greece into two groups, those found on agricultural land, which is normally privately owned, and those found on forest land, which belongs to the Government or to other non-public organizations. In the first group, agroforestry systems usually consist of two components, trees and crops. Trees may be found or planted isolated, in groups or in lines (e.g. windbreaks) within the arable fields or in their borders, while crops are usually cereals thus resulting in silvoarable systems. Rarely crops are forage species directly grazed by livestock suggesting that very few of these systems may function as silvopastoral. On the contrary, quite a few of them may be grazed after the harvest of the cereal crop thus becoming agrosilvopastoral involving three components, namely trees, crops and animals. The second group on forest land can be classified as silvopastoral systems because they involve trees and animals grazing on the understory which is a natural pasture with herbaceous or woody (shrubby) species. These systems include open forests as well as denser ones that support herbaceous or shrubby vegetation and can be grazed without significantly impairing wood production and other forest values (Papanastasis 1996). Consequently, these grazable forests (or forest grazing) are also considered as silvopastoral systems.

It should be noted that silvopastoral systems are important grazing lands for livestock. Greece has 5.4 million goats, which correspond to more than 43% of the goat population of the 25 member countries of the European Union (Eurostat 2002). Most of these goats graze on silvopastoral systems. In addition, sheep amounting to 8.8 million heads and to a lesser extent cattle amounting to 600 hundred thousand heads depend on these systems, too.

Table 5.1 shows the prominent agroforestry systems based on the dominant tree of the overstory. It must be noted that although all these systems form pure stands, in several of them the dominant tree species is grown together with other tree species as well resulting in mixed agroforestry systems. Table 5.1 also shows that the structure of the understory is quite variable, depending on the particular ecological zone and the geographical area where the system is distributed; the mentioned products/uses refer to both the overstory and the understory or to the system as a whole.

Table 5.1 Prominent agroforestry systems of Greece classified according to the dominant tree species (systems with bold numbers are described in detail in the text)

Dominant tree species	Main understory species	Region	Main products/uses
1 Natural coniferous			
1.1. *Abies cephalonica*	Herbaceous	Central Greece, Peloponnesus	Timber, forage
1.2. *Abies borisii-regis*	Herbaceous	Pindus mountain range	Timber, forage
1.3. *Pinus halepensis*	Evergreen shrubs	Attica, Euboea, Kassandra	Resin, fuelwood, timber, forage, honey,
1.4. *Pinus brutia*	Evergreen shrubs	Crete, Thassos, Dadia, Aegean islands	Timber, fuelwood, honey, forage, resin,
1.5. *Pinus nigra*	Herbaceous	Pindus mountain range	Timber, electricity poles, forage
1.6. *Pinus leucodermis*	Herbaceous	Pindus mountain range	Timber, barrel wood, forage
1.7. *Pinus pinea*	Herbaceous, evergreen shrubs	Peloponnesus	Forage, timber, pine nuts
1.8. *Pinus silvestris*	Herbaceous	Macedonia, Thrace	Timber, electricity poles, forage
1.9. *Cupressus sempervirens*	Evergreen shrubs	Crete, Aegean islands	Forage, timber
2. Natural broadleaved evergreen			
2.1. *Quercus coccifera*	Evergreen shrubs, phrygana	Crete	Forage, acorns, fuelwood
2.2. *Quercus ilex*	Evergreen shrubs	Western Greece	Charcoal, fuelwood, forage
3. Natural broadleaved deciduous			
3.1. *Quercus ithaburensis ssp. macrolepis*	Phrygana, herbaceous, arable crops	Western Greece, mainland, Aegean islands	Forage, fuelwood, acorns, cereals
3.2. *Quercus trojana*	Herbaceous, deciduous shrubs, arable crops	Western Macedonia, Thrace, Thessaly	Fuelwood, cereals, forage, timber, fodder, acorns
3.3. *Quercus pubescens*	Herbaceous, deciduous shrubs, arable crops	Various places in mainland	Timber, fuelwood, fodder, cereals, forage, acorns
3.4. *Quercus frainetto*	Herbaceous, deciduous shrubs, arable crops	Various places in mainland	Timber, fuelwood, fodder, cereals, forage, acorns
3.5. *Quercus petraea*	Herbaceous, deciduous shrubs, arable crops	Thessaly, Macedonia	Timber, fuelwood, fodder, cereals, forage, acorns
3.6. *Quercus cerris*	Herbaceous, deciduous shrubs, arable crops	Thessaly, Western Macedonia, Thrace	Fuelwood, forage, cereals, fodder, acorns
3.7. *Castanea sativa*	Herbaceous, arable crops	Various places in mainland	Poles, fuelwood, fruits, fodder, honey, mold

(continued)

Table 5.1 (continued)

Dominant tree species	Main understory species	Region	Main products/uses
3.8. *Fagus silvatica*	Herbaceous, potato crops	Northern Greece	Timber, forage, potatoes
3.9. *Pyrus amygdaliformis*	Herbaceous, deciduous shrubs, arable crops	Various places in mainland	Forage, fuelwood, cereals, fruits
3.10. *Acer campestre*	Herbaceous, deciduous shrubs	Epirus, Central and Northern Greece	Fuelwood, forage
3.11. *Celtis australis*	Herbaceous, arable crops	Northern Greece	Fuelwood, forage, timber, fruits
4. Cultivated conifers			
4.1. *Cupressus sempervirens*	Arable crops, herbaceous	In various plains	Windbreaks, agricultural products, timber
5. Cultivated broadleaved evergreen			
5.1. *Olea europea*	Arable crops, herbaceous	Mainland and islands	Olives, forage, fodder, cereals, grapes, fuelwood, wood
5.2. *Ceratonia siliqua*	Herbaceous, arable crops	Crete, Peloponnesus, Aegean islands	Fruits, forage, cereals, grapes, fuelwood
6. Cultivated broadleaved deciduous			
6.1. *Populus thevestina*	Arable crops	Macedonia, Thrace	Timber, vegetables
6.2. *Populus* (clones)	Herbaceous, arable crops	Macedonia, Thrace, Thessaly	Timber, vegetables, forage
6.3. *Juglans regia*	Arable crops, herbaceous	Various places	Timber, nuts, cereals, grapes, forage
6.4. *Prunus amygdalus*	Arable crops, herbaceous	Mainland and islands	Almonds, grapes, cereals, fuelwood, forage
6.5. *Ficus carica*	Arable crops, phrygana	Mainland and islands	Fruits, grapes, cereals, forage
6.6. *Robinia pseudoacacia*	Arable crops, herbaceous	Various places in mainland	Timber, honey, fodder, forage
6.7. *Morus alba*	Arable crops, herbaceous	Evros, Chalkidiki, Thessaloniki, Crete	Foliage (for silkworms), fodder, fuelwood, cereals, forage, fruits
6.8. *Castanea sativa*	Herbaceous	Various places in mainland	Timber, fruits, forage
6.9. *Prunus avium*	Arable crops	Various places in mainland	Fruits, cereals, vegetables, grapes, forages, fuelwood
6.10. *Malus communis*	Arable crops	Various places in mainland	Fruits, cereals, vegetables, grapes, forages, fuelwood
6.11. *Pyrus communis*	Arable crops	Various places in mainland	Fruits, cereals, vegetables, grapes, forages, fuelwood

(continued)

Table 5.1 (continued)

Dominant tree species	Main understory species	Region	Main products/uses
6.12. *Prunus persica*	Arable crops	Central and Northern Greece	Fruits, cereals, vegetables, grapes, forages, fuelwood
6.13. *Prunus armeniaca*	Arable crops	Various places in mainland	Fruits, cereals, vegetables, grapes, forages, fuelwood
6.14. *Prunus domestica*	Arable crops	Various places in mainland	Fruits, cereals, vegetables, grapes, forages, fuelwood
6.15. *Cydonia oblonga*	Arable crops	Various places in mainland	Fruits, cereals, vegetables, grapes, forages, fuelwood

Area Covered

There is no information on the exact area covered by agroforestry systems in Greece. As a matter of fact, no such land use is designated anywhere in the official national statistics. In order to arrive at some estimates, we used indirect statistical data and educated guesses.

For the agroforestry systems on forest land we used the latest official inventory of the Forest Service for the various types of forests (Ministry of Agriculture 1992). More specifically, we considered as agroforestry systems all forests which are open (less than 100 m^3 ha^{-1} of timber stock) and have trees with measurable DBH, i.e. >5 cm. We assumed that such forests have a crown canopy cover less than 40% and support an understory with herbaceous or woody vegetation that provides forage to livestock thus making grazing management their primary objective (Papanastasis 1996). Such systems amount to 1,079,611 ha or 32% of the total area of the industrial (high) forests (Table 5.2). This figure is a conservative estimation because it does not include the grazable forests, namely the forests that have a crown canopy of about 40–60% and support some understory vegetation that can be grazed by livestock but grazing management is a secondary objective to timber management. The exact area of grazable forests is not known, but if we take into account that most forests are grazed by livestock, we can claim that the agroforestry systems on forest land amount to more than 2 million hectares. The kind of forests subjected to livestock grazing include the so called Mediterranean forests, i.e. Aleppo pine (*Pinus halepensis* Mill.)and brutia pine (*Pinus brutia* Ten.) forests, most of the mountainous pine forests [e.g. Austrian pine (*P. nigra* Arn.),Scots pine (*P. sylvestris* L.) and Heildrich pine (*P. leucodermis* Ant.)] and the deciduous oak forests, especially the ones with a coppice form (Liacos 1980; Papanastasis 1986).

For the agroforestry systems on agricultural land we used the data of the National Statistical Service of Greece (2005). We assumed that agroforestry systems exist in the whole agricultural area of Greece amounting to 3,483,200 ha except in areas

Table 5.2 Area (in ha) covered by agroforestry systems on forest land[a]

Forest type	Timber stock (m^3 ha^{-1})	Area with measurable trees (DBH ≥ 5 cm)	Area without measurable trees (DBH < 5 cm)	Estimated area of agroforestry systems[b]
Industrial	0[c]	57,359	505,988	57,359
	1–100	1,022,252	1,283,358	1,022,252
	>100	404,876	85,353	–
Non-industrial[d]	0	–	3,153,882	–
Total		1,484,487	5,028,582	1,079,611

[a] Data from Ministry of Agriculture (1992)
[b] Grazable forests (forest grazing) are not included in this area (see text for explanations)
[c] About 10% of the area of this class was found to have trees with measurable DBH
[d] This category represents shrublands with no measurable trees and timber stock

Table 5.3 Area (in ha) covered by agroforestry systems on agricultural land[a]

Group of tree species	Individual species	Estimated area[b]
Natural	Oaks, wild pears and other forest trees	843,700
Cultivated		
Citrus trees	Orange, lemon, mandarin, etc.	6,498
Fruit trees	Apple, pear, peach, apricot, cherry, etc.	17,770
Nut and dried fruit trees	Almond, walnut, chestnut, carob, fig, etc.	41,352
Olive trees	Both for edible olives and olive oil	124,311
Other trees	Plum, mastic, poplars, cypress, etc.	11,244
Total		1,044,875

[a] Data from National Statistical Service of Greece (2003)
[b] See text for explanation

where land consolidation or reclamation was carried out followed by irrigation, which resulted in the removal of almost all the naturally grown trees. Consequently, we subtracted the irrigated area from the total agricultural area as well as the area under pure tree plantations (monocultures) and arrived to a figure of 1,044,875 ha, which represents 30% of the whole agricultural area (Table 5.3). This area includes agroforestry systems with both naturally occurring and cultivated trees. For the latter, we estimated their area using the data of the National Statistical Service of Greece (2005) for the cultivated trees planted out of pure plantations (monocultures). The results are shown in (Table 5.3) and indicate that such systems represent 19% of the whole area of agroforestry systems on agricultural land. This figure however is a conservative estimate because we assumed that these trees are planted in the same densities as the ones in pure plantations, which is not true. Nevertheless, it represents the closest estimation we can get with the available data.

Cultural Aspects

Agroforestry systems have a rich cultural history and constitute examples of traditional lifestyles and techniques. They represent management practices that are based on a body of local or indigenous technical knowledge, which has evolved over time in response to the vagaries of ecological, economical and political circumstances. They are a cultural, social, economic and ecological heritage of the people.

An important element of the traditional agroforestry systems is tree management (Fig. 5.1). Two techniques have been used, shredding and pollarding. Shredding

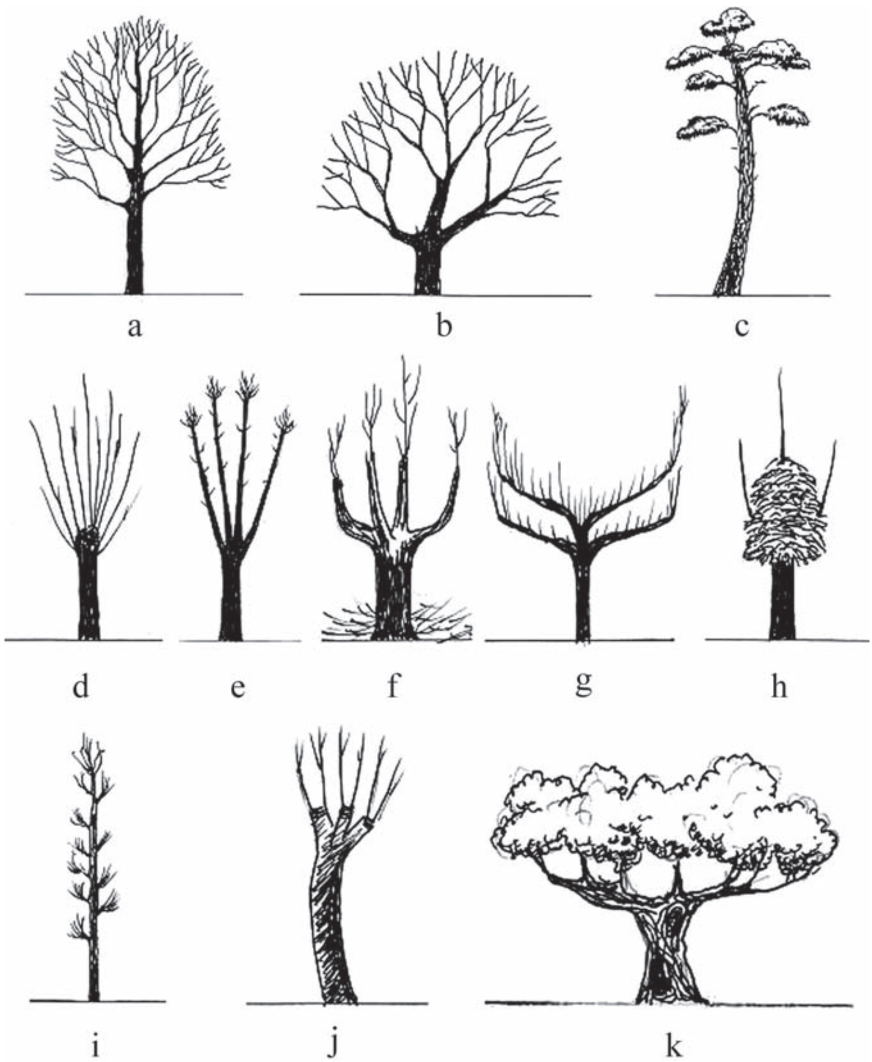

Fig. 5.1 Traditional tree management schemes: (a) non-managed tree, (b) managed walnut tree for a trunk of high timber quality, (c) pruned Aleppo pine tree for ship building timber, (d) pollarded tree of any species for fodder, (e, f) pollarded oak trees for fodder (g) pollarded mulberry tree for fodder, (h) pollarded tree for storage of fodder, (i) shredded oak tree for fodder (j) grafted tree for fruit production and (k) lopped olive tree for olives and fodder production (Drawings by I. Ispikoudis)

consists of cutting the lower branches of the tree for fodder, while pollarding involves cutting off the branches of a tree at a height at least 1.5–2 or 3 m of the trunk so that the new sprouts are out of the reach of the animals. The trees are first cut when they are 10–15 years old or when the stem diameter exceeds 15 cm. The technique of pollarding was a way of protecting the trees from browsing and/or cultivation practices. It seems that these techniques extend the life of a tree. The etymology of the Greek word 'koura' implies exactly this thing, since it derives from the words 'kouros' (young) and 'kourizo' (make young). 'Kouri' is also a place name, found all over Greece. All the places named 'kouri' are situated in areas where there was a high grazing pressure. The majority of the places named 'kouri' coincide either with areas or with the paths of transhumance (Ispikoudis et al. 2004).

Leaf and twig fodder cut from trees played a major role in animal husbandry and in many areas; stored hay was of critical importance to the survival of livestock during the winter period. This is because in many areas, mainly in uplands, winters are too cold and long for livestock to graze outdoors and they have to be penned in barns for three to six months (Halstead 1998). In addition, leaf and twig fodder harvesting also played a major role in shaping the cultural landscapes in Greece and in particular the structure and composition of vegetation. A whole cultural landscape with various forms of at least seven species of deciduous oaks has been created by the people called 'koupatsari', the oak people (Grove and Rackham 2001).

Tree fodder harvesting must have greatly influenced the Greek landscape. According to Halstead (1998), arboreal fodder has played a critical role in maintaining and shaping farming in agriculturally marginal environments. Also, shredding and pollarding of beech (*Fagus* spp.) and oak (*Quercus* spp.) trees had a widespread and drastic impact on the landscape of the mountains of Greece. Halstead (1998) has estimated that when a Greek village collectively owned around 2,000 sheep and goats the villagers would have to shred between 3,000 and 10,000 mature oaks.

Description of the Most Important Agroforestry Systems

Although Greece has still a great variety of traditional agroforestry systems, not all of them are equally important in terms of area covered. In this section, the most common and widespread systems are described following the classification proposed in the previous section and presented in Table 5.1. No distribution maps are available for these systems except one (valonia oak system) because they have not been studied yet.

Aleppo Pine Forests

Aleppo pine is a warm Mediterranean coniferous species distributed in several parts of the mainland as well as in the Ionian Islands. It has also been one of the main species used in reforestation projects. It is a light-demanding tree. As a result, Aleppo pine forests have open crowns that allow the establishment of a rich understory mainly consisted of evergreen shrubs. Among these shrubs several herbaceous species can also be found. Aleppo pine is well adapted to recurrent wildfires and its forests are the most commonly burned forest areas in Greece. This is because the rich understory often results in the accumulation of high quantities of very flammable biomass (Liacos 1986; Kailidis 1990). In addition, it exerts a strong competition to the overstory for water and nutrients (Liacos 1986; Papanastasis 1986).

Aleppo pine forests have multiple uses. Trees can be used for timber and fuelwood production but mainly for resin and honey. Resin is used for glue and as a flavour additive to 'retsina', a popular Greek white wine. Honey is produced by bees fed on honeydew secretions of *Marchalina hellenica*, an insect endemic in the Aleppo pine forests of Greece (Schultz et al. 1987). Understory vegetation is used for fuelwood production but mainly for grazing by livestock. This vegetation is not usually of high feeding value but in the absence of better quality feed, it is often indispensable for livestock nutrition, especially for goats (Papanastasis 2001). For this reason, Aleppo pine forests have been traditionally used as silvopastoral systems. Livestock grazing, especially goats, can control the understory vegetation to the benefit of the trees (Liacos 1980, 1986; Papanastasis 1986, 2001).

Brutia Pine Forests

Brutia pine is also a warm Mediterranean coniferous species distributed in the eastern part of the mainland, the Aegean islands and in Crete. It has been also extensively used in the establishment of artificial plantations, particularly in northern Greece. Its natural stands are open, because it is also a light demanding species. As a result, they support lush understory vegetation composed of different herbaceous or shrubby species (Liacos 1986). For this reason, brutia pine forests are very vulnerable to wildfires (Liacos 1986; Kailidis 1990).

It should be noted that the amount of the understory biomass and the species composition depend very much on the density of the overstory. In an experiment involving three spacings of an artificial plantation in northern Greece, it was found that both the amount of herbaceous understory and the tree diameter were increased as tree spacing increased (Platis et al. 1999; Mantzanas et al. 2001). Also, tree canopy helped maintain an average understory herbaceous biomass of 1,764 kg ha^{-1} in August, almost as high as in May (1,713 kg ha^{-1}), suggesting that brutia pine silvopastoral systems can extend the grazing period into summer, when herbaceous species get dormant without tree canopy under semi-arid Mediterranean climatic conditions (Mantzanas and Papanastasis 2003).

Brutia pine forests are also multiple use forest systems. Their timber though is of better quality but the resin production is less than in Aleppo pine. On the other hand, brutia pine forests are traditional silvopastoral systems with livestock grazing, mainly goats, contributing to the control of understory vegetation and consequently to the reduction of the fire risk (Tsiouvaras 2000). In addition, it helps maintain a high biodiversity including birds of prey, as it is the case of the Dadia forest (Bakaloudis et al. 1998).

Cypress Systems

Cypress (*Cupressus sempervirens* L.) is distributed in the southern Aegean islands and in Crete where it forms natural forests alone or in mixture with brutia pine. It has been introduced deliberately throughout Greece, in both the eu- and the sub-Mediterranean zones. Its natural stands are open forests with rich understory vegetation composed of various phryganic and herbaceous species. Such understory vegetation makes cypress forests very vulnerable to wildfires, although cypress itself is not as flammable as brutia pine.

The natural cypress forests are limited in distribution and size. They are used for timber production and especially for grazing by livestock thus making them important silvopastoral systems. The same uses are also applied to its artificial plantations. These plantations are normally pure but cypress is also established in the borders of pine plantation in the form of narrow strips in order to protect them from wildfires. Nowadays, the most common use of cypress tree is for ornamental purposes along national roads, in urban parks, in churches and cemeteries. In addition, it is also planted in arable lands as a border tree to mark boundaries or for protection of crops from the strong winds (windbreaks). These latter uses result in silvoarable or agrosilvopastoral systems.

Kermes Oak Forests

Kermes oak (*Quercus coccifera* L.) is an evergreen broadleaved tree species grown in the eu-Mediterranean and sub-Mediterranean zones of Greece. Due to its repeated cutting, burning and browsing however it is commonly found as a shrub forming extensive communities, pure or mixed with other evergreen or deciduous shrubs, which are known as ‘prinones’(kermes oak shrublands). ‘Prinones’ are mainly used for grazing by goats. Kermes oak trees, on the contrary, are only found in protected areas (e.g. urban and sub-urban forests, churches, cemeteries, private farms) either isolated or in small groves. Substantial areas of kermes oak trees are found only in certain parts of the mainland of Greece and in some islands, including Crete, where they form silvopastoral systems known as ‘prinodhasi’ (kermes oak forests). Other tree species may co-dominate with kermes oak.

Representative silvopastoral systems are found in Crete. They are usually grown in limestone areas and consist of a mixed understory with woody and herbaceous species. In such a system in the Psilorites mountain of Crete, the understory vegetation was composed of herbs (37 g m^{-2}) and shrubs (13 g m^{-2}) while the acorn yield was found to be 21 g m^{-2}. Sheep and goats consumed 73%, 29% and 89% of these yields respectively by the end of the growing period in June (Papanastasis and Misbah 1998).

Valonia Oak Systems

Valonia oak (*Quercus ithaburensis* Decaisne ssp. macrolepis (Kotschy) Hedge & Yalt.) is a deciduous species grown in several parts of the mainland as well as in various islands with an eu- or sub-Mediterranean climate, covering a total area of about 30,000 ha (Fig. 5.2). Its natural stands are relatively small and usually pure; they are rarely intermixed with other deciduous oak species such as pubescent oak (*Q. pubescens* Willd.) and Italian oak (*Q. frainetto* Ten.). The understory vegetation is composed of both woody and herbaceous species (Pantera and Papanastasis 2001; Papanastasis 2002; Platis 2002).

Overstorey density amounts to 20–50 trees per hectare and its cover rarely exceeds 40% of the ground (Schultz et al. 1987). This means that valonia oak forests are open

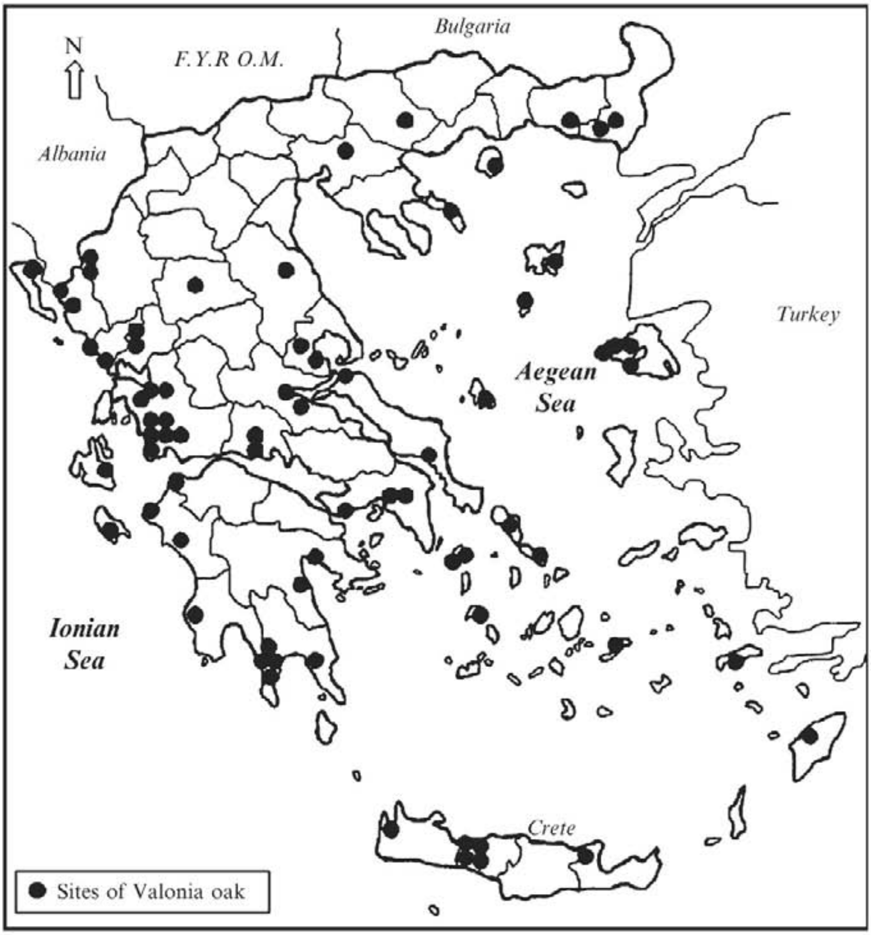

Fig. 5.2 Distribution of valonia oak in Greece (Pantera and Papanastasis 2003)

and support rich understory vegetation. In two natural stands located in Thesprotia, western Epirus, the amount of understory vegetation was found to be 2,360 and 880 kg ha^{-1} for woody [mainly Jerusalem sage (*Phlomis fruticosa* L.)] and herbaceous species respectively (Papanastasis 2002). In the Agrinio area, western central Greece, the amount of understory vegetation was found to be about 2,000 kg ha^{-1}, mainly consisted of herbaceous species, while the number of acorns fallen on the ground in December was found to be almost 8 acorns m^{-2} (Pantera and Papanastasis 2001).

As a result of their open crowns and the substantial understory vegetation, valonia oak forests are ideal silvopastoral systems, equivalent to the dehesas and montados of Spain and Portugal respectively (Papanastasis 2002). Sheep are using not only the understory forage production but also the acorns of the oak trees (Pantera and Papanastasis 2001). In several parts of its distribution zone, valonia oak is grown within arable fields or in the borders of terraces cultivated with cereals. In these cases, it is part of silvoarable systems, or agrosilvopastoral if grazing is also applied after the harvest of the cereal crop. In addition to grazing, oak trees are also used for fuelwood production, when they are old enough and result in significant amounts per tree cut. The demand for valonia oak fuelwood is getting high nowadays. In the past, the cups of its acorns were extensively used for extraction of tannins used in the leather industry.

Macedonian Oak Forests

Macedonian oak (*Quercus trojana* Webb.) is a deciduous oak tree, distributed in several parts of the mainland, particularly in western Macedonia where it is making extensive forests. These forests are either pure or mixed with other oak species such as pubescent, Italian, sessile [*Q. petraea* (Matt.) Liebl.] and Turkey oak (*Q. cerris* L.). However, most of natural stands are open thus supporting considerable understory vegetation, woody or herbaceous (Grove and Rackham 2001). Woody species may be several species of oaks (pubescent, Turkey, Italian) in a shrubby form as well as other shrubs [oriental hornbeam (*Carpinus orientalis* Mill.), manna ash (*Fraxinus ornus* L.)]. As a result of this rich understory vegetation, most Macedonian oak forests are used as silvopastoral systems for sheep and goats, which utilize not only the understory vegetation but also the fallen leaves and the acorns. In addition, oak trees are also used for the collection of fuelwood when they are old enough and result in significant amounts per tree cut. The demand for Macedonian oak fuelwood is getting high nowadays.

Macedonian oak is also found in silvoarable or agrosilvopastoral systems with arable crops, particularly cereals. In these systems, Macedonian oak is grown within or in the boundaries of the arable fields.

Other Deciduous Oaks Systems

Other species of deciduous oaks are common forest species in Greece covering almost 1.5 million hectares (Ministry of Agriculture 1992). They include pubescent, Italian sessile and Turkey oaks, all of them making high or coppice forests and primarily used for timber or fuelwood production. Although most of these forests are grazed by livestock, especially the coppice, they cannot be considered as silvopastoral systems because they are dense and therefore with limited understory vegetation while animals may damage their regeneration. Nevertheless, all these oak species form quite extensive silvoarable or agrosilvopastoral systems, particularly in the mountain areas. Isolated or small groups of these trees may be found within or in the boundaries of arable fields usually cultivated with cereals. The trees are used for fuelwood, fodder production (by shredding or pollarding), providing shade to livestock during midday in the summer or as markers of property boundaries. The arable fields are used for crops, particularly cereals, which are usually grazed after harvesting during summer. In some areas, the arable fields are cultivated with barley (*Hordeum vulgare* L.) or wheat (*Triticum aestivum* L.) not for grain production but as temporary pastures grazed during the winter or early spring.

Olive Tree Systems

Olive tree is one of the most commonly cultivated trees in the eu-Mediterranean zone of Greece. It has been cultivated since the 1st century BC (Sallares 1991). It is grown in pure orchards but most commonly in mixture with other fruit or forest species on flat or very often on terraced land, within the arable fields or in their borders. Olive orchards are kept free of understory crops with repeated cultivation of the soil in order to enhance olive production. Most often however various crops are planted in the understory such as vineyards, cereals or forages thus resulting in typical silvoarable system. In several cases, pasture is established under the olive trees or spontaneous vegetation is grown that it is used for grazing by livestock resulting in silvopastoral systems. Finally, more complex systems such as agrosilvopastoral are formed when olive groves are grazed after the harvest of the crop, as it is the case of combining olive trees with cereals. In all these cases, olive trees are mainly grown for the production of olives but the pruned branches are also used as fuel as well as for feeding animals either *in situ* or in the barn.

Poplar Systems

There are several species of poplars (*Populus* spp.), native or naturalized in Greece,but they occupy relatively limited area. On the contrary, artificial plantations with Lombardy poplar (*P. thevestina* Dode) and clones of hybrids between native and American species cover much larger area. These plantations contribute significantly to the timber production of Greece. Poplars are grown or planted in arable lands with good soils, irrigated or with good water conditions, such as water canals and riverbanks. They are usually open and support understory vegetation, which is used for livestock grazing thus making them special silvopastoral systems (Schultz et al. 1987). The most common pattern though is the establishment of Lombardy poplar or hybrids along watercourses or around arable fields, cultivated with vegetables or other summer crops. This planting pattern results in typical silvoarable systems, which are traditional in several parts of Greece, particularly in the north. Poplars are used for timber production but also serve other purposes such as boundary marking or wind breaking.

Walnut Tree Systems

Walnut is a common cultivated tree in the sub-Mediterranean and mountainous Mediterranean zones of Greece. It is planted in arable lands either in pure orchards or more commonly within arable fields or in their borders, alone or in mixture with other trees. It is usually combined with several crops, especially vineyards and cereals. In the former case it makes typical silvoarable; in the latter typical agrosilvopastoral systems are created that include livestock grazing after the harvest of the cereals. It is rarely used to establish pure silvopastoral systems. Walnut trees are used for the production of nuts, for high quality timber and for fuelwood.

Typical silvoarable systems combining walnut trees and vineyards, cereals, lucerne, vegetables or dry beans have been recorded in the Municipality of Askio, western Macedonia, in northern Greece (Mantzanas et al. 2006).

Almond Tree Systems

Almond tree (*Prunus amygdalus* Batsch) is a common fruit cultivated in the eu-Mediterranean and sub-Mediterranean zones of Greece, particularly in the dry areas of the mainland and in the islands. It is planted alone or in mixture with other trees such as olives, figs, walnuts and pistachios in pure orchards or most commonly in combination with vineyards or herbaceous crops. Pure orchards are kept free of any understory by frequent cultivation or use of herbicides. Joint cultivation with other crops is common in several parts of the country resulting in a typical silvoarable system. Herbaceous crops may include cereals, tobacco, forages and legumes. If also grazed after the harvest of the crop then agrosilvopastoral systems may be formed. Pure silvopastoral systems are rarely found.

Typical silvoarable systems combining almond trees and cereals (e.g. barley, wheat), lucerne or vineyards are found in the Municipality of Askio, western Macedonia, in northern Greece (Mantzanas et al. 2006). Also, extensive silvoarable systems of almond trees and cereals or vineyards are found in several Aegean islands.

Evolution of Agroforestry Systems

Traditional agroforestry systems have been considerably degraded during recent decades and especially after World War II. This degradation can be attributed to the decline in agriculture in the Greek countryside. This is due, on the one hand, to the rural exodus and migration of more than one million people in the period 1950–1970, who left agriculture and the rural areas for the urban centres and abroad and, on the other, to the agricultural modernization (Kasimis and Papadopoulos 2001). Since agroforestry systems are labour-intensive economic systems (Papanastasis 2004a), their function was significantly affected by the rural exodus, which largely involved the most economically active population. According to Tsoumas and Tasioulas (1986), agricultural abandonment was more pronounced in the mountainous areas, where arable lands are marginal and therefore more sensitive to market changes. Agricultural mechanization, particularly the introduction of the tractor in the past as well as the European Union support policy through subsidies did not lead to any structural improvement of family farms, especially in the marginal rural areas, mainly due to the small land ownership (Kasimis and Papadopoulos 2001).

According to Papanastasis (2004a), degradation of agrosilvopastoral systems may be caused by two opposing human actions, extensification and intensification. Traditional agroforestry systems in Greece have suffered from both these processes. They can be seen better if examined separately on forest and agricultural lands.

System Degradation on Forest Land

The degradation processes mostly affecting agroforestry systems on forest land are extensification and abandonment. Most of these systems have been maintained over the centuries through the following main human activities: wood cutting, charcoal and firewood harvesting, resin collection (in Aleppo and brutia pine forests) and livestock grazing (Papanastasis 2004b). All these activities have declined or even stopped in several parts of Greece over the last few decades. In western Crete, for example, the area covered by coniferous forests was increased by 20% from 1945 to 1989, but the area covered by dense (more than 70% tree cover) forests increased by 70% (Papanastasis and Kazaklis 1998). This increase seems to be the result of the decrease in human population in mountainous areas of that particular region and the concomitant reduction or ceasing of activities, especially livestock grazing (Ispikoudis et al. 1993). Similar results were found in Pindus mountain, in Central Greece, where the area of shrublands and especially forests increased between 1945 and 1992 at the expense of grasslands and arable lands, leading to dense stands (>70% tree cover). This was due to the reduction of the active human population and its traditional activities (Chouvardas 2001). In Lagadas County, Northern Greece, the area of kermes oak shrublands and deciduous oak forests increased and became denser between 1960 and 1993 as a result of the reduction of human population and its activities such as charcoal collection and livestock grazing (Chouvardas et al. 2006).

As far as the relation between livestock husbandry and agroforestry is concerned, Ispikoudis et al. (2004) have pointed out the importance of transhumance, a traditional pastoral activity which has created special landscapes in mountainous areas characterized by silvopastoral systems based on deciduous oaks and pines. Although transhumance is still practiced today, the number of animals involved has dramatically decreased. For example, the percentage of the total number of sheep involved was 15% in 1961 to get reduced to 7% in 2001 while for goats the respective percentages were 13% and 5% (National Statistical Service of Greece 2005). Also, the system applied has been significantly modified compared to the past largely as a result of the socio-economic changes which occurred during the last century. Typical silvopastoral systems involving 'kladonomi' (shredding) and 'koura' (pollarding) are still visible in several parts of Greece but they are rapidly fading down due to the interruption of the traditional tree management techniques (Fig. 5.1). Such an evolution has resulted in a considerable loss of cultural heritage.

Intensification has had a limited impact on agroforestry systems on forest land and it is largely localized. Overgrazing leads to the degradation of these systems by inhibiting tree regeneration and causing soil erosion. This is the case in the Psilorites mountain in Crete, where forests were reduced by about 9% but dense forest (more than 70% tree cover) by 33% as a result of a sharp increase in livestock numbers (by 290%) between 1971 and 1991 (Bankov 1998) primarily due to national and especially the European subsidies (Zioganas et al. 1998).

Systems Based on Agricultural Land

Degradation of agroforestry systems on agricultural land has been caused by both extensification and intensification processes. Extensification has mostly affected the systems on remote hilly and mountainous regions where the rural population exodus deprived these areas from the necessary labour to tend and maintain the systems resulting in their abandonment and breakdown. In some areas with acute labour problems, the traditional silvoarable systems have been completely neglected and degenerated. In the remote region of Sougia of western Crete, for example, agricultural land was decreased by 38% between 1945 and 1989, due to the reduction of the human population by 47% resulting in the breakdown of silvoarable systems involving olive, fig, and almond trees with cereals (Papanastasis et al. 2004). In other areas, where the lack of labour was not so acute, the traditional silvoarable systems have been simplified and converted to cropland. This happened in the case of the Municipality of Askio in western Macedonia, North Greece, where 32 types of traditional silvoarable systems were recorded combining a variety of cultivated and native trees with several crops, but only the crops are maintained by farmers due to the subsidies provided by European Union (Mantzanas et al. 2005).

Intensification, on the other hand, mostly affected the agroforestry systems grown in plains and in highly populated areas. In these areas, several projects involving drainage, land consolidation and irrigation have resulted in the conversion of the traditional agroforestry systems into intensively cultivated monocultures of trees or arable crops. Trees, in such cases, are considered as obstacles to agricultural equipment and they are partially or completely removed to facilitate the cultivation of the arable land. This evolution has happened in all major agricultural plains of Greece. A typical case is the Alikianou basin near the city of Chania in western Crete, where traditional cereal agriculture was replaced by intensively cultivated monocultures of citrus and olive groves in the last 50 years (Papanastasis et al. 2004).

Establishment of New Systems

In the last few years, a number of experiments were carried out aiming at establishing new agroforestry systems, which are sustainable under the current socio-economic conditions. They included the establishment of silvopastoral systems, based on fodder trees such as black locust (*Robinia pseudoacacia* L.) and mulberry (*Morus alba* L.) (Papanastasis et al. 1999) and on timber trees such as sycamore (*Acer pseudoplatanus* L.)and Scotch pine (Nastis et al. 1997; Gakis et al. 2004), as well as silvoarable systems combining timber trees [e.g. walnut, wild cherry (*Prunus avium* L.)] and various crops [e.g. wheat, maize (*Zea mays* L.)] (Mantzanas et al. 2005). None of these attempts however have attracted farmers who need special financial incentives to establish and maintain these trees or plant new ones in their fields (Mantzanas et al. 2005). It is expected that this attitude of the farmers will change soon since agroforestry has been recently incorporated in the EU agricultural policy and farmers will be financially assisted to promote this practice all over Europe, including Greece (Christidis 2005).

Conclusions and Recommendations

Traditional agroforestry systems are invaluable biological, economic and cultural resources in Greece that need to be protected and properly improved in order to become economically sustainable under current socio-economic conditions. Such an objective though cannot be implemented if their structure and distribution is not thoroughly explored. It is recommended that a special program should be developed to quantify traditional agroforestry systems by utilizing all the existing information and applying modern technology, including remote sensing and GIS. Subsequently, detailed studies need to be carried out in order to investigate their economic and environmental capacities so that their sustainable management is planned and implemented.

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Chapter 6
Silvopastoral Systems in Portugal: Current Status and Future Prospects

M. Castro

Abstract Portugal has a high diversity of agroforestry systems like other Mediterranean countries. This is the result of the Mediterranean climate, great variability of bioclimatic conditions, a long history of land use, and a marked variation in land tenure between north and south of the country. Four major silvopastoral systems are described: two classically Mediterranean – montado and Olive tree system, and two typically of the transitional environment between Mediterranean and Temperate conditions – Pyrenean oak and Chestnut systems. Some products of traditional agroforestry systems such as charcoal, organic manure, livestock production and others have become less valuable with the socio-economic transformation of the 1960s. These systems have been declining from approximately 1950 onwards. Currently, the focus on sustainable agriculture, with greater emphasis on nature and landscape conservation, has meant that environmental values now represent new opportunities for income generation from these systems. A better understanding of traditional agroforestry systems is needed for the formulation of a specific European policy that will preserve European landscapes. This paper looks at the future potential for silvopastoral systems in Portugal based on current status.

Keywords Pyrenean oak system, chestnut systems, olive tree system, *montado*, Portugal

Introduction

The countries of the Mediterranean basin are characterized by climatic variability fluctuations and unpredictability (particularly rainfall), leading to bimodal growth patterns (Gómez-Sal 2000b). These conditions have directly influenced the land use systems, and indirectly the character of the Mediterranean people (San-Miguel et al. 2002).

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The Mediterranean region has also had a long history of human land use. In this interactive process, the human-induced transformations shaped the landscape, modifying plant and animal communities, the genetic make up of individuals, races and ecotypes. Human adaptation leads to differentiated land use systems and forms of resource exploitation. Among these, multi-purpose uses like agroforestry occupy a place of major importance in this region.

Under unpredictable conditions, the diversification of agricultural production is essential. This and the low economic viability of wood and crop productions, these main features contribute to explaining the traditional multi-purpose land uses of the Iberian Peninsula.

The climate can be seen as a modeler of character of a people with high creativity and adaptive ability. As a result, there is a high diversity of landscapes and land use systems, some of them with high complexity and sustainability (Castro 2004a).

Portugal is located at the south-western end of the Iberian Peninsula (37°–42° N latitude and 6°–9°30´ W longitude), with a small land area (continental area of 88.796,7 km^2), but a high bioclimatic variability. Rainfall ranges from 400 mm (south of river Douro at Province of Beira Interior) to 3,000 mm (northwest region, the Province of Minho, influenced by the Gulf stream) (INMG 2006). The climate is of a Mediterranean type, controlled by the Atlantic influence on the north coast, and the continental influence of the Iberian Peninsula, in the centre. Mountains dominate the northern region (north of the river Tejo) and obstruct the moisture flow from the Atlantic to the inner regions of Portugal.

Associated with climatic conditions, timber production occurs with no silvoarable activity in the northern and central littoral, based on *Pinus pinaster* Ait. and *Eucalyptus globulus* Labill. In the south and north interior region, forestry production is limited by drought or cold, and agroforestry systems are common.

The agroforestry systems, or their practices, take place all over the Mediterranean basin with historic references over the centuries. The Celtic civilization made use of systems like *montado*, and the Visigoths regulated the use of pasture lands and "*montanheira*" (San-Miguel et al. 2002). Nair (1993) describe s livestock in olive and orange orchards in Roman times. Even in the last century in some rural areas, people used to make bread from acorn flour. This human consumption of acorns was widespread in the *Quercus* growing regions. Some authors believe that *Castanea sativa* Mill. was introduced into Portugal by Romans to feed slaves working in the mines.

As the result of biophysical conditions and historical colonization of the territory of Portugal, different agroforestry systems were established with marked differences relating to different land use patterns between north and south: small and scattered properties are normal in the north, and large properties predominates in the south.

A closed system called *montado* was developed in the south, but open fields involving several landscape components were developed in the north. Etienne (1996) considers that different components make up an agroforestry system and its spatial sequences have an ecological and economic meaning if interactions among them are maintained. De Miguel (1999) describes an agrosilvopastoral system in the Basque Country – *Caserío* – as the result of different components of the landscape. As far as this author was concerned, the system is the entire landscape of this region.

Based on our research and others, this paper intends to demonstrate and analyse and functioning respectively the diversity of silvopastoral systems found in Portugal. This information will be useful in making a case for their preservation. Four types of silvopastoral systems are described: the Olive tree system, the *montado* system, the chestnut system and the Pyrenean oak system. This last system will be more extensively dealt with as the author is familiar with its operation, its singular importance in the region, and its characteristics exclusive to the transitional environment of the Iberian Peninsula.

Other systems, like the Stone Pine system (*Pinus pinea* L.) and *bocage* are only listed, as the literature on them is inconsistent. The Stone Pine occurs in the Setubal Peninsula (south of Lisbon) and is mainly exploited for pine nuts. The *bocage* system – Ash trees and other riparian trees planted in lines or scattered through meadows – occurs in the Trás-os-Montes Province (northeast of Portugal). The trees, in addition to providing timber, are used in summer as fodder and for shelter by livestock.

Description of Systems

Pyrenean Oak System

Location

Pyrenean oak (*Quercus pyrenaica* Willd.) is one of the most abundant and characteristic oak species in the Iberian Peninsula (Calvo et al. 2003). It is a deciduous transitional Mediterranean oak, which is restricted to SW Europe (west-northwest Spain, southwest France and northeastern Portugal) and some isolated sites in northern Morocco. Pyrenean oak occurs where there is a transition between typical Mediterranean sclerophyllous and temperate deciduous forests (Tarrega et al. 2006).

Pyrenean oak is mainly found in the form of coppices or young forests. Oak forest system covers about 60,000 ha in Spain (Santa Regina 2000) and 62,000 ha in Portugal (Carvalho 1995). In Portugal, the main areas covered by this species are found in the northeast in particular in the Bragança region (Franco 1956), where they cover about 40% of the total forest area use. According to (Correia 1993), Pyrenean oak can also be found in some localised areas of the Alentejo region (southern Portugal) in the form of *montado*, where the average precipitation is relatively high due the influence of topography.

In the Bragança region (41°46 N latitude and 6°45´ W longitude), where the Pyrenean oak is most widespread in Portugal, the climate is mainly sub humid Mediterranean. The average annual temperature is 11.9°C and average rainfall ranges from 741 to 1,385 mm per year, according to altitude, mainly from October to May

(INMG 1991). The dry period occurs mainly in July and August. The soils, derived from schist or granite, are mainly characterised by their acidity and low productive capacity. The dominant soils are umbric Leptosols and dystric Leptosols.

Past Experience and Future Prospects

Throughout historical times, oak woodlands held a prominent place within the economy of Mediterranean regions by providing firewood, charcoal, by-products such as tannin, and by offering an important grazing area for livestock (Debussche et al. 2001). There was a continuous transfer of fertility from woods to cultivated land from animal manure and this helped make these areas successful for agriculture in the past.

After World War II, considerable socio-economic changes occurred in Mediterranean countries (Papanastasis 2004). In southern Europe, there was a massive migration movement of people from the rural areas. In Portugal, this movement increased due to the Colonial Wars in Africa and increased the afforestation rate of common lands (*Baldios*) by the State. These changes lead to the abandonment and simplification of agricultural processes, with poor connectivity between agriculture, forestry and animal husbandry. Also, the indigenous forests have been frequently replaced by coniferous species like *Pinus pinaster*, considered to be more highly productive from a forestry point of view. Under these conditions, there has been a marked decline in the use of multipurpose systems, such as those where the tree cover is Pyrenean oak.

The focus in Europe mow is on sustainable agriculture and conservation of wildlife and natural landscapes. Fortunately, modern social needs trends have increased people's awareness of environmental values. This situation creates a new opportunity for traditional silvopastoral systems, like the Pyrenean oak coppices.

This oak silvopastoral system produces firewood, fodder and welfare for traditionally managed flocks of small ruminants. Also it maintains a diverse landscape and a high biodiversity. It is seen as a strategic ecosystem for nature conservation as it maintains resources in a sustainable and productive way (Gómez-Sal 2000b). The high commercial value of firewood and the environmental needs of a more affluent European population all add to the potential value of this emerging resource.

In modern Europe, agriculture and forestry only exist in their present forms because they are to some extent maintained by subsides (Eichhorn et al. 2006). To maintain this oak system therefore and the landscape associated with it, special measures should be taken at different decision levels. According to Papanastasis (2004) the agri-environment measures currently implemented in the European Union countries should be adapted to also include these systems to ensure their conservation and sustainability values.

Characterisation of the System and Its Utilisation

In Trás-os Montes region, the landscape is characterised by a patchwork of different types of land use. Small livestock production is based on grazing patterns on different fields or vegetation areas. In this mosaic-like landscape, each area has a particular function for the animals.

Pyrenean oak coppice is a landscape component along with other forms of land uses like scrublands, pasturelands and annual crops. Unlike the silvopastoral systems in southern Portugal, the Pyrenean oak coppices represent a small proportion of the territory of the villages, named '*touças*'. These coppices are not used by flocks under private control as would be found in closed silvopastoral systems, but are held and managed communally.

Pyrenean oak coppices are characterized by the presence of a tree layer, planted at densities between 400 and 1,100 stems per hectare depending on the use and age. The understory is dominated by oak regeneration and to a lesser extent by shrubs such as *Cytisus* spp., *Erica* spp. and *Genista falcata* Brot. The herbaceous layer is scarce due to leaf fall and tree shading. Herbage production is from 570–2,500 kg DM ha^{-1} $year^{-1}$ (Castro 2004b).

In the past, the traditional coppice cycle of oak woodlands was very short, about 10–20 years depending on the region. Debussche et al. (2001) refers to coppice cycles of about 15–20 years, and Corcuera et al. 2006 to 10–15 years. Current cycles are longer than 20–25 years. The wood obtained during the felling operation is sold as firewood, the main commercial use and the woodlands are not generally managed conventionally. Pyrenean oak woodlands significantly improve local economic and social values by facilitating stock grazing. These forests provide forage and enhanced welfare to small ruminants (Castro et al. 2000a, b). Trees have a direct value as a fodder crop, providing acorns in autumn and leaves mainly in summer.

Contrary to other *Quercus* species, namely those found in the *montado*, Pyrenean oak regenerates easily producing abundant vegetative shoots, when felled. Grazing herbivores reduce biomass and vegetation cover of the herb and shrub layers and also reduces tree regeneration. Animals also play an important role in increasing soil fertility (Gómez-Sal 2000a).

Traditionally, the most common animals were indigenous goat and sheep breeds (*Serrana* and *Churra Galega Bragançana*). Currently, some shepherds cut tree branches to feed to the kids in winter. However, this practice is of no advantage to the trees because the commercial product from the coppice is firewood.

To increase acorn and understory herbaceous production, silvicultural practices such as pruning and thinning can be applied on the trees. These will improve conditions for the animal component in these systems. The introduction of pigs is another interesting proposition that needs to be considered. The Iberian pig is a native breed indigenous to the Iberian Peninsula. Their adaptation to the local environment and the high quality of its products has enhanced the persistence of the breed and the productive system it supports (Lopez-Bote 1998). The introduction of the Iberian pig to Pyrenean oak coppices could be of interest from an ecological and economical point of view.

In Portugal, Pyrenean oak woodlands are traditionally thought of as systems with multiple uses, but Castro (2004b) considers them as silvopastoral systems because of the important role played by the animals, in providing benefits to the trees and interacting with the trees (Fig. 6.1).

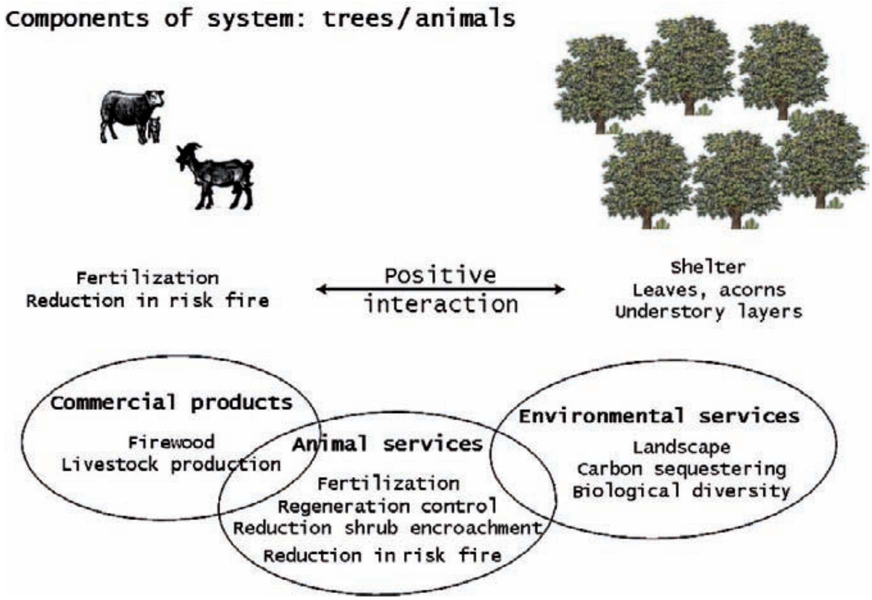

Fig. 6.1 Products and services offered by the Pyrenean oak system and interactions between the two components

According to Nair's Agroforestry concept (1991), silvopastoral systems involve at least two distinct components: trees and pasture/animals. One of the main conditions of agroforestry is the existence of reciprocal benefits between the entities of the system. According to Castro (2004b), fertilisation and control of encroachment are the benefits for the tree component. On the other hand, the advantages for the animals, the other component of system, are the provision of feed and shelter. The woodlands are used by small ruminants with different purposes (feeding, transit, shelter and resting), depending on animal species and season. Details of resources used are illustrated in Fig. 6.2.

This kind of silvopastoral system represents an efficient use of resources year-round through the optimal temporal use of the resource mixing the use of an understory tree layer as a feeding resource.

During the period when the trees are in leaf (May–October), sheep flocks move through Pyrenean oak woodlands, mainly searching for shelter and to rest during the middle of the day. The resting periods take place mainly inside the woods, and resting time represents about 20–30% of sheep and goat flocks respectively of their resting (Castro et al. 2004). Fodder resource from leaves is mainly used by goat flocks. Consumption increases through the season, becoming very high in August–September, when the other resources become less abundant and of less quality. Castro et al. (2004) found the summer diet of goats contained about 25% of leaves whereas it was only 2.5% in the diet of sheep.

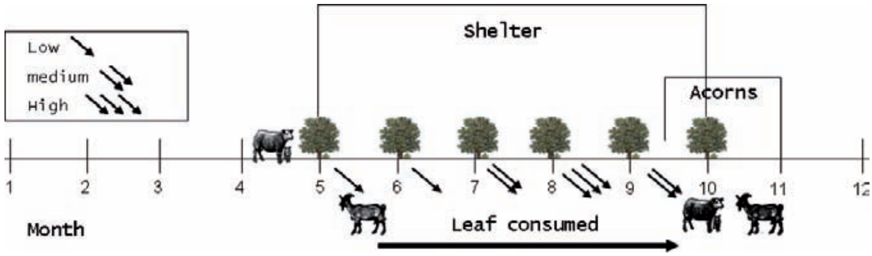

Fig. 6.2 Resources used by animals in the Pyrenean oak system during the year

Acorn production starts in late September and ceases in early November. Acorns are eaten by both sheep and goat flocks. The winter use of Pyrenean oak woodlands by sheep flocks is quite insignificant, (less than 1%) goats spend about 10% of their time in the woodland. During the winter period flocks move through the woodlands searching for and gazing understory shrubs and grass.

Chestnut Tree Systems: Coppices and Orchards

Castanea sativa (Mill.) is a multipurpose species that is cultivated for timber production nut production, or both timber and nut production and for tannin production (Monteiro 2000). Among a large number of associated products, mushrooms have been the most valued for both fresh consumption and the food industry (Scarascia-Mugnozza et al. 2000). Chestnut ecosystems also represent an important place in animal husbandry in the mountain regions.

The genus *Castanea* is distributed throughout the world, mainly in Asia (China, Korea and Japan), Southern Europe, Turkey and the United States. According to Pereira-Lorenzo et al. (2006), Asia is the most important chestnut growing area of the world, where *Castanea mollissima* Blume is found naturally as well as in cultivation. Southern Europe and Turkey are the second main area, where *Castanea sativa* Mill. is predominant. *Castanea dentata* Borkh. was naturally widespread in North-America but is now being substituted by hybrids.

Sweet chestnut (*Castanea sativa* Miller.) has been cultivated for centuries as coppice or orchards. It has been cultivated in northern Portugal since Roman times (Sales-Luis and Monteiro 1998). In the mountainous regions around the European Mediterranean basin and in the Southern Alps, Sweet chestnut still represents an important landscape component, covering more than 2.2 million hectares (Vogt et al. 2006).

In Portugal, chestnut forest ecosystems cover around 35,000 ha (Monteiro 2000). Coppices for timber production occupy only 10% of this area and high forest stands are unusual (Monteiro and Patrício 1996). The largest area taken up by the chestnut crop is in orchards for nut production. About 46% of the chestnut area is located in Northeast Portugal, in the Bragança region (Monteiro 2000). This is the origins of two *Denomination de Origin Protégé* (DOP) "*Castanha da Terra Fria*" (Ribeiro et al. 2007) and "*Castanha da Padrela*" (Abreu 2005).Chestnut trees can be found growing under diverse sorts of climatic conditions in Mediterranean Europe. For example, it can be found where elevation increases winter temperatures and moisture conditions (precipitation above 800 mm) – mainly on northern and eastern slopes – in the transition between Mediterranean sclerophyllous forests and in the temperate deciduous forests with *Quercus pyrenaica*.

Nowadays, favourable market conditions for chestnuts and gradual abandonment of full-time, permanent farming have stimulated efforts to establish new orchards. Unfortunately, high mortality rates caused by diseases such as chestnut blight (*Cryphonectria parasitica* Murr Barr. and chestnut ink (*Phytopthora* sp.) affect the main areas of chestnut production in Portugal.

In the Bragança region, the chestnut orchards are frequently intercropped with cereal crops for direct consumption by sheep. The low plantation density (70–100 stems per hectare; 12 × 12 or 10 × 10 m spacing) also allows crop cultivation for a number of years, generally producing forage for animals.

In the chestnut orchards, locally named *soutos*, utilization of pastures is generally limited to sheep as the *soutos* owners exclude goats since they can damage the bark of the trees.

Traditionally, sheep in flocks eat the chestnuts left over on the ground after the harvest. In the orchards intercropped with cereals for direct animal consumption, locally named *ferrã*, sheep grazing occurs during winter and part of the spring. When intercropping is absent, the coarse understory species are eaten, since the ground is less frequently ploughed.

Fruits become ripe around October–November and chestnuts are pruned every 3 years from February to March in order to increase fruiting. Regular ploughing occurs three to five times per year (Abreu 2005), mainly for weed control and facilitation of harvesting. This emphasis on ploughing has had a negative effect on the soil and has caused the spread of ink disease. Generally, these operations take place after harvesting to incorporate litter into the soil, and in spring, for weed control, and before harvesting to facilitate the collection of fruits. Some additional ploughing can be done for fertiliser incorporation. The details of resource use and cultural practices in the *souto* system are shown Fig. 6.3.

Chestnuts are readily eaten by animals for food. According to Pereira-Lorenzo et al. (2006) the nutritional value of chestnut varies by cultivar and by region. This author describes the composition of a large number of samples, characterised by higher starch content – between 45% and 60% of dry matter, and higher total sugars – from 13% to 20% (data refers to dry matter (DM)). The fibrous fraction is very low, with neutral detergent fibre (NDF) varying between 16% and 18% of dry matter, acid detergent fibre (ADF) between 2.7% and 3.5% and crude fibre (CF) between 2.5% and 2.9%, fat compounds varying between 2.8% and 3.2% and crude protein (CP) from 5.8% to 6.3%. According to de La Montana-Míguelez et al. (2004) chestnuts cultivated over schist soils contain higher protein than those over granite based soils.

Nowadays, farmers are strongly motivated to maintain or re-introduce silvopastoral practices, thus reducing the frequency of ploughing and its subsequent negative effects on soil and the spread of the disease. New harvesting techniques also provide space for intercropped pasture.

As for pyrenean oak, tree chestnut could also be used in silvopastoral systems when coppiced. This form of tree management was used for millennia, to regularly and intensively manage crops for fast timber production, frequently in short rotations. They are currently over-matured and most have been long abandoned (Vogt et al. 2006). In some of these areas, chestnuts from coppices are consumed by animals, mainly goats and pigs that make use of this valuable food resource. The details of resource use and cultural practices in a typical chestnut coppice system are shown in Fig. 6.4.

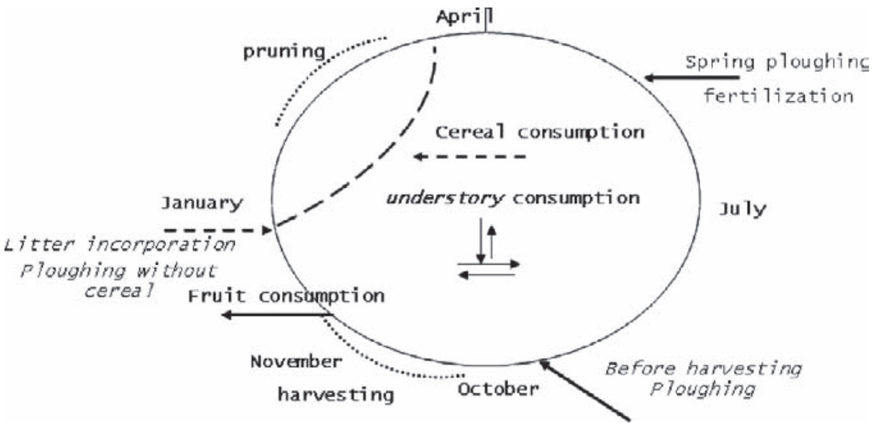

Fig. 6.3 Multipurpose use of the *souto* system and its functioning

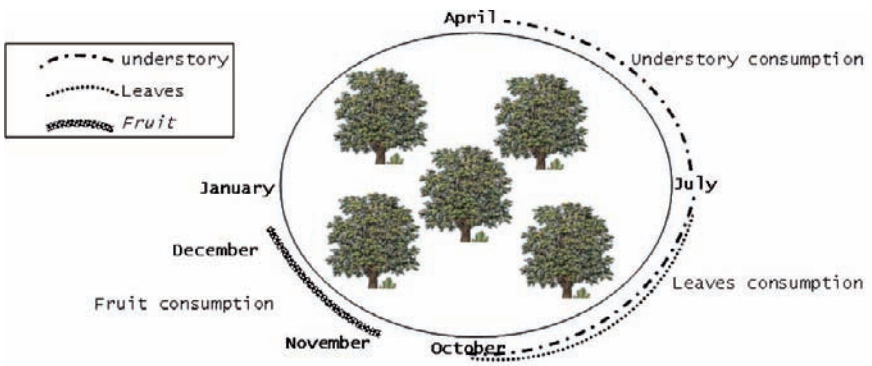

Fig. 6.4 Multipurpose use of the chestnut coppice system and its functioning

Frequently, in chestnut coppices, the shepherds used to lop the branches to feed their animals on the fodder. Alibes and Tisserand (1990) describe seasonal variations in the nutritious value of chestnut leaves, from spring to autumn as: CP 12.4% to 14.5%, NDF 33.3% to 37.5%, ADF 24.7% to 26.3% and CF 18.9% to 20.9%. On the other hand, shrubs and other understory plant resources can be used by the flocks of chestnut coppices.

Olive Tree Systems

Olive (*Olea europeaea* L.) orchards with other annual crops cultivated between the trees form a continuous landscape in many parts of southern Europe (Eichhorn et al. 2006). According to Papanastasis (2004), the olive tree (*Olea europaea* L.) is the most important planted evergreen species forming agrosilvopastoral systems in the Mediterranean region. Olive growing is of great economic and socio-cultural significance for the Mediterranean region, where 98% of the world's olive production is located (Kiritsakis 1998).

This system may be the most complete multipurpose form of land use in the world and delivers a large diversity of products. Olive trees can be used for both production of olives for man and foliage for animal feed. Commonly, the annual production is used for the production of olive oil and table olives (Ribeiro et al. 2007). The old and unproductive trees are used for firewood. In the past, olive oil was used for more than food. It was used in traditional medicine, pharmacy, for lighting, for religious ceremonies, etc. (Kiritsakis 1998). In the Mediterranean climatic type regions of Portugal, this system is very common. Generally olive trees are found associated with cereals or grape vines. In other areas, rye and oats are cultivated (for direct consumption by animals.

In Portugal, olive orchards cover about 340,000 ha, with 62,000 ha in northeast Portugal (Monteiro 1999).

Olive trees can be found in a wide range of climatic conditions, all over the territory of Portugal. Mediterranean conditions, with pleasant winters and an average rainfall of 450–800 mm, is the ideal environment for this species. Olive trees do not grow in winter temperatures below 9°C but must be subjected to a certain amount of chilling during the winter (November–February) to enable flowering (Kiritsakis 1998). On the other hand, it is very sensitive to excessive moisture (Monteiro 1999).

The fruits become ripe around November–December (in modern varieties the mature fruits come first). Every 2–3 years, olive trees are pruned to increase fruit production. This practice takes place after fruit harvest, in February–March, and represents a large time investment in what is specialised work.

The use of by-products of this crop (mainly olive leaves) has been part of the farming tradition in the countries of the Mediterranean basin (Sansoucy et al. 1985). In diverse systems, where animals are a component of crop production, pruning provides a useful additional foodstuff, thereby reducing the cost of animal feeds. According to Delgado-Pertíñez et al. (2000) olive leaves at the moment of

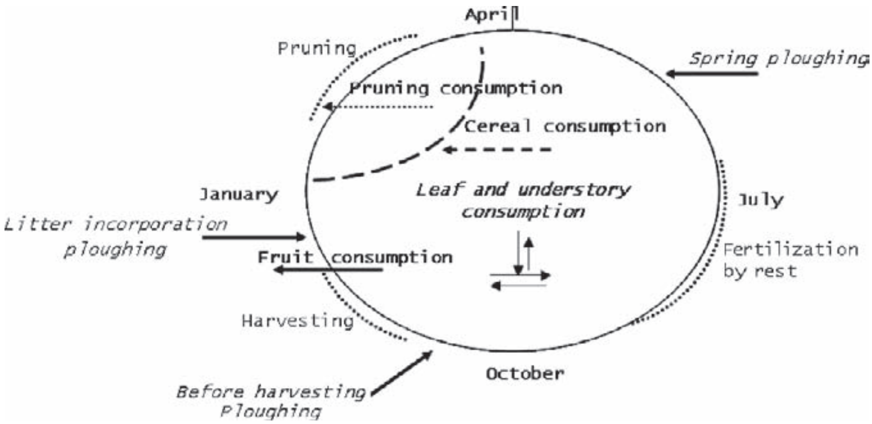

Fig. 6.5 Multipurpose use of olive orchards and its functioning

pruning have a high forage value. They consist of about 12% Crude Protein and 43% Digestible Organic Material. The details of resource use and cultural practices in the olive tree system are illustrated in Fig. 6.5.

After the commercial collection of olives, sheep and goat flocks feed on the remaining fruit left over on the ground. The understory species are grazed mainly in spring.

In ancient times, flocks slept in the olive groves during the summer to help fertilise the trees, another important component of their multipurpose use.

Traditionally, olive tree density is about 100 to 125 trees per hectare, (9 × 9 or 10 × 10 m spacing). In the more intensive systems, spacing decreases to 6 × 6 m for table olive and 7 × 7 m for olive oil production (Monteiro 1999). In recent years, some orchards have been planted at higher densities, with 400 trees per hectare (7 × 3.5 m spacing) or more; but multiple use is not an objective in these very intensive systems.

The soil under olive trees is ploughed two to three times per year. Farmers do not like having competitive vegetation in the orchards. This results in negative effects for the soil. *Agro-environmental subsidies*, which encourage the maintenance of a vegetation cover, have a positive effect by reducing the frequency of ploughing.

New practices to increase olive yields and to increase the returns on the cash crop include the use of irrigation, synthetic fertilisers, repeated short-term planting of early fruiting cultivars at high densities, and intensive use of pesticides. These more intensive systems threat the multipurpose use of olive tree systems, which are usually reduced in area.

Montado Systems

The *montado* is the most extensive agroforestry system in the Iberian Peninsula, occupying an area of about 3 million hectares, 2,248,000 ha in south-western Spain and 869,000 ha in southern Portugal (Eichhorn et al. 2006). It represents a man-made ecosystem which is dependent on human practices and management for its conservation (Joffre et al. 1999). The *montado* is characterized by the presence of an open tree layer, mainly dominated by Mediterranean evergreen oaks – holm oak (*Quercus ilex* L.) or cork oak (*Quercus suber* L.) – and to a lesser extent, by deciduous oaks (*Quercus pyrenaica* and *Quercus faginea* Lam.). The understory herbaceous vegetation is dominated by winter annuals and to a lesser extent by small evergreen shrubs (Vicente and Alés 2006). The general structure is similar to tropical savannahs (Joffre et al. 1999).

The *Montado* system occurs under the Mediterranean climate, long and dry summers where the temperature often reaches 30–40°C, with an average precipitation of 500–650 mm irregularly distributed, concentrated in the period October–March, and with important annual (interannual and intraanual) fluctuations of precipitation (Correia 1993). Cork oak dominates in the coastal areas where the oceanic influence is stronger, while the holm oak is characteristic of the driest areas. Hence Portugal has a larger area of Cork oak than Spain, and the main area of holm oak is in the interior of the Iberian Peninsula.

Generally, in the Portuguese literature, the term *montado* is synonymous with Spanish *dehesa*. Nevertheless, this is not absolutely correct. According to Vicente and Alés (2006), the term *dehesa* comes from the Latin word *defesa* (protected), and it means “enclosed”. Until the 20th century, it has meant private grazing land, with no reference to any vegetation type. These authors showed that the term *dehesa* – grasslands with scattered trees, where shrubs have been mostly eliminated (Spanish Society for Pasture Research – SEEP) – has been used since the forties.

Dehesa has a dual meaning, as a vegetation type and as private grazing land. *Montado* (Dictionary of Portuguese Academy of Language) is a land use generally dominated by *Quercus suber* or *Quercus ilex* where pigs graze. The term *montanheira*, originating from *montado*, means the practice of acorn grazing by pigs, supporting this designation. *Montado* and *Dehesa* have not the same origin.

Both terms – *montados* and *dehesas* – mean a multi-propose agroforestry system with an open tree layer above a grass layer which depends on human practices and management.

The cork or holm oak stands frequently occurring in the Trás-os-Montes Province are not a *montado*, because the agro-pastoral component is not present. In this case, they are called cork oak stands or cork oak forest.

This system of land use may have been practised for up to 4,500 years (Stevenson and Harrison 1992) as a result of the progressive transformation of pristine forest into more productive land-use based on a selection of trees – “the *frutalization* the oak woodlands” (González-Bernáldez 1995). This transformation leads to a land-use system based on the diversity and complementarily of production (Pinto-Correia 2000).

In the traditional *montado*, the herbaceous layer has been maintained by cereal cultivation over long rotations. Regular ploughing is necessary as an efficient method to avoid shrub colonisation. More recently, this practice has been associated with the spread of cork oak diseases (Castro 1998).

According to Pinto-Correia and Mascarenhas (1999), tree cover does not follow a regular pattern, and densities vary from 20 to 80 trees per hectare. Jofre et al. (1991) reported 40 to 50 stems per hectare. Usually, in the cork *montado*, tree density is higher than in holm *montado*. In the first case, the main product is cork, while in the second, the aim is to maximise acorn production for feeding livestock.

Cork and holm oak trees have a direct value as a fodder crop, providing acorns and leafy branches, and indirect value as shelter for cold in winter and heat in summer (Vicente and Alés 2006). Acorns are eaten by livestock when they fall during the autumn and winter. At this time there is a need for supplementing animal diets and when there is a relative herb shortage (Pulido et al. 2001). The trees were periodically pruned to further enhance acorn production and its branches provide also a useful additional feed.

In ancient times, before the development of fossil fuels, holm oak was also highly valued for charcoal production. In more recent times, the income from forestry practices (pruning, thinning) was marginal for the household economy (Díaz et al. 1997). Nowadays, only cork production is highly valued, among the forest products of the *montado*.

Portugal is the major world cork producer, with an average annual production of approximately 190,000 t, which corresponds to about half of the world production (Leal et al. 2006). Portuguese conditions mean that cork bark can be removed in cycles of 9 years (Pinto and Torres-Pereira 2006). Cork products represent 3% of Portugal's exports.

The Cork oak area in Portugal is 725,000 ha and in Spain 475,000 ha (Pereira and Tomé 2004). These areas include *montados* and forest stands. However, some authors have reported that the development of plastic screw caps for wine bottles will threaten the cork industry in the future. Fortunately, the resurgence of a wine culture, and also the demand for quality products, will protect the market for genuine cork wine bottle stoppers.

The traditional system was highly diversified in terms of livestock types (sheep, goats, pigs and cattle). In Portugal, the indigenous pig was the most common animal in the *Montado*, before African swine disease arrived in the late 1950s. Recently, Portuguese *montados* used to be rented by Spanish pig owners for *montanheira*. On the other hand, Spanish wild cattle for bullfighting are a key income of the *dehesa*, but its importance is incomparably low in Portugal.

Joffre et al. (1999) reported that pigs graze the seasonal acorn production, between October and February, gaining about 60 kg live weight over 75 days. Rupérez (1957) reported that 9 kg of *Quercus ilex* acorns corresponds to the production of 1 kg of pork meat.

Today, *montado* has a renewed relevance due its environmental value. This system has been qualified, together with the remains of lightly used Mediterranean forests, as habitats to be preserved within the EU Habitats Directive because of the high biological diversity that they support (Pulido et al. 2001).

As for the other systems, the size of private property has an essential role in the functioning of *montado* systems. The relationship between property size and degree of autonomy of systems is marked (Fig. 6.6).

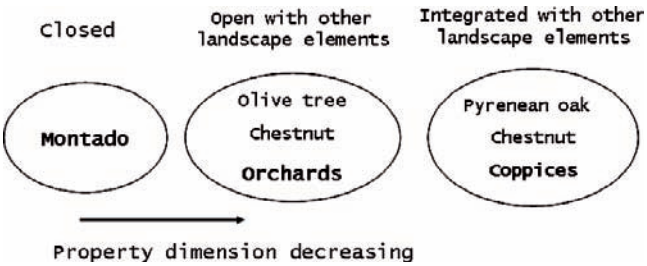

Fig. 6.6 Relationship between type of silvopastoral systems and land tenure

Conclusions

A broad outline of trends in silvopastoral systems has been described. There are gaps in knowledge of these land uses and these require more research about them.

Agroforestry systems are related to the environment, culture and history of the Mediterranean basin. Their geographical distribution is related to primary production, where it is limited by drought or coldness, but also where agricultural specialization was not possible.

Both systems studied (typically Mediterranean and environmental transitional) have comparable functions: all possible food resources are utilised by animals, and the role of grazing is in soil fertilisation and shrub encroachment control. Trees provide additional incomes from direct trade of products such as cork, firewood, or fruit production, as well as benefiting the soil structure, nutrient content, and soil protection. The main practices with trees are reported: pruning and ploughing are common for all systems and increase fructification. In Pyrenean oak and chestnut coppices, thinning is the only tree operation reported.

The maintenance of these extensive systems appears to need support by future Common Agricultural Policy (CAP) measures.

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Chapter 7
The Functioning, Management and Persistence of Dehesas

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Abstract Dehesas are the most widespread agroforestry systems in Europe, where they cover 3.1 million hectares. They are multipurpose open woodlands, mostly created by clearing the natural forests, where livestock rearing, cereal cropping, cork and firewood harvesting, and hunting are combined. In dehesas, trees can be seen as "ecosystem engineers", as they allow the maintenance of grass production in poor soils under a semiarid climate. We summarize the most outstanding results on both the effect of trees on the production and quality of the understorey (crop and native grasses) and also on the consequences of reduced tree density for the physiological condition and production of trees. The ecological basis of tree-understorey interactions is explained based on spatial distribution and use of above and belowground resources. Dehesas have been considered habitats to be preserved because they maintain a high biological diversity including several globally endangered animal species. They are considered an example of sustainable land use, although their conservation has been threatened in the last few decades. Excessive tree cutting, including complete elimination in some cases, has taken place as a consequence of increased mechanisation and stocking rates. This has caused a lack of natural regeneration and tree death in over-aged stands. We make a critical analysis of the ecological stability and sustainability of the system following four different approaches related to current problems: (i) historical evolution of the dehesa range, (ii) soil degradation and erosion, (iii) plot and farm-level factors precluding tree regeneration, and (iv) economic profitability of the dehesas. From these analyses, we derive a number of recommendations for dehesa management aimed at ensuring both its multifunctional role and its sustainability. The critical role of the shrub understorey for the ecological function, nutritional contribution and biodiversity is emphasized.

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Keywords Agrosilvopastoral system, mosaic-like landscape, regeneration failure, soil degradation, tree-grass interaction

Introduction

Dehesa is an agrosilvopastoral system originating from clearing of evergreen woodlands where trees, native grasses, crops and livestock interact positively under specific management practices (Campos 1992; Montero et al. 1998; Joffre et al. 1999). They are among the most prominent and widespread agroforestry land-use systems in Europe (Grove and Rackham 2001; Papanastasis 2004). At present, dehesas occupy 2.3 million hectares in Spain and 0.7 million hectares in Portugal, where they are called "montados" (MAPYA 2004; Pereira et al. 2004).

Dehesas result from a simplification, in structure and species richness, of Mediterranean forests and shrublands, and are attained by reducing tree density, eliminating *matorral* cover, and favouring the grass layer by means of grazing and crop culture (Montero et al. 1998). Dehesas are characterized by the rearing of traditional livestock breeds at low stocking densities and careful exploitation of evergreen oaks (Plieninger and Wilbrand 2001). The environmental setting of the Iberian dehesas is influenced by the Mediterranean climate, the low fertility of soils, and the usually undulating topography, that make arable farming unprofitable. Under these circumstances, dehesas have arisen as the only feasible way of productive land use (Montero et al. 1998). Dehesas are among the best preserved low-intensity farming systems in Europe, and in them the integration of traditional land-use and biodiversity conservation is considered exemplary land use management (Gómez-Gutiérrez and Pérez-Fernández 1996; Blondel and Aronson 1999; Plieninger and Wilbrand 2001).

The importance of dehesas rests on both environmental and socio-economic values. First, dehesas play a prominent role in the economy of rural areas in southwestern Spain (Escribano and Pulido 1998; Campos 2004; Pereira et al. 2004), because they occupy about 50% of grazing lands (Campos and Martín-Bellido 1997). In addition, dehesas are a fundamental component of regional identity, and are the source of high-quality food products derived from livestock production. On the other hand, dehesas have been valued at an international policy-making level for their biodiversity, aesthetic qualities and potential for tourism and recreation (Shakesby et al. 2001; Schnabel and Ferreira 2004). Dehesas support a large number of species and a diversity of habitats (Díaz et al. 1997), qualifying them to be listed in the EU habitat directive as being of community-wide interest.

Nevertheless, over the last few decades, dehesas and other agrosilvopastoral systems in Europe have faced several threats due to intensive land use imposed by a concomitant change in the technological and socio-economic conditions and common agricultural policies (Escribano and Pulido 1998; Papanastasis 2004; Pereira et al. 2004). These changes have resulted in a shift from traditional farming systems with very low external inputs to a simplified system involving intensive management techniques and decreased diversity of land uses (Schnabel and Ferreira 2004). Indeed, during the second half of the 20th century, around six million trees were removed (Elena-Roselló et al. 1987). A significant decrease in the area of distribution of dehesas and in the tree density has been occurring as a result of increased mechanisation, stocking rate and death of trees in over-aged stands (Fernández-Alés et al. 1992; Plieninger et al. 2003; Papanastasis 2004; Pereira et al. 2004). Additionally, the loss of traditional agrosilvopastoral practices has increased at least three sources of environmental degradation: (i) soil erosion rates due to changes in vegetation, soil properties and hydrological processes (Coelho et al. 2004; Schnabel and Ferreira 2004); (ii) over-aged oak stands due to a prolonged lack of regeneration (Montoya 1998; Pulido and Díaz 2005) and (iii) loss of diversity at various spatial scales (Díaz et al. 1997; Plieninger and Wilbrand 2001).

In this context, the sustainability of the dehesa system has been seriously questioned (Montoya 1993; Hernández 1996; Montero et al. 1998), and a considerable debate concerning the long-term persistence of dehesas has emerged, because most stands have over-aged trees and saplings are extremely scarce. Some authors have indicated that lack of regeneration is an inherent feature of grazed dehesas (e.g. Pulido et al. 2001; Plieninger et al. 2003). Others argue that the present lack of tree regeneration is mostly linked to the intensification of dehesa management and loss of multiple uses and management practices (e.g. Llorente-Pino 2003). Regardless of past dehesa regeneration patterns, at present there are no tested management practices for ensuring tree regeneration (based either on traditional or scientific knowledge). Hence, the following questions arise: (i) are dehesas declining? (ii) are dehesas a well-designed agroforestry system or a phase of forestland degradation? (iii) how much does dehesa persistence depend on management practices and/or dehesa structure? and (iv) to what extent are trees important for dehesa functioning?

Here we suggest that a mosaic-type structure of dehesa with a combination of grazed, shrubby and cultivated open woodland and dense forest (called *manchas*) plots is the only way to maintain the function and persistence of dehesas. In this paper, we address three central issues of dehesa literature, namely ecological function, productivity and persistence, and analyze the consequences of the different management practices on them. As far as possible, we have relied on quantitative information from recent literature and from our own studies. Thus, this chapter is conceived as an insight to new challenges for dehesa management in the face of new socio-economic status of the *local society* and environmental needs of the *global society*.

Structure and Management of Dehesas

The history of human management of dehesas has resulted in a complex form of current exploitation. Dehesa structure at three spatial scales, referred to as in-plot, in-farm and off-farm are described. Attention is focussed on recent changes in management practices that could affect dehesa structure and function.

In-Plot Structure: Components of an Integrated Land-Use System

Most dehesas are characterised by a two-layered vegetation structure, with the presence of a savanna-like open tree layer and an understorey pasture or crop in the same land unit. The tree layer is dominated by the evergreen holm oak (*Quercus ilex* subsp. *ballota* (Desf.) Samp.) and cork oak (*Q. suber* L.) and, to a much lesser extent, by the deciduous *Q. pyrenaica* Willd., *Q. faginea* Lam., and *Fraxinus angustifolia* Vahl. These tree species have a density ranging from 5 to 80 trees per hectare (usually 15–45 trees per hectare) and 21–40% canopy cover, this variation depending on its main use: lower densities occur in intercropped areas and higher densities in areas devoted to big game hunting (Montero et al. 1998; San Miguel 1994). Holm oak stands are regularly thinned and pruned for multiple purposes, such as enhancing herbage growth, ensuring maximum yield of acorns and obtaining browse, firewood and charcoal (San Miguel 1994). Most of the pasture species are annual herbs, with two non-vegetative periods in summer and winter (Montero et al. 1998). Although there are many species varying enormously among dehesas and also within each dehesa (because of the topography and the presence of trees), some of the more ubiquitous species are: *Aira caryophyllea* L.*, Airopsis tenella* (Cav.) Asch. & Graebn.*, Psilurus incurvus* (Gouan) Schinz & Tell and *Bromus* sp. among grasses, *Ornithopus compressus* L., *Biserrula pelecinus* L.*, Lathyrus angulatus* L. and several species of *Trifolium* among legumes, and *Xolantha guttata* (L.) Raf.*, Geranium molle* L.*, Spergularia rubra* (L.) J. Presl & C. Presl*, Silene inaperta* L.*, S. portensis* L.*, Cerastium glomeratum* Thuill.*, Tolpis barbata* (L.) Gaertn and *Bellis annua* L. of other families (Devesa 1995). In late successional and more fertile pastures, especially beneath tree canopies, perennials gradually replace annuals (Puerto 1992). Here, pasture is dominated by *Poa bulbosa* L. and *Trifolium subterraneum* L., frequently accompanied by *Trifolium bocconei* Savi*, Bellis perennis* L., *Erodium botrys* (Cav.) Bertol., *Parentucellia latifolia* (L.) Caruel. and different species of *Ranunculus* L. and *Plantago*.

Livestock are the main tool for maintaining stable understorey vegetation. According to Montero et al. (1998), the main functions of livestock are: (i) preventing colonization of pastures by invading shrubs; (ii) improving grassland quality; (iii) ameliorating soil fertility; and (iv) quickening the nutrient cycle. Different types of livestock (cattle, sheep, goats, pigs, horses) are common in dehesas, with some seasonal differences, to obtain an optimum yield from its varied structure (San Miguel 1994; Escribano and Pulido 1998). Briefly, sheep are the most suited species for exploitation of most dehesas. Cattle are found in the most humid dehesas, while goats are often used as a complement to make better use of woody fodder. Finally, pigs are introduced in the dehesa during October-January to take advantage of the abundance of acorns (San Miguel 1994). In recent decades, a noticeable increase of stocking rates in dehesas has taken place (Fig. 7.1).

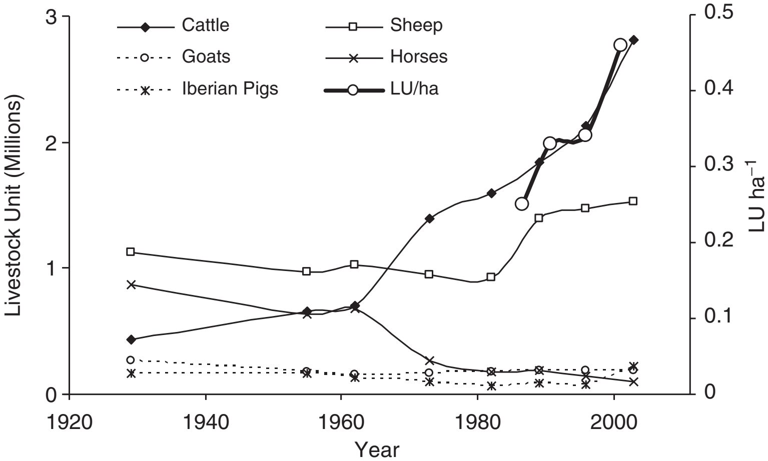

Fig. 7.1 Temporal evolution of livestock numbers in south-western Spain. Data are expressed as livestock units (LU), according to the following equivalence: 1 cow = 1 LU; 1 sheep = 0.15 LU; 1 goats = 0.15 LU; 1 pig = 0.45 LU; 1 horse = 1 LU; 1 mule = 0.75 LU and 1 donkey = 0.5 LU. Author's estimates from data available in the Spanish National Annuals of Agricultural Statistics (MAPYA 1929 to 2004). Stocking rate (LU ha^{-1}) from Pulido (2002). Note: Due to the lack of statistics on stocking rate in dehesas, livestock data are aggregated for 13 provinces (Badajoz, Cáceres, Salamanca, Huelva, Sevilla, Cordoba, Ciudad Real, Toledo, Zamora, Avila, Madrid, Cádiz, Jaen)

In-Farm Structure: Rotational Cycles in Mosaic-Like Estates

Dehesas are an unstable vegetation type that requires continuous human intervention to prevent shrub encroachment. Undergrazing encourages the invasion of various species of shrubs (e.g. *Cistus salviifolius* L.*, C. ladanifer* L.*, C. monspeliensis* L.*, Genista hirsuta* Vahl*, Ulex eriocladus* C. Vicioso*, Retama sphaerocarpa* (L.) Boiss.*, Citysus* L.), which will eventually replace the understorey grasslands (Montero et al. 1998). The importance of the shrub layer is reflected in the diversity of feed it provides for domestic animals during the periods of grass shortage in summer (Patón et al. 1999; Hajer et al. 2004).

Periodic or rotational ploughing is also a common practice in dehesas to control shrub encroachment, avoid soil compactation, and obtain a fodder complement through sowing. The system is therefore referred to as being agro-silvopastoral, because it combines crops, pasture and trees, shifting irregularly over successive years (every 3–12 years). After 3 years the number of species found in the ploughed pastures is usually similar to that found in the neighbouring unploughed pastures (Casado et al. 1985). Gradually, the improvement of pastures (*posío*) leads to reduced cropping, and even to elimination of tillage when livestock can stop the encroachment of woody vegetation (Montero et al. 1998). In some areas, where edaphic amelioration takes place due to nutrients gathered and excreted by livestock, very dense grassland of annuals and perennials of high nutritional value (called *majadal*) results. Pasture yield and quality is also increased through mineral fertilization and sowing of native and alien species (e.g. INIA/SEAIADG 1984; Olea et al. 2005). Therefore, there is a seasonal replacement of food sources for livestock in the dehesas: pasture in spring and autumn, acorn, tree and shrub browse in winter, and fodder crops in summer and winter (San Miguel 1994).

This trend has resulted in a sharp decrease in the arable area under cereal cultivation, which became increasingly unprofitable. At present, the most representative image of dehesa landscape is that of a vast savanna lacking any bushy understorey or croplands, and nearly half of the dehesa estates have only a grassland understorey (Campos et al. 2002).

Off-Farm Structure: An Adaptive Management to Cope with Seasonality

In spite of the amelioration of pasture yield and quality and the in-farm resource integration mentioned above, dehesas are not currently self-sufficient because the feeding of livestock depends on neighbouring systems in periods of food shortage, mainly summer (Montero et al. 1998). The strong seasonality and variability of pasture herbage and its generally poor quality increase this problem (Escribano et al. 1996; Olea et al. 2005). On three representative farms of south-western Spain Escribano et al. (1996) have shown that as a whole, dehesas provide 57–73% of feed needs for ruminants, but only 43–47% for Iberian swine. Fodder scarcity in summer was traditionally overcome by *transhumance* livestock migration over some 300–500 km to mountain pastures. However, the abandonment of transhumance practice due to the use of external fodder and concentrates has resulted in an increasing presence of livestock in summer.

Recent Changes

Dramatic changes in dehesa management schemes have occurred in the last decades. Gómez-Gutiérrez (1992), Plieninger and Wilbrand (2001), Campos et al. (2003a), Linares and Zapata (2003), and San Miguel (2005) have summarized these changes: (i) massive emigration of the rural population, with a labour shortage on many dehesa estates, a five-fold increase in the salary of workers, a reduction of specialised hand labour (herdsmen, shearers, pruners, and charcoal burners, among others) and increased mechanization; (ii) loss of land use diversity, with a dramatic decrease in the use of tree products (charcoal, firewood, browse and wood), strong decrease in crop cultivation, and loss of self-sufficiency due to dependence on external food, fertilizer and agro-chemical inputs; and (iii) partial substitution of extensive, low-intensity grazing for a semi-intensive management regime, with partial substitution of traditional breeds by artificial crossing, abandonment of shepherding (replaced by large-scale free-range grazing), partial substitution of sheep with cattle (as a result of the lack of shepherds and Common Agricultural Policy (CAP) subsidies; Fig. 7.1) and abandonment of periodic transhumance to summer mountain pastures. Since Spain and Portugal joined the EU in 1986, subsidies for ewes and suckler cows were granted as headage payments, having stocking rates equal to those needed for more productive northern (Atlantic biogeographic) regions in spite of lower productive Mediterranean environments, thus encouraging further increase of livestock numbers and dehesa overgrazing (Campos 2004).

Ecological Function: Interactions Between Dehesa Components

Spatial Distribution of Resources: The Role of Trees

A key issue for sustainable management of dehesas is to understand the function of isolated trees in the ecosystem. Their effects can be understood in terms of stabilisation and productivity (Gómez-Gutiérrez and Pérez-Fernández 1996; Montero et al. 1998). The influence of trees is reflected in the spatial distribution of above- and below-ground resources (light, soil water and nutrients and forage biomass), which vary with the distance to the tree.

Microclimate and Light Availability in Scattered Oak-Trees

The low tree density in dehesas allows most of the light to reach the understorey, with values of 78% of full sunlight for a stand with 24 mature trees per hectare and 13% of canopy cover (Montero and Moreno 2005). These values are considered enough for optimum understorey production, according to the common values reported for herbaceous plants in temperate regions (around 70% of full sunlight; Montard et al. 1999). Nevertheless, the presence of scattered trees implies a strong heterogeneity in the spatial distribution of the light (Fig. 7.2). Considering 25% light reduction as a threshold and 25 trees per hectare, almost 20% of the surface could be significantly affected by shading (Montero and Moreno 2005).

The decrease of light availability in the vicinity of the tree canopy can be seen as a beneficial or detrimental effect on understorey yield (McPherson 1997). In dehesa, the decreased solar radiation beneath the canopy has a positive effect on both air and soil temperature (Nunes et al. 2005; Fig. 7.2). Temperature was significantly lower beneath than beyond the tree canopy on warm days, whereas on cold days the reverse was true (Moreno et al. 2007).

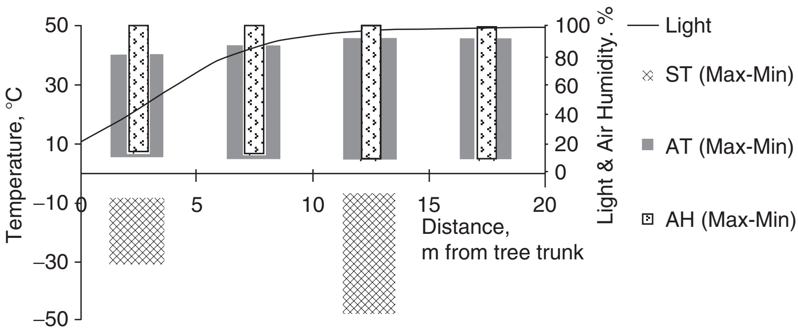

Fig. 7.2 Light distribution and microclimate parameters beneath and beyond holm-oak canopies in a mature dehesa stand in central-western Spain. ST (soil temperature at 0–10 cm depth); AT and AH: Air temperature and humidity, respectively (Elaborated from Montero and Moreno (2005) for light and Moreno et al. (2007) for microclimate)

Water Dynamics

The geographic range of dehesas is characterized by low rainfall, high PET (potential evapotranspiration), and high rainfall variability within and between years. Thus, one of the major ecological factors affecting dehesas is water availability (Infante et al. 2003). Puerto (1992) and Joffre and Rambal (1993) found that soil water content was always higher beneath than beyond the tree canopy in southern and northern subhumid dehesas, respectively. Joffre and Rambal (1988) estimated that maximum soil water storage was between 40 to 110 mm higher beneath than beyond trees in three southern subhumid dehesas. This increased soil moisture occurred in spite of the soil beneath the canopy receiving significantly less water than the area between trees as consequence of rainfall interception by trees (between 58% and 71.1% of annual rainfall Luis-Calabuig (1992) and Mateos and Schnabel (2002), respectively).

These results indicate an improved microclimate and soil physical properties beneath tree cover. A positive effect of trees on soil organic matter, dry bulk density (1.51 vs 1.58 g cm^{-3}, beneath and beyond canopy, respectively), infiltration rate, available soil water (243 vs 155 mm, respectively), and texture (increasing the abundance of fine particles) has been found in dehesas (Joffre and Rambal 1988; see also Fig. 7.3). Other authors (e.g. Escudero 1985; Cubera and Moreno 2007b) did not find that the canopy had any significant effect on soil texture. Anyway, as a result of the physical changes, the onset of drought is usually delayed by 1 month (Joffre and Rambal 1988) or by 1.5 month (Puerto 1992).

A recent study in semi-arid dehesas (annual rainfall around 500 mm) has shown that soil beneath than beyond the tree cover dried at nearly the same rate (Cubera and Moreno 2007b; Fig. 7.4). A similar pattern was reported by Nunes et al. (2005) in an area with an annual rainfall of 666 mm $year^{-1}$. Thus, the widely accepted idea that trees improved soil water status in dehesas is not certain in all dehesas, especially in the driest ones. In these latter cases, the volume of water extracted by tree roots must have had a major effect on the spatial and temporal changes in soil moisture. Indeed, trees can reach water located beyond the canopy cover (Joffre and Rambal 1993), even that located up to 20 m away from the tree (Cubera and Moreno 2007b). Soil moisture can be also be affected by the understorey vegetation and hence shrub encroachment in dehesas can significantly reduce soil moisture to values below those of an adjacent dense forest, at least in the first metre of soil depth (Fig. 7.4).

The presence of trees also affects the water balance, as Joffre and Rambal (1993) have shown. Trees significantly increase water consumption by transpiration, whereas water is easily lost by deep drainage and/or surface runoff beyond the tree canopies. In their study, water yield (excess of soil water) occurred with 570 and 200 mm of annual rainfall beneath and beyond the canopy, respectively.

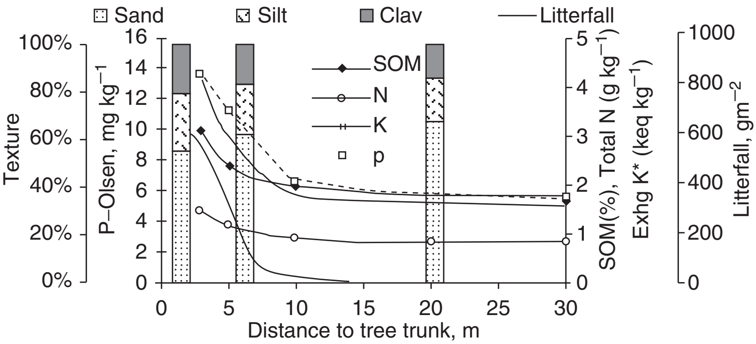

Fig. 7.3 Summary of the main consequences of the presence of trees on the heterogeneity of soil properties. SOM (soil organic matter) (Elaborated from Puerto 1992; Escudero et al. 1985; Moreno and Obrador-Olán 2007)

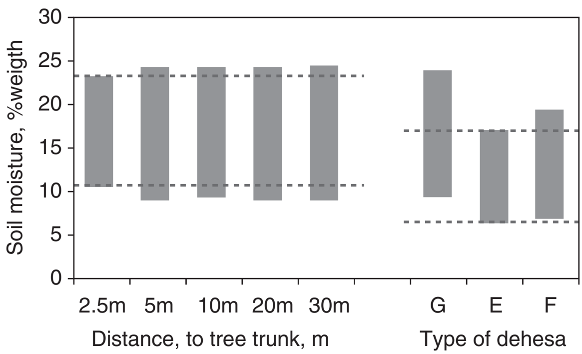

Fig. 7.4 Maximum and minimum values of soil moisture measured (monthly) during a 3-year period. Soil moisture was measured at different distance of the trees and in different habitat types (G: grazed dehesa; E: Shrub encroached dehesa; F: Forest) of CW Spain. Soil moisture data were averaged from the first metre of soil depth (Elaborated from Cubera and Moreno 2007a, b)

Nutrient Cycling and Soil Fertility

In semi-arid ecosystems isolated trees have an important effect on the spatial and temporal heterogeneity of soils, which can determine the structure and function of the herbaceous and animal communities in the soil (Gallardo et al. 2000). Trees immobilize large amounts of nutrients in their living and dead tissues (Table 7.1), which can be a detrimental short-term effect for understorey but a favourable long-term effect for nutrient storage (Escudero 1992). Tree roots bring up nutrients from deep in the soil profile that are inaccessible to herbaceous vegetation, and extract nutrients laterally from areas beyond the canopy (McPherson 1997; Scholes and Archer 1997). As a result, more than 50% of the nutrients are annually recycled beneath the canopy despite a canopy cover of only 20% of the dehesa surface (Table 7.1).

The role of trees in nutrient dynamics is critical because dehesas have a mostly internal nutrient cycle (Escudero 1992). Both nutrient inputs *via* atmospheric deposition and output *via* animal harvesting are very low when compared with internal fluxes (Table 7.1). Litterfall in dehesa is unusually high, even higher than in dense holm oak forest (1,900 and 1,600 kg ha^{-1}, respectively; Escudero 1992). Thus litterfall comprises an annual input to soil of 0.30–1.43% of the soil pool of N beneath the canopy, 21–59% of available P, 1.8–9.5% for exchangeable K, and 1.1–9.9% for exchangeable Ca (Escudero et al. 1985).

Additionally, the turnover rate of nutrients on the soil surface of dehesa ecosystems is also unusually high (Escudero et al. 1985). Dehesa litterfall decomposes up to 24 times faster that in dense forest (Escudero 1992). The amount of litterfall accumulated on the soil surface was estimated at 400 kg ha^{-1} and 8,000 kg ha^{-1} in

Table 7.1 Main nutrient pools and fluxes of dehesas

POOL and FLUX		N	P	K	Ca	Mg
TREES	Pools kg ha^{-1}	44.3	5.54	49.6	301.2	22.7
PASTURE		25.0	2.98	16.9	4.7	2.5
Atmospheric input[a]	External cycle kg ha^{-1} $year^{-1}$	7.7	0.76	2.2	7.7	1.6
Output[b]		2	0.8	–	–	–
Litterfall[c]	Internal cycle (Turnover) kg ha^{-1} $year^{-1}$	15.2	1.21	4.6	13.7	2.3
Pasture beneath canopy[c]		6.4	0.8	6.3	1.7	0.8
Pasture beyond canopy[d]		19.0	2.0	15.3	6.7	2.7
Canopy leaching[a]		<0	0.40	7.95	1.2	2.9
Turnover beneath canopy	% per year[e]	53%	55%	55%	71%	69%

Adapted from
[a] Moreno and Gallardo (2002)
[b] Escudero (1992)
[c] Escudero et al. (1985)
[d] Escudero et al. (1983)
[e] Turnover beneath canopy = (Litterfall + canopy leaching + pasture beneath)/Total turnover

Table 7.2 Main N pool and fluxes in dehesas (Adapted from Gallardo et al. 2000)

Nitrogen variable	Under trees	Between trees
Net N mineralization rate, $\mu g\ g^{-1}\ d^{-1}$	4.77	2.09
Net ammonification rate, $\mu g\ g^{-1}\ d^{-1}$	–0.46	–0.20
Net nitrification rate, $\mu g\ g^{-1}\ d^{-1}$	5.32	2.28
Available ammonium, $\mu g\ g^{-1}$ soil	19.3	11.4
Available nitrate, $\mu g\ g^{-1}$ soil	20.2	13.2
Microbial biomass-N, $\mu g\ g^{-1}$ soil	122.2	73.1

dehesa and dense forest, respectively (Escudero et al. 1985). This rapid decomposition may be explained by the action of herbivores, which can recycle up to 85% of the phytomass (Escudero et al. 1985). Trees play a prominent role in the process, because net mineralization is higher beneath than beyond the canopy cover, as Gallardo et al. (2000) reported for N dynamics (Table 7.2).

As a result of the nutrient dynamics in dehesas, soils beneath the tree canopy are richer in soil organic matter (SOM) and nutrients than soil beyond the canopy (Fig. 7.3), (González-Bernáldez et al. 1969; Escudero 1985; Puerto 1992; Gallardo 2003; Nunes et al. 2005; Moreno and Obrador-Olán 2007). Although the effect of the trees is usually observed in the whole soil profile (Joffre and Rambal 1988), significant differences in soil properties beneath and beyond canopy are usually only found for the uppermost soil layer (from 0 to 20–30 cm) (Escudero 1985; Moreno and Obrador-Olán 2007).

Beside trees, shrubby vegetation may significantly modify soil fertility, although the information available on this is very scarce. Moro et al. (1997) has shown a positive effect of Mediterranean shrubs on soil fertility. In encroached dehesas Moreno and Obrador-Olán (2007) reported an increase in SOM, total N and exchangeable Ca^{2+} and K^{+} but a decrease of available P and mineral N.

Oak Tree Competitive Effects

Trees exert a series of positive effects on dehesa resources, but trees can also compete for resources (light, nutrients, and water) with understorey vegetation. Like all agroecosystems, dehesa is a non-equilibrium system and only the persistence of grazing or ploughing disturbances allows its maintenance (Díaz et al. 2003). Nevertheless, in dehesas some mechanisms of plant-to-plant interaction used to explain the coexistence of trees and grasses can be invoked, that is, niche separation by the different rooting systems and phenological differences (Scholes and Archer 1997).

Annual and perennial grasses take water mostly from the upper 40–60 cm of soil (Joffre et al. 1987), whereas holm-oak has been reported to extract water from depths of 3 m (Cubera and Moreno 2007b), to 13 m (David et al. 2004). Holm-oak seedlings exhibit a high stomatal conductance and photosynthetic rate (Mediavilla and Escudero 2004) during the rapid development of the root system (more than 1 m depth during the first 3–4 months after germination; Cubera 2006). It seems that trees can easily avoid competition with grasses for water. But, can grasses easily escape this competition? Moreno et al. (2005) have shown a certain degree of spatial separation between grass and tree root systems in dehesas, as root length density (RLD) of grasses were five times higher than RLD of trees in the first 40 cm of soil depth. Phenological segregation could also be acting to some extent in dehesas. Maximum amounts of nitrate and ammonium occur in October–November and December–January, respectively (Gallardo et al. 2000), when roots of grasses are developing (Joffre et al. 1987) and trees are inactive (trees sprout in April–May; Oliveira et al. 1994). As a result, it appears that trees and grass are not highly competitive for nutrients and water, although more specific studies are still needed, especially for some key periods (e.g. early spring).

Moreno et al. (2007) have shown that (i) tree growth and acorn production did not increase significantly with soil fertilisation and irrigation, (ii) nutritional status of trees was not enhanced by fertilisation, and (iii) tree foliar nutrient contents did not correlated significantly with the nutrient content of the uppermost soil layer, while herbaceous plants did. In fact, herbaceous understorey responds positively to both irrigation and fertilisation (Nunes et al. 2005). These results indicate a low dependence of holm oak and a high dependence of herbaceous plants on the resources in the uppermost soil layer. By contrast, the dense foliage of evergreen oak becomes a limiting factor for forage production given that the photosynthetically available radiation (PAR) was reduced by around 25% (Nunes et al. 2005), but only in the vicinity of the trunk (Fig. 7.2). Indeed, maximum pasture yield is found with a canopy cover of 30%, (Qarro et al. 1995). Overall, results abovementioned indicate that the combination of holm oak with herbaceous plants could be an example of competition avoidance. The rooting system and the low growth rate of holm oaks could determine a low competitive potential of holm oak with grasses.

Tree Physiological Status: Benefiting from Dehesa Structure

Dehesa trees have to cope with the high variability of the Mediterranean climate (Joffre et al. 1999). These authors demonstrated that dehesa structure could be interpreted as the result of an ecological adjustment, the distribution of tree density being to a great extent controlled by water availability because as rainfall increased, mean tree density increased. According to Rambal (1993), evergreen oaks are ‘regulator’ species, with three mechanisms for drought resistance: stomatal control, deep rooting and reduced leaf area. This set of functional strategies allows evergreen oak species to survive dry environments, but at a cost of very low rates of water transpiration and photosynthesis (Mediavilla and Escudero 2003).

Despite this, *Quercus ilex* L. growing in a dense forest reached predawn water potential below −4 MPa (Sala 1999), and suffered dieback in severe drought episodes (e.g. Peñuelas et al. 2001). By contrast, the low tree density of dehesas allows high per capita water availability for isolated individual trees. Infante et al. (1999), David et al. (2004) and Montero et al. (2004) recorded predawn leaf water potential remaining relatively high throughout summer: above −1.9, 2.16, −0.75 and −1.1 MPa, respectively, in dehesas with tree canopy cover between 20% and 40%. These results indicate that holm oak experienced moderate stress in dehesas as compared to that suffered by holm oaks in dense forest (Damesin and Rambal 1995; Sala 1999; Savé et al. 1999). Daily and seasonal transpiration patterns analysed at the leaf and whole-tree levels have also shown that prolonged drought hardly affected the water relations of holm oaks in dehesas (Infante et al. 2003; David et al. 2004). The advantage of the reduced canopy cover has been demonstrated by Cubera (2006), analysing leaf water potential in trees with distinct availability of soil, e.g. different tree densities (Fig. 7.5).

Tree clearance can also affect the nutritional status of trees. Úbeda et al. (2004) reported an obvious benefit of forest clearance on the leaf nutrient concentration of *Quercus suber* L. (Table 7.3). Finally, overstorey structure can also have a significant effect on leaf nutrient concentration of trees. Shrub encroachment was associated with a significant increase in K and P in *Quercus ilex* leaves of dehesas in west-central Spain, while the concentration of N, Ca and Mg was negatively affected (Table 7.3).

As a result of the improved water and nutritional status of trees in dehesas, holm-oak produced 13 times more acorns in open than in dense stands Pulido and Díaz (2005). Nevertheless, the determination of the most suitable density for optimizing the productivity of the dehesa is a controversial and an under-researched topic in dehesas. The complex combination of products and the influence of tree cover on understorey yield and quality make determination of an optimal density a very difficult task (Montero et al. 1998).

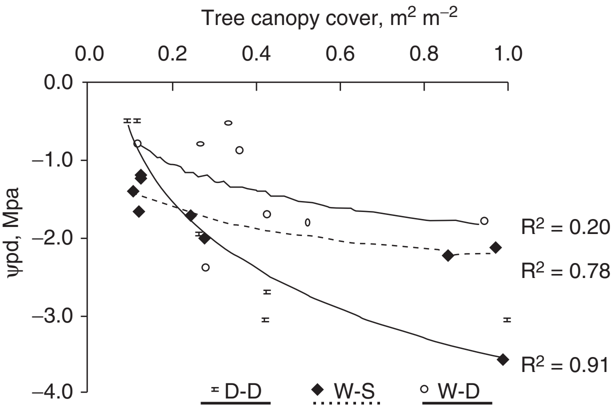

Fig. 7.5 Leaf water potential (predawn) as a function of both tree density (expressed as relatively available soil for each individual tree) and edaphoclimatic conditions. Values for early September. D-D: Dry climate and deep soil; W-S: Wet climate and shallow soil; W-D: Wet climate and deep soil (Elaborated from Cubera 2006)

Table 7.3 Leaf nutrient concentration of Mediterranean oaks growing with different stand densities and understorey structures

Source	Species	Plots	N	P	K	Ca	Mg
			---------------------mg g^{-1}---------------------				
Úbeda et al. (2004)	Quercus suber	Dense	7.8	0.60	3.1	2.4	0.30
		Open	7.6	0.90	3.6	2.6	0.39
Obrador-Olán et al. (2004)	Quercus ilex	Encroached	10.0	0.65	5.0	6.5	1.25
Moreno et al. (2007)		Grass	11.5	0.48	4.0	9.0	1.5

Dehesa Production

Dehesa is a multipurpose system providing direct and indirect products and benefits. Among the former, pasture, browse, acorns, firewood, cork, and game are most important. Indirect benefits involve the high recreational and landscape value and very high levels of biodiversity in dehesas. Additional benefits include prevention of fire hazards, protection of soil and vegetation and an enormous historical and cultural value (Montero et al. 1998).

Pasture Yield

Pasture yield in dehesa is usually low and shows a huge spatial variation (both at regional and local scales) and temporal variation (both annual and seasonal). The range reported by Puerto (1992) for northern dehesas is 400–9,000 kg DM ha^{-1} $year^{-1}$ in the driest and wettest areas, respectively, with mean values around 2,400–3,500 kg DM ha^{-1} $year^{-1}$. Figures for southern dehesas given by San Miguel (1994) are 300–3,000 kg DM ha^{-1} $year^{-1}$. Pasture yield increases from 1,440 kg DM ha^{-1} $year^{-1}$ in natural pasture to 2,238 and to 2,670 kg DM ha^{-1} $year^{-1}$ with P fertilisation and P fertilisation plus seeding, respectively, in dehesas of Extremadura. Most of the primary production of this annual grassland is concentrated in spring, with a minor peak in autumn, depending of the amount of precipitation (Fig. 7.6). Nevertheless, the high spatial variability within each dehesa determines also certain temporal replacement of grassland types (Fig. 7.6). By contrast, the strong year to year variability (more than 250% in a 5 year period), imposes a serious drawback for livestock management (Olea et al. 2005).

The effect of trees on pasture is a controversial issue. Many authors have reported a positive effect on pasture yield (e.g. González-Bernáldez et al. 1969; Puerto and Rico 1988), nutritional quality (Puerto 1992; Pérez-Corona et al. 1995; Vázquez de Aldana et al. 2000; Moreno et al. 2007; Fig. 7.7), composition (greater

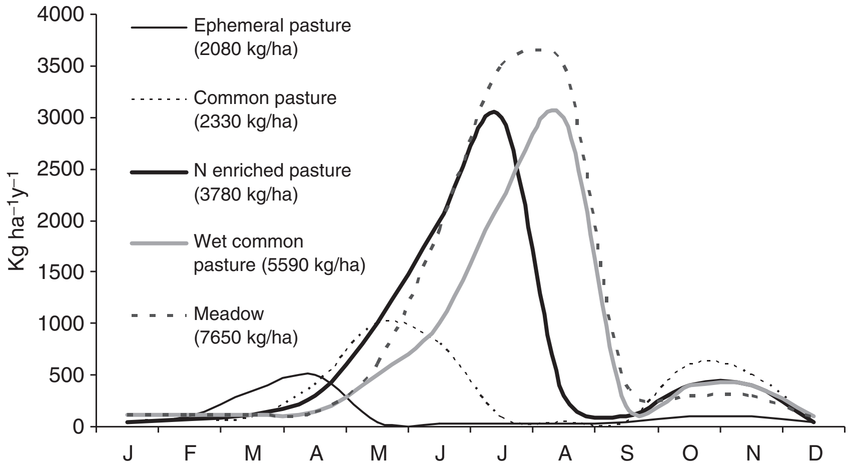

Fig. 7.6 Seasonal variation of pasture yield at different locations of common northern dehesas (Salamanca province, Spain). (Elaborated from Gómez-Gutiérrez and Luis-Calabuig 1992.) Parenthetical Values in parentheses express mean annual yield of different types of pasture: ephemeral pasture (annuals in shallow soils), common pasture (mostly annuals in medium-depth soil), N-enriched pasture (annual and perennial grasses and legumes in soil enriched in manure), wet common pasture and meadow (mostly perennial grasses alive in early summer or along all the summer, respectively). Note that the onset of drought is earlier in central and southern dehesas. The onset of drought can occur between early May and the end of June

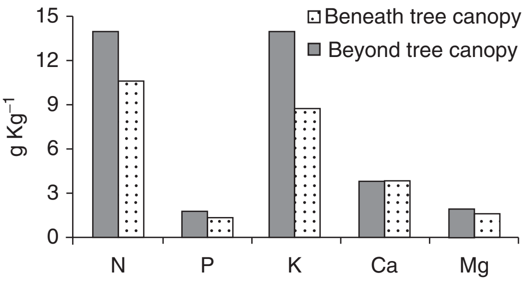

Fig. 7.7 Effect of the trees on the nutrient concentration (quality) of pasture in dehesas of Salamanca province (Elaborated from Escudero et al. 1983)

abundance of perennials beneath canopy; Marañón 1986; Puerto 1992), length of growing season (Joffre et al. 1987; Puerto and Rico 1989), and stability against climatic variability (Puerto 1992).

The nature of the tree-crop interaction can vary among years and sites according to soil water availability. For instance, Puerto (1992) reported several cases where trees reduced the pasture yield (Fig. 7.8), but he also found that in the poorest soils or driest years, yield was homogeneous across distances or even it was higher

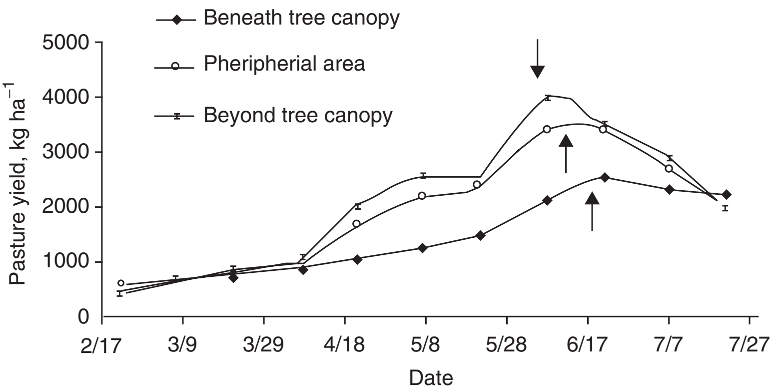

Fig. 7.8 Temporal evolution of pasture yield at three distances from the tree. Note the decrease of pasture yield beneath the canopy, but also the temporal difference on the maximum yield (arrows indicate the period of maximum pasture production at each area) (Elaborated from Puerto 1992)

beneath than beyond the tree cover. Similarly, we have found a strong influence of fertility on the spatial pattern of crop yield in intercropped dehesas. Without fertilisation crop yield was higher beneath the canopy than in the open, while it was higher beyond the canopy in fertilised crops (Moreno et al. 2007).

Tree Production

Acorn Production

Acorns are the main winter food for several wild birds and mammals and domestic animals (pigs and others) inhabiting dehesas. In addition, both the initial number of acorns produced and the rate of removal by vertebrates strongly influence oak recruitment and potential for future production of acorns (Pulido and Díaz 2005). In holm oak dehesas, mean number of fully grown acorns (either viable or not) produced by trees and year was 3,773 and 5,851 in 2 years in grazed plots (García-López 2005). Mean weight of total acorns produced by individual trees in grazed dehesas was 18.12 kg (range: 6.0–28.0, SD = 7.2, n = 15 sites within the whole dehesa range). Mean production per hectare was 420 kg (range: 234–674, SD = 142, n = 9 grazed sites). In the only study available testing the effects of understorey management, cropping was shown to significantly increase production, while shrub encroaching caused a slight decrease as compared to grazed sites (Moreno et al. 2007; Fig. 7.9). Management affected total production through its effect on tree size and tree density, but also by increasing or reducing the probability of successful transition from flower to sound acorns (García-López 2005; Pulido and Díaz 2005). Finally, in the few studies available for cork oak grazed dehesas mean production per tree was 7.66 kg (range: 6.7–8.4, SD = 0.87, n = 3 sites), while

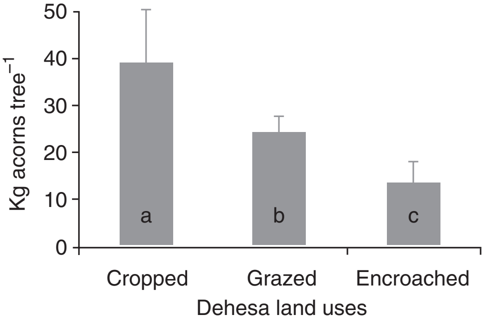

Fig. 7.9 Comparison of acorn production per tree in three distinct dehesa land uses. Elaborated from Moreno et al. (2007). Bars indicate standard deviations, and different letters indicate significant differences ($p < 0.05$)

mean production per hectare was 315 kg (range: 240.5–448.5, SD = 115.6, n = 3 sites). Besides understorey characteristics, tree pruning has been shown to increase holm oak acorn production 2–6 years after branch elimination (Porras-Tejeiro 2002), though the presumed effects of pruning, tree density and site quality have not been tested with appropriate experimental designs.

The main environmental traits determining oak fecundity and acorn availability for animals are weather factors related to fertilization of pistilate flowers, the existence of leaking fruits (those showing abnormal sap exudates causing early abortion) fruits, and the infestation by borer insects. In a dehesa stand only 28% of flowers produced fruits, and the incidence of abiotic (weather-related) factors was much higher (90%) than that of borer infestation (10%) as a source of pre-dispersal losses (García-López 2005; Pulido and Díaz 2005). All these losses, and also those caused by episodic caterpillar outbreaks, are subjected to the effects of management on tree condition. Hence acorn production could be improved by appropriate management of the understorey and the tree canopy (García-López 2005).

Cork Production

Cork is exploited periodically throughout the life of cork-oak trees, and the average production of cork per adult tree in each 9-year cycle varied from 5 kg (young trees) to 71 kg (mature trees) (Montero et al. 2003), i.e. 480 kg ha^{-1} year^{-1} (Pereira et al. 2004). The production of cork has been decreasing in the last few decades in the Spanish dehesas. However, the economic potential of cork has increased markedly in the past 2 decades (Fig. 7.10), and presently, thousands of hectares of arable and pastureland are being afforested with cork oaks. In Portugal, where production has been rather stable in the last 50 years, the value of annual cork production is comparable to that of the national wood production, 258 vs €222 million respectively in 1998, (Pereira et al. 2004).

As long as the international markets continue to consider cork as the most efficient bottle-stopper, the future of cork-oak woodlands should be assured.

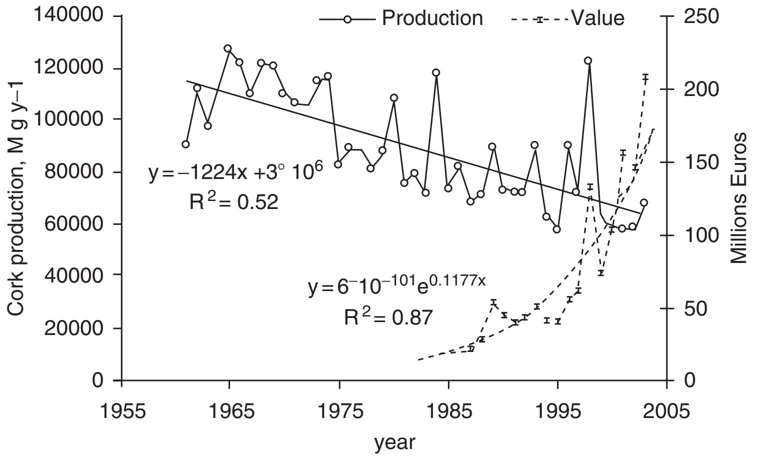

Fig. 7.10 Historical data of cork production in Spain and the value of total national production. Note a linear decrease in cork production ($R^2 = 0.52$), but an exponential increase in the commercial value of total cork production ($R^2 = 0.87$) (Elaborated from Montero et al. 1994; MAPYA 2004)

However, future drops in the price of cork, its substitution by synthetic materials, and the degradation of cork oak stands, may threaten the maintenance of vast cork-oak woodlands (Pereira et al. 2004).

Other Direct Tree Products

Dehesa trees are periodically pruned, and lopped branches are used for firewood or charcoal production and as fodder in winter. Several prunings are carried out during the life of the oaks, traditionally performed in the year preceding arable cultivation to increase light availability for the crops. Due to the sclerophyllous evergreen nature of dehesa trees, they represent substantial fodder reserves for wildlife and livestock (San Miguel 2005). A rational pruning can yield 300–500 kg ha^{-1} $year^{-1}$ of dry browse material (Cañellas et al. 1991).

However, the economic costs of traditional light or moderate pruning are very high, and there are attempts to compensate these costs by obtaining income from firewood, charcoal or virgin cork. This generally implies an increase in the intensity of pruning, which can be too intense and cause damage to the tree (Cañellas et al. 2007). There is a traditional belief that pruning increases acorn production (San Miguel 1994; Gómez-Gutiérrez and Pérez-Fernández 1996) but a recent study has shown that, overall, pruning decreases acorn production (Cañellas et al. 2007). They found that pruning significantly decreased acorn production when production was above the average, whereas production was not affected by pruning the years that acorn yield was below the average. Hence, the effect of pruning in Mediterranean oak woodland is still controversial and more information based on research is needed to form an objective and rational opinion upon the response of trees to this important silvicultural practice (Cañellas et al. 2007).

Other Direct Products

Big game has become one of the most important direct benefits of the dehesa, and has also great potential, because it is a high quality product, compatible with dehesa conservation (Carranza et al. 1991; Vargas et al. 1995). Red deer ingest a high proportion of browse in summer during dry years (0.83% to 0.89% of total diet) and also in wet years (0.47%; Bugalho and Milne 2003; see also Fig. 7.11). However, few attempts to quantify the effects of game on dehesa vegetation and sustainability have been carried out (Patón and Pulido 1999). Special attention should be given to the transformation of the vegetative cover, food supplementation, population structure and disease and genetic effects caused by the uncontrolled transference of animals between hunting estates (Carranza 1999; San Miguel 2005). Another direct product, agrotourism, represents an important growing source of income in dehesas, especially those located close to nature reserves, where recreation can account for a considerable proportion of total income (Campos 1998). The number of estates offering entertainment services is growing rapidly as a result of increasing demand by visitors, especially in naturally protected areas. In this way, environmental values of dehesas will be increasingly internalized by landowners as a source of income values.

Finally, other direct products commonly exploited in dehesas are honey (especially in encroached areas), and a variety of medicinal and edible herbs and fungi.

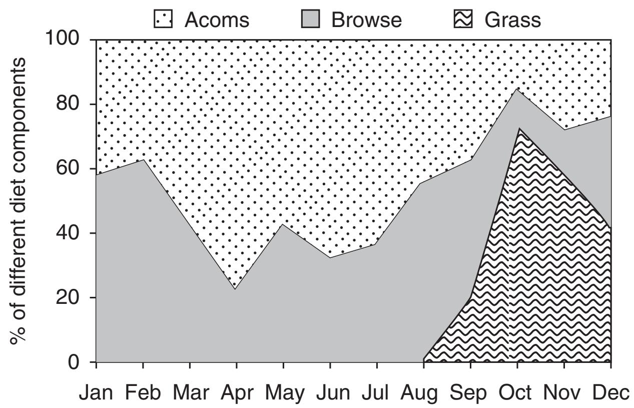

Fig. 7.11 Seasonal variation in the proportion of acorns, browse and grass in the diet of deer grazing dehesa systems (Elaborated from San Miguel and Pérez-Carral 1996)

Wildlife and Biodiversity

Dehesas serve as the main habitat for several endangered species and for very high diversity of animals and plants. The Spanish imperial eagle (*Aquila adalberti* C. L. Brehm), the black vulture (*Aegypius monachus* L.), the black stork (*Ciconia nigra* L.) and the Iberian lynx (*Lynx pardina* Temminck) use dehesas as feeding habitats and adjacent forests and scrublands for breeding, and a noticeable fraction of their world populations depends on dehesas (Díaz et al. 1997). Many bird species, notably common cranes (*Grus grus* L.), use dehesas as their preferred winter habitat. As a consequence, a large proportion of the dehesa range has been included in the Natura 2000 European web for nature conservation, and dehesa grasslands are also a habitat to be protected by the EU Habitats Directive (Díaz et al. 2003). In addition, dehesas sustain a high species richness of several contrasting taxonomic groups. For example with vascular plants, research has described 135 species in 0.1 ha in holm oak dehesas or 60–100 species per 0.1 ha in cork oak stands (Marañón 1986). Values of species richness of this and other taxa are much higher than those of other European man-made habitats. Also, diversity values of plants, birds and butterflies have been shown to be similar, or even higher, to those found in natural or semi-natural habitats located nearby (Díaz et al. 2003). As the only example available of a comprehensive biodiversity survey is from a 220 ha montado farm where, 264 fungi, 75 bryophytes, 304 vascular plants and 121 vertebrate species were recorded (Santos-Reis and Correia 1999).

The main explanation for the diversity values found in dehesas is the intimate mixture of habitats at various scales. First, at the very fine scale the presence of trees increases habitat heterogeneity and plant richness as compared to treeless grasslands. Second, within the same management type (pasture, crop or shrubland), differences in tree density or age and topography determine local variations in animal and plant diversity, respectively. Third, the habitat mosaic generated by the combination of land-use units enhances farm-level diversity by favoring a combination of habitat specialists and generalists via the "hybrid habitat" hypothesis (Díaz et al. 2003). According to this hypothesis, bird diversity values have been shown to follow a nested pattern in dehesas, that is, the number of forest species increases with tree density while the number of grassland specialists remains unchanged. From these results, it follows than the anthropogenic maintenance of multi-scale habitat heterogeneity is crucial for biological diversity in dehesas (Tellería 2001; Díaz et al. 2003). Also, globally threatened species, which have large home ranges, are clearly favored by landscape diversity, as they simultaneously exploit different habitat types (Donázar et al. 1997).

Nevertheless, the effect of dehesa land use on diversity remains a controversial issue that deserves further investigation. Thus, for example, the abundance of lizards increased when understorey bushy vegetation increased, while grasslands or cereal fields were scarcely colonised even if holm oak tree were present (Martín and López 2002). This and other less studied taxonomic groups may experience a reduction in species diversity as a result of forest clearance and grazing. Also, even if species diversity is enhanced by management, human practices may affect species which have a critical role in ecosystem function, as has been described for acorn dispersal on which oak regeneration relies (see Díaz et al. 2003; Pulido and Díaz 2005). Hence, the net effect of dehesas on diversity is not fully understood, and the assumed value of dehesa for the Mediterranean biota is more based on its importance for threatened species than on diversity values.

Are Dehesas Sustainable?

In the last 2 decades, an intense debate about the sustainability of the dehesa system has gathered momentum in view of the lack of oak regeneration in dehesas. Plieninger et al. (2003) showed that the mean age of trees is closely related to the age of the dehesa formation, indicating that the maintenance of dehesa structure or management lead to a lack of tree recruitment, to the ageing of the tree population and, eventually, to its disappearance. In fact, it has been estimated that in the absence of artificial regeneration dehesas would have disappeared in 80 years at the rate of decrease estimated for the middle 20th century (Elena Roselló et al. 1987). By contrast, other authors argue that the present lack of tree regeneration is mostly linked to recent changes of dehesa management, regarding both soil and trees (e.g. Llorente-Pino 2003). He has documented cases of very old dehesas that currently maintain tree cover; therefore they must have experienced episodes of regeneration in the last 5 centuries.

Temporal Evolution of Dehesa Range

Silvopastoral practices intended to transform dense evergreen forests and shrublands into wooded pastures have been used for centuries in lowland areas of the Mediterranean (Stevenson and Harrison 1992; Blondel and Aronson 1999). In southwestern Spain, recent historical analyses show that the increase in the area covered by dehesas parallels the growth of human populations from the 18th century onwards as a consequence of need for arable and grazing lands (Linares and Zapata 2003). The process of dehesa establishment was accelerated by advances in mechanization in the 20th century. This process was considered complete by the middle of the 20th century, when almost all natural habitats in flat areas had been converted into open dehesas (Fig. 7.12). During the period 1940–1970 an intensification of agricultural practices and socio-economic changes led to a crisis in the traditional dehesa system (Díaz et al. 1997). Consequently, the dehesa range suffered a sharp decrease due to tree cutting and lack of tree regeneration, a process that ceased during the 1980s as a result of new regulations. For instance, a specific law for dehesa management was created in 1986 in Extremadura (Law 1/1986), which forbids the cutting-down of oaks and the transformation of the dehesas into

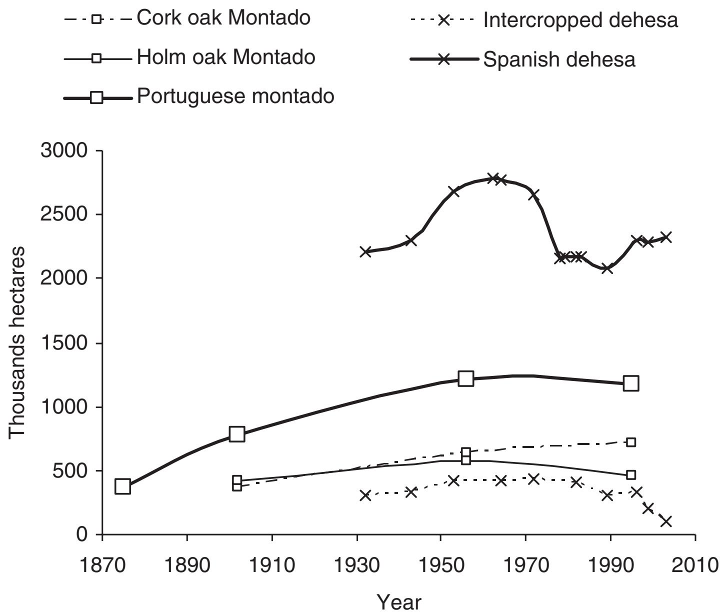

Fig. 7.12 Historical variation in the area occupied by Spanish dehesas (total and intercropped) and Portuguese montados (both dominated by holm-oak and cork-oak). Elaborated from Annual of Agricultural Statistics for Spanish dehesas (MAPYA 1929 to 2004) and Radich and Monterio Alves (2000) for Portuguese montados. NOTE: Estimated by summing the area (thousands of hectares) covered by open woodlands in 13 provinces located in sothwestern Spain: Cáceres (502), Badajoz (403), Cordoba (275), Salamanca (273), Huelva (194), Sevilla (167), Ciudad Real (116), Cádiz (88), Jaén (74), Toledo (71), Ávila (61), Madrid (50) and Zamora (32). Open woodlands are defined by MAPYA (2004) as oaklands with a fractional canopy cover between 0.05 and 0.20 and whose main use is grazing

other land uses. Before that, 23% of oak trees were lost in Extremadura, and 9.6% of the dehesa area disappeared due to intensification, with a loss of around 5.7 millions oak trees over 1960–1985 period (Elena-Roselló et al. 1987). Nevertheless, dehesa landscape was relatively stable during the second half of the 20th century (García del Barrio et al. 2004) with less than 10% of dehesas experiencing any significant change in the last 50 years. After this phase of decrease in dehesa area and tree density, encroached areas and tree density have experienced moderate to high increases from the middle 1980s onwards (García del Barrio et al. 2004; Lavado et al. 2004; Roig et al. 2005; Plieninger 2006; Fig. 7.12). However, an apparently high oak tree mortality is presently occurring (Peñuelas et al. 2001; Sánchez et al. 2002), through a poorly defined process called *seca,* where both biotic (e.g. *Phytophthora cinnamomi* Ronds) and abiotic (e.g. sharp alternation of wet and dry periods) causes seem to be involved (Brasier et al. 1993; Tuset and Sánchez 2004).

At present, from the above information, it seems that the trend toward tree loss due to lack of regeneration and dieback in ageing oak stands is more than compensated for by recovery in areas that have been abandoned, protected or devoted to big game hunting. Nevertheless, due to a lack of spatially explicit historical information, exact timing of a specific dehesa creation is unknown (Plieninger et al. 2003) and it is difficult to confirm if old dehesas have regenerated (e.g. been abandoned) periodically or have been replaced by new ones elsewhere.

Soil Degradation and Soil Loss

Land degradation is recognized as a significant problem in many of the dehesas and montados, implying impoverishment of the pasture cover, accelerated soil erosion and physical soil degradation (Murillo et al. 2004). Although the mean soil erosion rate on hill slopes is usually not too high (540 kg ha^{-1} $year^{-1}$), it is considered excessive because of the degraded state of the soils. Nonetheless, it is clearly higher than that usually considered typical for non-managed or disturbed systems (4–200 kg ha^{-1} $year^{-1}$), and around 30 times higher than values reported for a dense holm-oak forest in Catalonia (Schnabel 1997).

Table 7.4 Effect of land use, management practices and tree cover on dehesa soil conservation

	Land use[a]			Management practices[b]				Tree cover[c]			
Soil parameter	Forest	Dehesa	Crop	NP	TS	DS	FP	HTD	MTD	Tree-less	BC
Soil cover, %	57	21	12	50	58	58	58	85	55	35	80
Soil compactation, kg cm^{-2}	3.08	3.95	–	–	–	–	–	–	–	–	–
Overland flow, % rainfall	6.5	36.3	16.0	12.3	12.7	2.3	18.6	12.0	30.5	36.3	9.6–13.2
Erosion rate[a,b,c]	5.0	87.5	200	98.4	14.5	12.7	27.8	3.1	5.2	5.8	0.9

Adapted from

[a] Coelho et al. 2004; Erosion rate determinates by Rainfall simulator (g h^{-1} m^2)

[b] Murillo et al. 2004; Management practices: NP: Natural pasture, TS: Traditional seeding, DS: Direct seeding, FP: Fertilised pasture; Erosion rate determinates by erosion plots of 0.5 ha (g m^{-2} $year^{-1}$)

[c] Schnabel 2001; Tree cover: HTD: High tree density, MDT: Medium tree density, BC: Beneath canopy; Erosion rate determinates by Gerlach traps (g m^{-2} $year^{-1}$):

Moreover, the increased stocking rate of dehesa could have led to an increased risk of soil and pasture degradation (Coelho et al. 2004; Schnabel and Ferreira 2004; Shakesby et al. 2001). Heavily grazed evergreen oak sites both in Portugal and Morocco had a significant increase in soil compactation, overland flow and erosion rates (Table 7.4). Furthermore, ploughing for control of understorey vegetation and/or to improve pasture (seed sown) increased overland flow and erosion (Coelho et al. 2004; Table 7.4).

As previously stated, erosion rate is lower beneath the canopy than in open spaces (Table 7.4). Thus, to minimize the risk of erosion, apart from the maintenance of the tree cover, it is advisable to reduce the stocking rate, especially in summer to avoid excessive degradation of pasture cover before the onset of heavy autumn rainfall. Hence, the maintenance of transhumance would be of great benefit for soil conservation because dehesas would be destocked during the summer. Another recommendation is to improve pasture yield through fertilization and/or sowing selected native species (mostly legumes), but avoid soil ploughing on medium and steep slopes (Schnabel 2001).

The Lack of Tree Regeneration

Several authors (Montoya 1998; Pulido et al. 2001; Plieninger et al. 2003) have pointed out that the forest cycle has been disrupted in most dehesas, where the lack of regeneration is an inherent problem to their exploitation. Disruption begins as each dehesa farm is developed from forest, and it has been exacerbated by the recent intensification of the agroforestry use of dehesa. Undisturbed oak forests, where oak recruitment occurs regularly, have size or age structures consistent with a negative exponential (inverse J-shaped) function (Pulido et al. 2001; Fig. 7.13). Recent studies conducted in oak stands, from local to regional scales, have revealed strong departures from the natural pattern of tree regeneration due to the lack of saplings and juveniles. In the case of cork oak dehesas, 72% of the stands showed regeneration failure (n = 159 stands; Institute of Cork, Wood and Charcoal of Extremadura, 2001 unpublished data), while the corresponding figure for holm oak dehesas is 87% (n = 60 stands; Naveiro et al. 1999; see also Pulido et al. 2001; Plieninger et al. 2003). In a comparative analysis of holm oak recruitment capacity in natural forest and dehesas (Pulido and Díaz 2005), the probability of establishment of new saplings was 75 times lower in dehesas (0.00150 and 0.00002, respectively; see also Fig. 7.13). This disparity was the result of differences in the success of seed dispersal to suitable sites and the lack of shrubs that have been found to exert a nurse effect in natural forests. This finding, confirmed by other studies (Plieninger et al. 2004b, García-López 2005), explains the general lack of natural regeneration of dehesas as compared to the holm oak forest. Both dispersal and safe site limitations are related to the lack of shrub cover associated with intensive dehesa management, thus, shrub encroachment predictably results in higher recruitment rates as compared with dehesa grazing or cropping (García-López 2005).

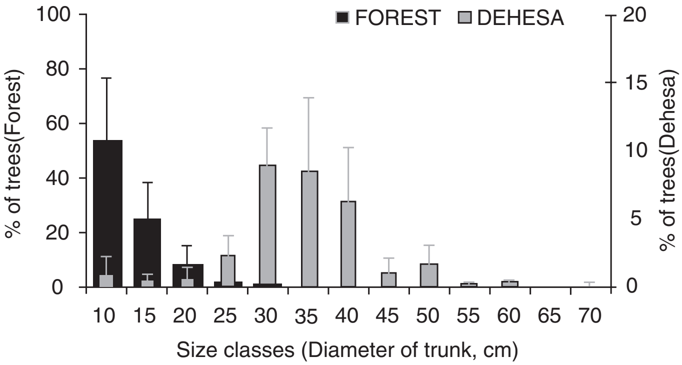

Fig. 7.13 Size structure of the populations of mature trees in *Quercus ilex* dehesas and adjacent forests. Bars indicate standard deviations (Elaborated from Pulido et al. 2001)

Plieninger et al. (2004b) found that juveniles and saplings are highly associated with mature trees, shrubs, and rock outcrops, a result of directional dispersal, facilitation of seedling establishment and sheltering from browsing by livestock.

For decades dehesa researchers and technicians have agreed that regeneration failure is the main problem for the long-term persistence of dehesas, and that ensuring tree turnover should be a requisite for sustainable management (Montero et al. 1998). Nevertheless, the short timeframe in which land owners make management decisions implies that tree regeneration was not customarily considered as an important constraint. In fact, measures devoted to tree conservation have only been adopted under public intervention through subsidies for afforestation under EU regulations (Campos et al. 2003b). Subsidized oak plantations within large livestock exclosures have been a substantial source of income over the last 15 years, despite the cost of reduced grazing area. Over 186,000 ha were planted in the period 1996–2002 (MAPYA 2004). Plieninger et al. (2003) have showed that dehesa degradation is easily reversible if abandonment is periodically practiced, but specific measures promoting owners' interest in natural regeneration after partial exclusion of livestock have been anecdotal. They can be expected to become more widespread as the perception of subsidies became more dependent on the fulfillment of agri-environmental objectives.

Dehesa Profitability

Dehesa is an extensive but labour-intensive land-use system. Thus, the increased labour costs in Europe threaten dehesa profitability and hence persistence (Gómez-Gutiérrez 1992). Commercial profitability of direct dehesa products is usually low

(Campos 2004). Applying the conventional net value added (NVA); dehesa profitability is very low, even in many cases negative (Escribano and Pulido 1998), with a range of −14.7 to 9.7 of NVA. Only in some cases, e.g. for cork oaks with low livestock grazing and red-deer hunting, is commercial profitability clearly positive (Campos et al. 2001). However, according to the total economic value theory (Campos et al. 2001), economic analysis based only on NVA produces an incomplete annual forestland income assessment. Whenever there are multiple uses of renewable resources, a new operative approach called Agroforestry Accounting System (AAS) can be used to incorporate environmental goods and services (Campos et al. 2001).

In the last 25 years, dehesas and montado have attained large capital gains; e.g. the price of dehesa land in Extremadura has increased at a real cumulative annual rate adjusted for inflation of 5%, (Campos 2004; see also Escribano and Pulido 1998). The constant rise of land prices of dehesas, at a time when commercial profitability of dehesa farming is declining, is thought to be largely due to the revaluation of self-consumed private environmental services (indirect products); in other words, 'leisure has become a product of the dehesa' (Pardal 2002; Campos 2004). Indeed, several studies carried in Spain showed that private environmental services used by landowners themselves account for 33–43% of the market price of land reported by landowners (Campos 2004). There is a consumptive value associated with ownership of rural land, reflecting innate desires to own land, live in a rural environment, obtain or maintain the lifestyle of a farmer, engage in outdoor recreation, get back to nature, and partake of any other real or perceived benefits of rural land ownership (Campos and Caparrós 2005).

As a result, dehesas have an unexpectedly high discount rate of 4.5% on average, which is higher than that of many European forests (around 2–3%; Campos et al. 2003b). Considering both capital gains and direct product-included subsides, which account for between 43% and 80% of the commercial income in a common dehesa (Calvo et al. 1999), the total private real profitability of dehesas is in the range of at least 3–5%, not including hypothetical incomes from public environmental services (Campos 2004). These public direct goods and services, and environmental functions are insufficiently known and are not fully incorporated to the present accounting systems (Escribano and Pulido 1998; Campos et al. 2003b).

The fact that current profitability depends less on income from direct productivity than on capital appreciation, and the low capital flux and long waiting period needed for financial returns from most forest operations, has very negative effects on dehesa conservation. Land owners are usually more interested in obtaining economic profit than in the rational long-term exploitation of dehesa resources. This attitude leads to a lack of capital to finance the management and improvements needed to exploit direct products in a sustainable way (Montero et al. 1998). As previously mentioned, only the implementation of direct policies for sustainable management of dehesas (subsides) seem to be contributing to solve this problem. According to Campos et al. (2003b) these subsidies can be justified in terms of economic efficiency and social fairness.

Future Prospects for Sustainable Dehesas

From the experimental results presented here, there is a true opportunity for dehesa sustainability and conservation becomes apparent, because oaks are able to regenerate after several years of set-aside, e.g., systematic abandonment of agricultural and grazing activities according to a rotational scheme (Plieninger et al. 2003). The time needed to ensure natural regeneration excluding grazing activity has been roughly estimated for different livestock species but we still lack quantitative regeneration models accounting for the whole variability in the dehesa scenarios (Montero et al. 2003). Even assuming a set-aside period of 20 years and a mean holm oak lifetime of 200 years, 10% of any estate would be required. The establishment of long-term experiences allowing tree regeneration in fenced portions involving pilot farms is largely needed for to develop more accurate models.

The present total private economic profitability of dehesas and montados appear to be moderate to high. Nevertheless, this is mainly due to the income through livestock subsidies – as direct productivity – the self-consuming environmental services – as indirect productivity – and to the capital gains, with a low commercial operating profitability (Campos 2004). Landowners are aware of regeneration failure on their farms but they are reluctant to give up part of the moderate cash-flow to ensure the future profitability of the system by adopting a less intensive management (Campos 2004; Plieninger et al. 2004a). Hence sustainable management of dehesas should be encouraged by the national agencies through subsidies, justified by the social goods and services delivered and conditioned to the maintenance of the environmental functions of dehesas.

Under the appropriate EU regulations, biological diversity can be considered as environmental value contributing to economic sustainability of dehesas. There is an urgent need to correct deficient environmental regulations to guarantee the sustainability of dehesas and montados. For example, livestock income, the primary driver of overgrazing in dehesas, could be replaced by *set-aside regeneration reserve* subsidies. These should involve the creation of a mosaic-type farming, where shrubland patches (called *manchas*) should be also included. This type of landscape mosaic is assumed to have positive impact on biodiversity and sustainability (natural regeneration) of the dehesas (Pineda and Montalvo 1995; Carranza 1999; Plieninger and Wilbrand 2001; Pulido and Díaz 2005); however, the implications of this approach on economic returns should be explored in pilot farms before its widespread application. Similar criteria for forest management in support of the conservation and productive role of the landscape have been proposed by Fullbright (1996).

Dehesa management and structure should go beyond that of a simple concept of a two layered agroforestry system *sensu* Nair (1993), even beyond a combination of spatially and economically interacting plots with different vegetation structure *sensu* Etienne (1996). Dehesa should be managed as a *temporal* sequence of a set of plots, with distinct vegetation structure, integrated in a rotational cycle, as a modification of the traditional, crop-pasture cycle, to an expanded crop-pasture-shrub cycle. This expanded, long-term rotational cycle would allow both soil restoration and tree regeneration. The coexistence of two-layered plots, with multilayered plots (encroached open woods) and mono-layered plots (either dense forest or mono-pasture/monocrops) would give a mosaic at both estate and landscape scales. This would ensure the maintenance of a high structural diversity in dehesas. In this way, the environmental value of the dehesa could be maintained, and contribute to profitability in the context of the total economic value *sensu* Campos (2004).

A Research Agenda

Explicit long-term strategies must be designed to promote management practices that ensure dehesa conservation; however, to convince landowners, administration and policy-makers, more knowledge is needed. For instance, spatially explicit studies on tree population dynamics and temporal regeneration trends as influenced by ecological and management variables are needed. A suitable demographic model for oak replacement has not yet been developed. The optimal tree density of dehesas under different uses and ecological constraints is unknown. Insufficient information exists on the stocking rates that can sustain dehesa regeneration. Stocking rate at each dehesa should be based on the overall forage availability and its seasonal pattern, but also on the need to have regular or periodical tree recruitment through avoiding grazing in summer or for periods of several years. Shrub encroachment is certainly favourable for tree regeneration, but it is doubtful whether this would maintain stand function (e.g. hydric and nutritional tree status, biodiversity) and profitability (e.g. livestock carrying capacity) of dehesas. Biodiversity, soil conservation, CO_2 fixation, landscape amenity, etc. are objectives of interest to the EU and affect society as a whole. The cumulative influence of these environmental functions of dehesas is also a crucial issue to be studied given that future dehesa profitability depends mostly on these indirect incomes. Finally, the stability of the dehesa system in the face of long-term climatic change will need to be studied. A projected increase in the probability of extreme climatic events could have dramatic consequences in driest dehesas (Joffre et al. 1999). Finally, more studies are needed on the origin and consequence of *la seca* and its relationship to global change (increase of climate aridity, soil compaction, and shrub encroachment).

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Chapter 8
Silvopastoral Systems in the Northeastern Iberian Peninsula: A Multifunctional Perspective

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Abstract This paper aims to analyse the present situation of silvopastoral systems in the Northeastern Iberian Peninsula and to foresee the role that silvopastoralism might play in the future. In the region, silvopasture form part of an extensive livestock farming system which integrates agriculture, livestock production and forestry, mostly in family-based farms. Forest grazing is the most important silvopastoral system in the study area where the mountainous topography and the dominant Mediterranean climate influence the grazing strategies. Despite the low contribution of silvopastoralism to the total Gross Domestic Product of the Catalan region, extensive livestock systems play an important social and economic role in the structure of rural areas. Moreover, this role is expected to increase in the future due to the implementation of new agrienvironment measures in the framework of the latest European financial program (2007–2013). The present paper discusses the role of silvopastoralism as an economically viable tool to prevent wildfires and conserve biodiversity in these systems.

Keywords Agroforestry, biodiversity conservation, fire prevention, forest grazing, fuelbreak management, agrienvironment measures

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Introduction

In the Northeast of the Iberian Peninsula, as in the rest of the Mediterranean basin, land use for centuries has shaped and organised the present landscape (Le Houérou 1990; Montserrat and Fillat 1994). The diversity of ecosystems resulting from the complex topography and multiple microclimates in the area was enriched by the cultural systems adapted to each particular set of conditions. Agriculture (mainly grazing) and forest management created an integrated and structured mosaic landscape of agroforestry systems with high cultural and biological values (Fabbio et al. 2003; MacDonald et al. 2000).

Nevertheless, as a consequence of the shift from the primary to the tertiary sector which took place throughout Spain, and especially in the Northeastern region, during the second half of the last century, traditional and sustainable multifunctional activities were abandoned or substituted with more purely production-oriented ones. These changes have adversely affected the ecological and cultural goods and services that agroforestry systems produce (Quétier et al. 2007). The reduction of traditional uses, mainly extensive livestock and multipurpose forestry (for timber, woodfuel, charcoal, resins…) has allowed, in many cases, a secondary vegetation regeneration characterized by bush proliferation, which dominates and homogenizes the landscape, increasing the risk and extension of wildfires and reducing recreational and aesthetic values (e.g., Perevolotsky and Seligman 1998; Bartolomé et al. 2005; de Bello et al. 2005). On the other matter, many plant and animal species have long coexisted with human activities and, more importantly, the abundance of some species may have been facilitated by low impact agrosilvopastoral management (e.g. Perevolotsky and Seligman 1998; Canals and Sebastià 2000). Both intensification and abandonment imply a disruption of subtle relationships among species and between species and habitats, and, thus might involve a loss of diversity (de Bello et al. 2006).

Silvopastoralism could be an essential tool for the sustainable management of Mediterranean forests from a biological, social and economic perspective; in fact, the future of Mediterranean agroforestry is built on the recognition of its multifunctional role. Environmental quality and food safety are high priorities of the European Union, and this is clearly reflected in the most recent European policies and financial programs.

Our aim in this paper is both to analyse the present situation of agrosilvopastoral systems in the Northeastern Iberian Peninsula and to foresee the role that silvopastoralism may play in the future. Key priorities for confronting the new scenarios are then discussed.

Characterisation of the NE Iberian Peninsula

Abiotic Characteristics

The scope of the present work is the Northeast of the Iberian Peninsula, 40°34´ to 42°26 N and 0°10 to 3°10 E. This area is administrated by the autonomous government of Catalonia and it is subdivided into 41 local administrative counties.

The topography of the NE of the Iberian Peninsula was conformed in the alpine orogeny due to its tectonic proximity to the collision axis between the Iberian and the European crustal plates. Thus, it is a highly mountainous area with the exception of the southwestern plains of the Ebro basin. Three main physiographic units can be distinguished: the Pyrenean ranges in the North, the Littoral ranges limiting the Mediterranean coast and the interior Catalan depression belonging to the Ebro geomorphologic formation. The distribution of altitudes, from sea level up to 3,000 m, is quite homogeneous with an average altitude of about 700 m. The most common soil parent materials are limestones and marls, though low metamorphic schists and granodiorites are also frequent in the north and Northeast while in the south-west there are more evaporitic rocks. The dominant climate is Mediterranean with a wide array of local microclimates depending on the altitude, continentality and topography. In the Pyrenees, mid-European and alpine climates can also be found. In spite of its environmental heterogeneity, the study region is culturally homogeneous, sharing a common history, social structure and management traditions.

Grazing Resources

The grassland resources in the Northeast of the Iberian Peninsula can be classified in five categories (according to the Second Forestry National Inventory, Table 8.1; Fanlo et al. 2005). Grazing resources consist of wooded grasslands or forests (43.4% of the Catalonian region), shrublands (8.5%) and herbaceous grasslands (6%), most of the latter (3.2%) being concentrated in the Pyrenean ranges (Table 8.1; subalpine and alpine grasslands >1,600 m a.s.l.).

Taking into account the different vegetation cartographic units (CORINE habitat classification), a hierarchical cluster analysis (similarity index on the proportion of different vegetation units in terms of surface in each county) grouped the 41 counties into eight regions (Fig. 8.1a, Table 8.2). The vegetation in regions I and II is typically boreo-alpine with mountain coniferous forests (*Pinus mugo* Turra ssp. *uncinata* (Mill. ex Mirb.) Domin and *P. sylvestris* L.), deciduous forest (*Fagus sylvatica* L., *Quercus humilis* Mill., *Q. petraea* (Matt.) Liebl.) and alpine, subalpine and montane grasslands and meadows; region III with *P. sylvestris* and *P. nigra*

Table 8.1 Classification of grassland resources in the NE Iberian Peninsula. Surface (km^2) and proportion with respect to the whole study region (Fanlo et al. 2005)

	km^2	%
Grassland resources		
Grasslands under dense woodland	12,681.8	39.4
Grasslands under shared woodland	1,292.3	4.0
Shrublands	2,746.3	8.5
Lowland and montane grasslands (<1,600 m a.s.l.)	863.3	2.7
Subalpine and alpine grasslands (>1,600 m a.s.l.)	1,036.2	3.2
Agricultural and unproductive land-uses		
Croplands	11,911.0	37.0
Unproductive	1,675.9	5.2
Total region	32,206.8	100

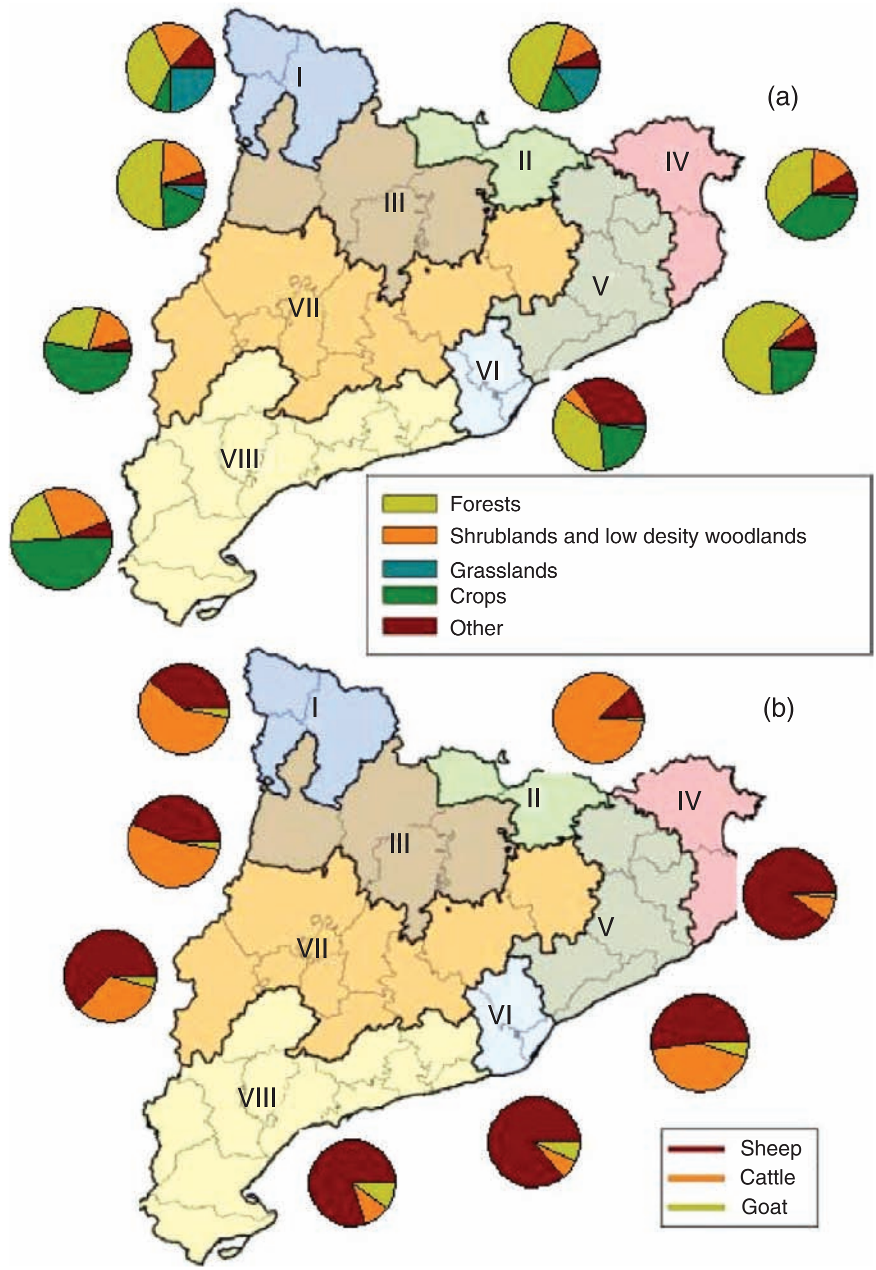


Fig. 8.1 Percentages in each silvopastoral region for **(a)** land-use system and **(b)** extensive livestock husbandry system in the NE of Iberian Peninsula (Cataluña region). Silvopastoral regions were obtained by a hierarchical cluster analysis based on the proportion of vegetation units in each county. Animal systems were compared as livestock units (1 LU = 1 cow or 8 ewes or goats)

Arnold forests and calcareous scrublands includes the Pre-Pyrenean counties (Table 8.2). Evergreen sclerophyllous Mediterranean forests of *Q. ilex* L. and *Q. suber* L. and secondary acidophilus communities are widespread in regions IV and V while secondary calcareous scrublands and shrublands are characteristic of regions VI, VII and VIII. In these last regions, the tree stand is dominated by *Q. ilex* and *Q. rotundifolia* followed by *P. nigra*. Regions IV and VII are dominated by herbaceous crops and region VIII by non-irrigated fruit tree crops (Fig. 8.1a, Table 8.2).

Extensive Livestock Farming

The silvopastoral systems in the Northeast of the Iberian Peninsula are included in the area's extensive livestock farming system and are characterized by an intimate integration of agriculture, livestock production and forestry within family-based farms. Extensive grazing strategies can be broadly grouped into two main categories: (i) rotational grazing, where the total rangeland is divided into intermittently grazed plots (transhumance could be included here), and (ii) continuous grazing, where animals can freely graze the whole area. The animals used in extensive grazing regimes are those best adapted to mountainous topography and difficult feeding sources, that is, meat-producing livestock (cattle, sheep and goats). Horses and other equine species are also managed under this extensive system. In Catalonia, both pig and dairy production are linked to intensive farming. Feed requirements of animals raised for milk production are thought to be too high to be satisfied through forest grazing and browsing alone (Sineiro and Diaz 1983).

In 1999, extensive livestock production (meat-cattle, sheep and goats) represented about 18% of the total livestock production and about 10% of the total agricultural production (DARP 2003). Agricultural production was about 2% of the total Gross Domestic Product in the Catalan autonomous region (taken from statistical data provided by the Department d'Economia i Finances (2004)). Two main trends have characterised the extensive meat producing system found in the study region in recent years: (i) a high decrease both in the total number of animals and in the total number of farms, especially for the sheep and goat sector where one of every three animals was lost over the period 2000–2003, and (ii) an increase in the number of animals per farm (DARP 2003). The consequent increase in the average number of animals in the remaining herds has resulted in a decrease in the overall grazing pressure but, presumably, with localized overgrazed areas.

In December 2003, throughout the whole region there were about 70,000 head of cattle, 825,000 sheep and 70,000 goats (DARP 2003) under extensive systems. The territorial distribution of the extensive livestock farms reflects the vegetation patterns described above (Fig. 8.1, Table 8.3). Thus, extensive cattle is dominant in the Pyrenean regions (I and II) while sheep flocks are more important in the Mediterranean areas where agricultural land is dominant (IV, V, VI, VII and VIII; Fig. 8.1). In the Pre-Pyrenean region (III; Fig. 8.1b) both sheep and cattle have similar importance.

Table 8.2 Principal plant communities in the silvopastoral regions. Mean percentage cover of each community in each region

	Silvopastoral regions							
Plant communities	I	II	III	IV	V	VI	VII	VIII
Subalpine and montane *Pinus uncinata* forests	11	12	3	0	0	0	0	0
P. sylvestris forests	6	20	17	0	1	0	2	1
Fagus sylvatica and *Abies alba* forests	5	4	0	0	1	0	0	0
P. nigra forests	0	0	15	1	1	0	5	1
Sub-Mediterranean oak forests (*Quercus faginea, Q. humilis, Q. petraea*)	3	5	5	1	2	0	3	0
Q. ilex and *Q. rotundifolia* forests	2	1	6	8	22	3	4	3
Q. suber forests	0	0	0	16	10	0	0	0
P. halepensis forests	0	0	0	0	0	1	1	2
Betula sp. *and Fraxinus excelsior* forests	1	3	0	0	0	0	0	0
Castanea sativa and other woods	0	0	0	1	5	0	0	0
Heaths and temperate scrublands	4	9	0	0	0	0	0	0
Buxus sempervirens scrublands and montane bushes	3	1	3	0	0	0	0	0
Calcareous sclerophyllous shrublands	0	0	1	5	7	17	3	5
Calcareous Mediterranean scrublands	1	2	10	4	2	8	12	19
Garrigue and thermophilus scrublands	0	0	1	2	0	3	1	11
Acidophilous sclerophyllous shrublands	0	0	0	3	8	1	0	0
Acidophilous scrublands	0	0	0	9	1	1	0	1
Hay meadows and Medio-European grasslands	8	15	5	0	1	0	1	1
Alpine, subalpine and montane grasslands	19	11	3	0	0	0	0	0
Mediterranean and sub-Mediterranean grasslands	0	0	0	0	0	1	0	1
Irrigated tree crops	0	0	0	1	0	1	4	2
Herbaceous crops	2	5	14	32	22	9	47	3
Non-irrigated tree crops	0	0	1	3	1	4	7	35

Silvopastoral Systems in the Northeast of the Iberian Peninsula

The traditional silvopastoral system in the Northeast of the Iberian Peninsula has been forest grazing, and it is still the most common practice found. Other less widespread silvopastoral systems in the area respond either (i) to tree management

Table 8.3 Livestock resources[a] in 2003 for each silvopastoral region in the Northeastern Iberian Peninsula

					Total	
Region	Surface (ha)	Cattle (LU)	Sheep (LU)	Goat (LU)	LU	LU ha^{-1}
I	191,999	6,647	4,478	286	11,411	0.06
II	141,165	13,674	1,901	139	15,714	0.11
III	465,662	14,840	12,020	724	27,583	0.06
IV	203,896	2,900	29,660	476	33,036	0.16
V	374,029	10,027	11,999	1,050	23,076	0.06
VI	120,129	230	2,877	243	3,350	0.03
VII	880,983	13,524	25,911	1,760	41,195	0.05
VIII	710,494	1,977	16,503	2,054	20,534	0.03
Total	3,088,357	63,819	105,349	6,731	175,898	0.06

[a] Obtained by grouping the livestock statistics for each county (DARP 2003). Heads were converted to livestock units (LU) according to 1 LU = 1 cow = 8 ewes or goats

objectives, such as weed or bush control (i.e., grazing in tree plantations and, more recently, grazing in post-fire forest areas covered by a bush layer that constrains tree regeneration) or (ii) to animal management objectives (i.e., improved forest grazing systems and, in a very few cases, the use of oak and ash *Fraxinus* spp. branches after pruning as a fodder resource).

Forest Grazing

Forest grazing has been historically practised in Mediterranean and montane forests all over the Northeast of the Iberian Peninsula. This is linked to the two main defining characteristics of the region: (i) a mountainous topography, in which forest grazing can be used by the farmer to maximise existing resources and (ii) a Mediterranean climate, which imposes a strong seasonality requiring resource diversification. Nowadays, forests play a secondary role in the feeding strategy of extensive grazing systems in the study area, where grasslands and agricultural land (either cereal crop residues or forage grasses) are the main feed resource. Nonetheless, available data from the Forest Management Plans (FMP) approved by the Catalan Government show that the forest understory is grazed in approximately 55% of the forests managed under a FMP (2825 FMP at 31 December 2006 accounting for 26% of the privately owned forests in Catalonia which, in turn, represent 77% of the total forested area in the region; Centre de la Propietat Forestal, 2007).

There are many grazing strategies in the forest grazing systems of the study area, mainly depending on resource availability, type of livestock used, scale of exploitation and land tenure. In contrast, the management of the tree component is less variable. The forest is usually managed under conventional silviculture that it is practically unmodified by the presence of livestock.

Forest grazing management can range from occasional gatherings of animals in forests to actual planned systems where the forest fodder resource is integrated in a detailed fodder calendar (Etienne et al. 1994). The most valued tree effects reported by farmers in the pre-Pyrenean area were the shade that trees provide the animals, the cooler microclimate under the tree canopy which favours pasture conditions in late summer and the possibility of obtaining edible fruits, stems and leaves for animal feeding (Baiges 1999).

Silvopastoralism with cattle is practised mainly in large, rotationally managed, mid-mountain rangelands. These include forest, grassland and cropland. The cattle generally belong to the Bruna, Pirinenca and Alberesa races (Parés et al. 2006). The herd is always kept outdoors, even during the calf breeding period which lasts from 6 to 9 months. Animals are kept in plots with the help of electrified wire fences. The grazing period usually lasts from 5 to 8 months in autumn, winter and spring. When the herds are too big or the available herbage resources are not sufficient in summer, farmers might go on transhumance to grazing areas in the Pyrenees. The stocking rate in forests grazed by cattle is around 0.1 head per hectare per year and it is normally limited by the grassland area available in the leanest period (Baiges 1999), although supplementary food is also used. In this system, animal management is simple and cheap in terms of initial investment and labour demand. However, there are differences in costs related to farm size. While investments in land hiring and supplementary feeding are higher in larger farms (>30 head of cattle in the driest areas and >100 in the wettest ones), labour demand is higher in the small-to-medium ones (Baiges 1999). Silvopastoralism with sheep is particularly common in two environments: (i) bushy areas and fallows, mainly in the Ebro depression (south-eastern region VII, Fig. 8.1) which are generally used for grazing in winter, and also (ii) areas where forest is the main resource, although some previous silvicultural intervention is always necessary to ease the access and feeding of the animals. This system is not suitable for pregnant sheep as their requirements are too high. Types of animals used can range from autochthonous races (Ripollesa, Xisqueta, Rasa Aragonesa and Aranesa; Parés et al. 2006) to more prolific ones such as Lacaune. Most animal management relies on shepherding (daylight grazing outside and night in the shed). Only on very few occasions does grazing take place in fenced rangelands. Goats are often included in the bigger sheep herds. However, in Mediterranean dry mountains (Montsant, Montmell, Montsec…) some pure herds still exist. The most common races are Blanca de Rasquera (autochthonous, Parés et al. 2006) and Murciano-Granadina. The flocks are always shepherded. Grazing resources include bush areas and forests, and the grazing period covers the whole year. Supplementary food is reduced to a protein supplement during the breeding period. Stocking rates can be a little higher than that with cattle (0.1–0.2 LU ha^{-1} $year^{-1}$).

Costs of Forest Grazing Within the Extensive Farming System

One of the major advantages of extensive farming systems is their low infrastructure requirements, implying a low implementation cost (with respect to fences,

Table 8.4 Approximate cost (€ per hectare per year, minimum and maximum interval) of supplementary feed, infrastructure and works for forest grazing[a]

		Cattle		Sheep and goats			
		Fenced plots		Fenced plots		With shepherd	
Supplementary feed[b]	€ ha^{-1} $year^{-1}$	2.2	9.7	2.0	9.1	2.0	6.7
Infrastructure[c]	€ ha^{-1} $year^{-1}$	4.5	10.5	16.1	18.3	21.2	22.8
Works[d]	€ ha^{-1} $year^{-1}$	8.6		8.6		29.6	
Total	€ ha^{-1} $year^{-1}$	15.3	28.8	26.7	34.0	52.8	59.1

[a] Considering a forest farming standard of 40 livestock units, 100 ha of forest and a stocking rate of 0.1 UR ha^{-1} $year^{-1}$

[b] Supplementary feed considering low and high forest intakes (10% and 90% of their energetic requirements)

[c] Feeding, fences and other devices. To calculate a yearly basic cost an amortisation period of about 15 years is considered

[d] Considering the salary for 90 days of forest grazing (Economic Activity unit = 12,000 € $year^{-1}$)

shepherds' wages and water points). Moreover, the system is organised in such a way that other inputs such as silage, minerals and vitamins (i.e., concentrated feed) are needed only under specific climatic circumstances, such as a long summer drought or a very cold winter.

A set of in-depth interviews of selected farmers was conducted with the aim of collecting information on management, animal requirements and economic constraints. By comparing these findings with the bibliography we were able to make a preliminary analysis of the costs of implementing forest grazing in relation to supplementary feed requirements and the need for infrastructure (Table 8.4). Considering a standard herd of 40 livestock units (LU) and a stocking rate of 0.1 LU ha^{-1} in a 100 ha farming system, the cost depended both on the type of animal and the farming system: cattle grazing systems cost less than sheep or goat systems because the electric fences used in the former are less expensive than sheep fences or shepherd wages.

Improved Forest Grazing Systems

The very wide use of supplementary feed in lean periods and the very limited use of investment in land to increase pasture production is a common feature of forest grazing systems in the Mediterranean basin (Selingman 1996). Nevertheless, a growing number of improved silvopastoral systems originating from forest grazing situations can be found in the study region, as illustrated in the Forest Management Plans being implemented in the area (Table 8.5). They are generally concentrated where livestock is the main economic output of the system (Fig. 8.1; regions II, V and VII).

In these improved systems, the main forest is managed with the main objective of enhancing livestock performance, while timber or fuelwood production is secondary. The main tree species under this treatment are oak (*Q. humilis* Mill.) and

Table 8.5 Forests (ha) converted to improved forest grazing systems or to open grasslands for each silvopastoral region in the period 2001–2005 (Centre de la Propietat Forestal)

Region[a]	New open grasslands (ha)	Improved forest grazing systems (ha)	Total forest area converted (a) (ha)	Forest surface included in a FMP[b] (b) (ha)	Proportion of forest converted (a*100/b) (%)
II	70	73	143	24,740	0.58
III	106	25	131	88,105	0.15
IV	87	21	108	35,090	0.31
V	34	135	169	84,733	0.20
VII	316	786	1,101	100,438	1.10

[a]FMP: Forest Management Plan. In Catalonia, the proportion of forests under a Forest Management Plan for regions II, III, IV, V and VII represents 30% of all the private forest land in the territory. This means a total of 362,024 ha included in 2522 FMP at 31 December 2005

[b]Regions not shown had not converted forests to improved forest grazing systems or open grasslands

holm oak (*Q. ilex* L.), both providing extra feeding resources such as edible fruits, tree branches and leaves. Scots pine (*P. sylvestris* L.) is also widely used even if only because of the shade and regulation of the microclimate under its canopy, which provides a better and more persistent pasture. Examples with cork oak (*Q. suber* L.) and Aleppo pine (*P. halepensis* Mill.) can also be found. The improvement practices involve heavy thinning, understorey clearance, sowing of forage species and, sometimes, fertilisation. The forest is then converted to a wooded pasture. Trees are maintained in the system until they pass their optimal physical state. Regeneration can be achieved through successive thinning (through natural regeneration by seedling establishment facilitation in recently opened areas) or clear-cutting and plantation. The regeneration period lasts no less than 10–15 years depending on the tree species and the regeneration strategy chosen. During this period animals are not allowed to graze and a rotational grazing system is needed. If regeneration is achieved through tree plantation, it is possible to use tree shelters to enable the grazing animals to remain on the plot.

Other Silvopastoral Systems

Silvopastoral systems such as trees on pasturelands (Fig. 8.1; region II), orchard grazing with fruit and olive trees (region VIII) or grazing during the early stages of regular plantations with poplars (regions IV and V) are nowadays very rarely seen in the Northeast of the Iberian Peninsula. However, there are prospects for future grazing in the new quality-timber plantations being promoted in the region with mainly nut (*Juglans* spp.) and cherry trees (*Prunus avium* L.), or in holm oak plantations for truffle production. Some research in this regard is being carried out by the Forest Technological Centre of Catalonia. Preliminary results highlight the importance of good tree provenances, the need for heavy and early pruning to obtain good quality timber and the necessity of finding cost-effective tree shelters (CPF 2007).

A Way to the Future: Multifunctional Role of Silvopastoral Systems

Mediterranean silvopastoral systems are characterized by their multipurpose nature, which includes 'direct-use values' like food, wood and other secondary products with a market price along with other goods and services that are non-marketable and whose benefits are felt both by other species and society as a whole (Fabbio et al. 2003).

The main objective of stockbreeders is to produce food and related primary products, such as wool or raw animal skins, with a market value. Likewise, the primary aim of the forester is to produce wood, pine kernels or cork. In terms of strict competitiveness, the future of European Mediterranean agroforestry lies in value-added products such as organic and or specific regionally labelled foods. In recent decades, the interest of European consumers in healthy food and environmentally sensitive farming has been increasing. Food quality and security are two priorities of the European Union (Regulation 178/2002/EC of 28 January 2002) and, in the coming years, financial support for organic farming and other quality productive systems is expected to increase. Silvopastoral systems easily suit organic production standards and might represent a solution to the shortage of organic forages in specific regions.

At the same time, the risk of fire and the loss of both landscapes and species diversity are the two main environmental concerns in southern European countries. The new Common Agricultural Policy (CAP) reform (approved in Luxembourg in 2003) focuses on maintaining and increasing the sustainability and multifunctionality of rural areas. The new European Financial Frame (2007–2013; Regulation n° 1698/2005/CE of 20 September 2005) provides financial tools and agrienvironmental measures addressed to healthy food and nature conservation; it may offer E.U. Member States an opportunity to implement silvopastoralism as an economically viable system with added values in fire prevention and biodiversity conservation. In line with this, the Environment and Agriculture Departments of the Catalan Autonomous Government are preparing a set of agrienvironment measures to be implemented in the frame of this new European Financial Program (2007–2013).

In the following sections, we analyse the future role of extensive silvopastoral grazing in fire prevention and nature conservation, focusing especially on certain key considerations which could be better implemented through agrienvironment measures.

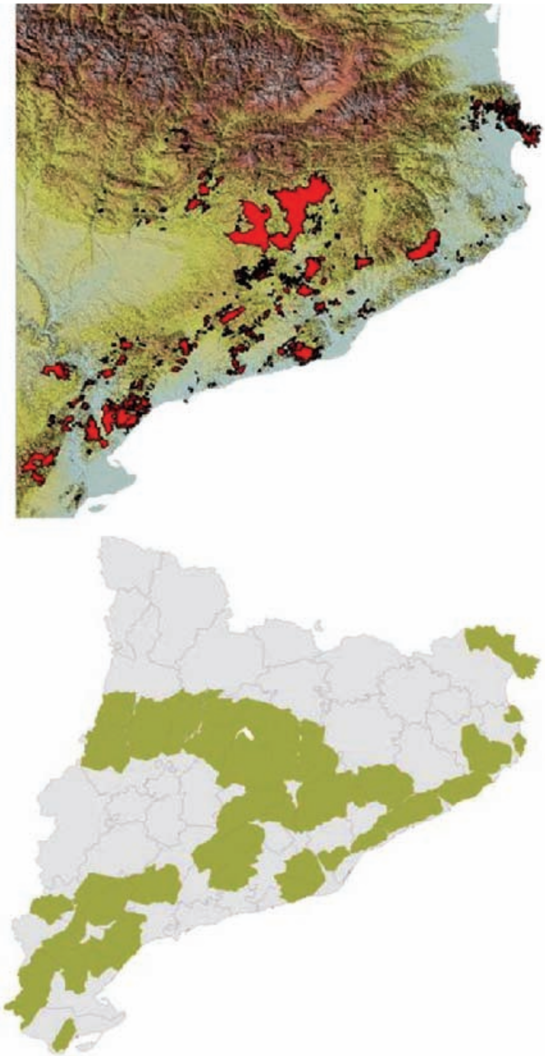
Forest Grazing as a Tool for Fuel Load Control

In spite of increased fire suppression efforts during the last decades, forest fire risk is still one of the greatest threats to the Mediterranean forests in the Northeastern Iberian Peninsula. The concept of fighting against large forest wildfires has for years been shifting from fire extinction *per se* to a preventive silviculture aimed at modifying and reinforcing stand structure and reducing fuel loads (Vélez 1990). Likewise, the drafts of the new Spanish and Catalan instruments for fire fighting emphasize the importance of fire prevention *versus* fire extinction (Plana et al. 2005a). Thus, the new Forest Policy General Planning (2007–2014; Catalonian Government) defines more than 40 tools for fire risk management. Worthy of note here is the role that this proposal confers on agroforestry and, especially, on silvopastoralism as a tool for fire risk prevention (Plana et al. 2005a, b).

Fire prevention strategies are focused on the location, characterization and implementation of key areas. Thus, using computer simulations and analysis of historical records, the territory is classified into fire risk levels based on the most likely behaviour of a large fire for each forest massif (Fig. 8.2a; Martínez et al. 2005). In these key areas, among other requisites, forest fuel must be reduced and controlled so that fire fighters can directly and successfully fight a fire in relatively safe conditions (Plana et al. 2005b). In addition, in Catalonia, a net of Priority Protection Perimeters (PPP) has been designed and is slowly being implemented (Fig. 8.2b). Its objective is to link already existing discontinuities (mainly agricultural fields, grasslands and riparian forests) with other forest areas with reduced understorey biomass and tree density (around 200 stems per hectare) to obtain a wooded pasture.

Suitability of Forest Grazing as a Fire Prevention Tool

The effectiveness of herbivore grazing as a means of maintaining fuelbreak biomass under a critical threshold for fire prevention purposes has been widely demonstrated in different experiments throughout the Mediterranean basin (Etienne et al. 1990; Pardini et al. 1993). But the widespread feasibility of this practice must be studied in relation to the possibilities for integrating the existing farm management strategies of a given region into a Fire Prevention Plan. In this regard, a study carried out in the Pre-Pyrenean area (Baiges 1999) concluded that cattle grazing was the most suitable extensive livestock farming practice for maintaining fuelbreaks in the area. Other practical experiences from drier regions have also found sheep and goat farming suitable for this purpose. For example, in the Montsec massif, 170 ha of holm oak forest, forage grasses and cereal crop residues were grazed by a flock of 800 sheep under rotational management for 12 months. Plots included both forest under a fuelbreak treatment and forage grasses. When no forage crops were available, animals were given a supplement of 250 g of barley per day or were allowed to graze on cereal stubbles. Stocking rate in the fuelbreak forests was about 0.3–0.5 LU



a

b

Fig. 8.2 Large fires occurred in the NE of Iberian Peninsula (Cataluña region) in the last years (a) and Priority Protection Perimeters designed to implement preventive silviculture against fire (b) (b: Departament de Medi Ambient i habitatge, Generalitat de Catalunya, http:/www. mediambient.gencat.net/cat/el_departament/cartografia; a: Direcció General d'Emergències i Seguretat Civil-GRAF, Generalitat de Catalunya)

ha^{-1} year^{-1}. After one year an efficient control of understory biomass was observed. The understory was dominated by *Q. coccifera* L. and *Rosmarinus officinalis* L. bushes which were an important part of the animals' diet, especially in summer (unpublished data). In the Littoral ranges, a 500 ha fuelbreak network in a *P. halepensis* forest was maintained by using 410 goats (0.1 LU ha^{-1} year^{-1}). After mechanical clearing the understorey dominated by garrigue (*Q. coccifera* and *Ulex* *parviflorus* Pourr.) was kept under a height of 30 cm for 4 years. Feed supplement, based on olive leaves and almond subproducts, was only occasionally provided.

Thus, there is evidence that forest grazing can be used for fire prevention purposes with no significant changes in traditional management practices. Nevertheless, there are cases in which the low nutritional value of the understory biomass does not allow the profitability levels required in the meat-production sector (i.e., two lambs per year). Then, alternatives aimed at the production of added value products (i.e., ecological milk, cheese and meat) or the re-introduction of more rustic autochthonous races (preventing, in turn, their extinction) must be explored. A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of the possibilities of integrating forest grazing in a Fire Prevention Plan shows that the main constraints are related to socio-economic issues such as the need for the creation of agrienvironment measures of compensation and the resolution of potential conflicts (Tables 8.6 and 8.7; Baiges 1999).

Table 8.6 SWOT analysis framework for the integration of extensive livestock farming in a Fire Prevention Plan (Baiges 1999)

Opportunities	*Threats*
+ Good acceptance by farmers	– Insecurity regarding EU subsidies
+ Future EU subsidies for preventive silviculture	– Ageing in rural population and insecurity about continuity
	– Potential conflicts
	– Legal gap for works carried out on private property
Strengths	*Weaknesses*
+ Proved efficiency in reducing understorey biomass	– High dependence on EU subsidies
+ Management strategies compatible with FPP	– Requires complementary methods for bushes/ dead fuel
	– Costs of fences

Table 8.7 Requirements identified by local farmers for their participation in the maintenance of strategic areas; based on the proportion of affirmative answers with respect to the total number of interviews (Baiges 1999)

	Requirements	Percentage of farmers (%)
	Technical	
1	Availability of sufficient and well-localised water points	50
2	Availability of nearby field areas	42
3	Forest with high quantity and high quality understorey biomass	33
4	Good access conditions (possible tracks)	25
5	Grazing area already fenced in, with access to roads impeded	17
6	Available grazing area should be able to maintain a minimum number of animals (20 heads of cattle) for a minimum period of time (4 months)	17
	Economic	
1	It should not impose an extra effort or expense for the farmer	67
2	Existence of compensation measures in case infrastructure is needed (fences, supplementary feeding, water points…)	42
3	Costs of hiring land or animal transport subsidised	25

In relation to the economic viability of forest grazing as compared to other possible methods for maintaining understory biomass under a critical threshold, forest grazing is seen as the best cost-effective treatment, in spite of the fact that it requires certain investments (water supplies, fences, forage supplementation) and must be combined with another method. Thus, using a combination of manual and mechanical treatments, the calculated cost for maintaining key areas is 200–300 € ha^{-1} per year, with a return interval of 3-to-5 years and a manual-to-mechanical ratio of 2/3. In contrast, the approximate cost of grazing ranged from about 6–30 € ha^{-1} per year depending on animal type and management system adopted (Table 8.4). The cost of complementary manual or mechanical treatments must be added to this grazing cost. Another forest fuel reduction technique, prescribed fires, also has a low implementation cost (600–1,000 € ha^{-1}; Larrañaga et al. 2005) and has proved to be suitable in some cases; however, it cannot be used repeatedly without jeopardizing the nitrogen fertility of the ecosystem (Casals et al. 2004).

Agrienvironment Measures for the Promotion of Forest Grazing as a Fire Prevention Tool: Key Considerations

To formulate agrienvironment measures that promote forest grazing for fire prevention, the following considerations must be taken into account:

Objective of the Agrienvironment Measure. The objective of preventive silviculture is to reduce fuel biomass to sub-critical levels, thus maintaining the potential fireline intensity within the limits of the capacities of fire extinction through the years. Grazing is ideal to obtain a low herb biomass and to control shrub spread, although a regular mechanical shrub clearing is generally necessary every few years. Thus, agrienvironment measures must focus on the objective (whether biomass reduction has been achieved or not) more than on the mechanism utilised (grazing or mechanical clearing).

Fuel Load Threshold. The effect of herbs and shrub fuels on fireline intensity is not easily predicted (Agee et al. 2000). A grassy cover may decrease fireline intensity but increase the rate of spread. No single, definitive threshold for the amount of fuel reduction is likely to exist. In the south of France, the maintenance standards for surface fuel loads are about 2,500 m^3 ha^{-1} (Masson 2002).

Available Grazing Area. Besides controlling fuel loads, it is also necessary to provide sufficient accessible forage resources for the herd at any given moment. In this regard, Baiges (1999) determined that for the pre-Pyrenean region: the available grazing area must be larger than the fuelbreak area, allowing the use of cereal crop residues. An alveolar shape is better than a linear one, based on animal behaviour requirements; and enhancing the grazing capacity of these areas through oversowing might be needed.

Grazing Management. The management strategy must be rotational to allow instant high stocking rates to control fuel biomass. It is extremely difficult to establish an ideal stocking rate due to the variability in both the forest grazing resources and the animals used. Grazing must be undertaken before summer to ensure that the fuel load is reduced prior to the most risky period. Accessible water points need to be assured within a suggested area of about 60–70 ha for cattle or at distances of no more than 7–10 km for sheep or goats.

Social Participation. To address agrienvironment measures with efficacy the agricultural, forestry and environmental sectors must be considered and involved in the decision process (Baiges 1999). A good diagnosis of the existing farming practices in the region is also needed to design the best strategy of integration into a fire prevention plan. The option of hiring a shepherd in case there does not exist any farm in the area, is possible though not advisable regarding past experiences in neighbouring areas.

Provision of compensation. In a unit involving private land and animal tenure, it is important to establish who bears the costs as usually the farmer and the forest owner are not the same person. To consider this issue, it is necessary to clearly identify winners/losers and potential disputes or illegalities so that appropriate compensation strategies can be provided when necessary.

Rural development issues. The use of forest grazing with fire prevention purposes relies in the fact that farmers are maintained in the territory. Forest grazing maintenance, whether it is connected to fire prevention or not, cannot be understood unless it is framed under rural development issues. This idea has been long claimed by many local farmers who demand as the real fire prevention strategy a whole change in the agricultural and forestry policy. This, on the other hand is highly reasonable, as rural absenteeism has been identified as the primary cause of forest fire.

Silvopastoralism as a Tool for Biodiversity Conservation

Vegetation changes induced by land use changes in recent decades could be affecting biodiversity and ecosystem functioning, modifying the conservation value and the regulation of environmental services that might be obtained from the managed system (Lavorel 1999). As a result of these threats, landscapes, plant communities and their related fauna are being increasingly revalued and subjected to nature conservation strategies.

Strategies for Biodiversity Conservation

Natura 2000 sites are a network of areas across the European Community selected for the purpose of conserving natural habitats and species of plants and animals which are rare, endangered or vulnerable. The Natura 2000 network emanated from the two European Council Directives on Birds (79/409/CEE of 2 April 1979) and Habitats (92/43/CE of 21 May 1992) and their modification by Directive 97/62/CE of 27 October 1997. Both Directives impose certain obligations on Member states regarding the protection of habitats and species and the management of the sites that support them. Although the role of herbivores in controlling species richness and diversity is a critical issue (Olff and Ritchie 1998), in some circumstances silvopastoralism may contribute to the management of ecosystems in terms of their biological conservation. In this context, the following sections will focus on the consequences of grazing regime changes on both plant biodiversity and bird conservation on steppe-land.

Consequences of Changing Grazing Regimes on Plant Biodiversity

In the hills and mountains of Mediterranean countries, most pasture systems are sub-climax communities and thus require periodic defoliation to control succession, otherwise they tend to succeed into scrubland and, ultimately, woodland. In different climatic conditions of the Northeast of the Iberian Peninsula, ranging from semi-arid to alpine climates, for example, abandonment of sheep grazing appears to favour the colonization and growth of shrubs and trees (de Bello et al. 2005). The consequences of these successional changes on species diversity have often been based on anecdotal evidence (Rook et al. 2004). It is, however, generally recognized that grazing has been present in these ecosystems for centuries, thus, current species and vegetation types have evolved to cope with this disturbance factor.

In general, the effects of grazing practices on plant diversity are different under different climatic conditions (Milchunas et al. 1988). Similarly, in arid environments in Northeast Spain, vegetation is normally clumped in patches that can be separated by bare soil. In this vegetation excess grazing pressure normally increases the proportion of bare ground, with consequent risks for erosion (de Bello et al. 2007). At the same time, however, the increase of bare soil caused by grazing in arid areas may also increase the patchiness and thus the spatial heterogeneity of the species, ultimately increasing the number of species at higher spatial scales (de Bello et al. 2007). This implies that a moderate grazing pressure in arid regions might both avoid the risk of erosion and maintain sufficient habitat heterogeneity to preserve the traditional species in the region. In more humid regions, on the other hand, the grazing pressure can be higher than in more arid ones as there are less risks of erosion and more productive conditions can support faster vegetation regrowth (de Bello et al. 2006, 2007). Thus the maintenance of rational grazing practices can be a tool to conserve the traditional plant diversity of these systems (Perevolotsky and Seligman 1998).

The Role of Extensive Grazing on Animal Biodiversity: The Case of Steppe-Land Bird Conservation

In the Northeast of the Iberian Peninsula, under a semi-arid climate, the landscape is a mosaic dominated by non-irrigated cereal or fruit-tree crops and natural Mediterranean low, soft-leaved scrublands (*tomillares*). In the past, these communities together with stubbles and fallows were used by transhumant flocks as winter grazing areas (Montserrat and Fillat 1994), and they were also used as a source of fuel biomass for domestic fires. Nowadays, these areas are still used for sheepherding, aromatic and medicinal plant harvest, apiculture production and hunting. Extensive sheep grazing systems combine the exploitation of these scrub patches resources with fallows and stubbles.

The pseudo-steppes of the Iberian Peninsula hold a significant percentage of the European populations of steppic bird species (Burdfield 2005), and the scrub-steppe patches and fallows found in Catalonia are essential habitats for these threatened bird species (Mañosa et al. 1996; Mañosa and Bota 2006).

In the arid part of the Northeastern Iberian Peninsula, grazing activities have also suffered abandonment during recent decades, increasing the plant cover of scrub communities and, therefore, reducing the habitat suitable for steppic-birds (Bota et al. 2004; Estrada et al. 2004; de Juana et al. 2005). One paradigmatic example of the role of grazing in bird conservation is the extinction of the unique Catalonian Dupont's Lark population. This tiny population was confined to a 100 ha scrub-land dominated by *Thymus vulgaris* L. and *Sideritis scordioides* subsp. *cavanillesii* (Lag.) Nyman. The abandonment of sheep grazing has been highlighted as one of the most important factors in this bird's population decline, owing to increases in the herbaceous cover and changes in plant composition (Bota et al. 2004; Mañosa and Bota 2006).

The only way to maintain viable populations of most of these bird species is to create an appropriate network of Special Protection Areas (SPA), which would protect the best remaining sites and implement successful agrienvironment measures targeted to the ecological requirements of the species. SPA are expected to be managed primarily for bird conservation within the context of sustainable extensive agricultural and livestock production. The promotion of management practices leading to scrublands and fallows with different structural characteristics will benefit steppe-land bird populations. In this context, sheep grazing is seen as a useful management tool for bird conservation.

Promotion and planning of different stocking rates should be carried out at the local scale and with clear objectives that adequately address the conservation of focal species. Nevertheless, more research is needed to adapt stocking rates to the different scenarios and ecological requirements of steppe-land birds.

Environmental Measures for Biodiversity Conservation: Key Considerations

To formulate agrienvironment measures for biodiversity conservation it is necessary to take into account the following considerations:

Objective of the Agrienvironment Measures. In contrast to measures aimed at fuel load control, it is difficult to test the effects of grazing implementation in terms of the conservation of a specific species. Thus, the objective of these measures must be related to the achievement of a specific vegetation structure or the reduction of direct impacts derived from grazing. In theory, it should be possible to manage on the basis of specific prescriptions for each species or group of species. In practice, and nowadays, this would be complicated not only because of the difficulty of flock management but also because of the lack of specific information on the stocking rates needed to achieve the structural vegetation objectives.

Stocking Rate. Most ground-nesting birds benefit from some grazing as it provides the required vegetation structure; however, at high or low stocking levels, this structure could be unsuitable. Precise stocking rates should be given on the basis of conservation objectives.

Grazing Timing. To reduce the dominance of a particular plant species, grazing is likely to be most successful if carried out during the period of maximum growth, when a smaller proportion of the plant's resources are stored underground. However, to reduce the proportion of nests trampled, grazing should be restricted during the breeding period in highly sensitive areas.

Implementation Cost. Any agrienvironment measure must support the costs both of shepherds' wages and of the infrastructure needed to implement grazing for biodiversity conservation. In areas of high conservation concern, grazing should be regarded more as a conservation tool than as a productive activity. Considering a standard flock of 400 sheep and goats grazing at a 0.1 LU ha^{-1} $year^{-1}$ stocking density, a shepherd's wage might range from 25 to 40 € ha^{-1} per year (Table 8.4). In addition, because of the patchiness of many steppe bird areas immersed in agricultural land, transport costs may need to be considered if many sites are grazed by the same flock. Herds may require supplementary feeding and water.

Final Remarks

In parallel to the application of new agrienvironmental measures it is necessary to increase knowledge of technical and socio-economic issues through management-scale studies. A major hindrance is that management experiences are rarely quantified, documented and disseminated. Practically all management activities should be followed by well-documented monitoring in order to obtain a set of guidelines on sustainable practices. This may range from a detailed analysis to a subjective view. It is necessary to identify and evaluate agroecological and economic indicators of the thresholds for sustainable forest grazing. For further progress, a more in-depth cost-benefit analysis of agrosilvopastoral systems could be the basis for the social recognition of the non-profit values of Mediterranean agroforestry.

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Chapter 9
Agroforestry Systems in Southeastern Spain

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Abstract Two types of agroforestry systems can be found within the Segura river basin: (a) silvopastoral systems (forest-pasture-ruminants) on cold and moist mountain zones (1,000–2,000 m); – occupying 20% of the basin, where the Segura river originates and the major proportion of protected forest is concentrated – but where human presence is insignificant (1%) – livestock activity is scarce (11.6% of the census), and (b) agrosilvopasture systems (sheep-cereal-rangeland), on dry and cold high tableland (500–1,000 m altitude); occupying 40% of the basin; sustaining half of the ruminants; where half of the land is cultivated under dryland agriculture and sustains a high biodiversity, its human population is scarce (16% of total basin); the economic situation is marginal and; soil erosion losses are high (40% of total). In the other 40% of the basin (lower coastal areas), true agroforestry systems do not exist because livestock is fed with forage by-products from agriculture and concentrates, maintaining high stocking densities, exceeding the capacity of the natural resources. Altogether, agroforestry systems occupy 60% of the basin territory and maintain 62% of the livestock population, but only 17% of the human population, who live under a marginal economic situation and depend on external assistance to maintain their economic activity and to protect the water, forest and biodiversity resources of the basin.

Keywords Segura river basin, agrosilvopasture, land use, desertification

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Introduction

The study area is the Segura river basin, a representative natural unit in the southeast of the Spanish Peninsula, with an area of 18,840 km^2 (3.7% of Spain), and affecting four self governing regions: Murcia, Castile-La Mancha (province of Albacete) Andalusia (provinces of Almería, Jaén, Granada) and Valencia (province of Alicante) (MMA 1997). This diversity makes overall management of the area difficult.

The Segura river basin is the most deficient basin in water resources in Spain with an annual demand of 1,760 hm^3, and only 860 hm^3 renewable. The difference is made up by 540 hm^3 transferred from the Tajo river basin, 210 hm^3 from non-renewable subterranean water and the rest from recycled water. Higher consumption of water for irrigated agriculture, (89% of the total water demand) followed by the urban population of the basin (3.9% of the total Spanish population consuming 10% of the water) and by industry (only 1%). The basin is currently in a fragile equilibrium. In some areas this means there is overexploitation and unsustainable activities, and in others it is the opposite, human desertification and loss of agro forestry activity. The present chapter will deal with the main types of agroforestry systems, environmental issues related to land management (biodiversity, desertification, and fire risk), socioeconomic changes, the future and potential improvements. In the past, agroforestry systems were an important land use and economic activity in the higher and moister areas of the basin. Currently, however, it is now a marginal activity which is less important due to the intensification of agricultural activities in the drier but climatically milder lower plateaus and coastal areas. This has attracted away a large part of the population from the higher and middle basin areas. The future of agroforestry systems in the Segura basin will probably be linked to the preservation of water and biodiversity resources, and to the re-establishment of organic, sustainable agroforestry systems. These issues will be discussed in this paper.

Physical Geography, Topography and Climate

Around a 60% of the Segura river basin is situated in the Region of Murcia (11,150 km^2), 25% in the Province of Albacete (4,713 km^2), 9% in the Andalusia provinces of Almeria, Jaén and Granada and 7% in the Province of Alicante (Fig. 9.1).

The orography of the territory is very complex, with abundant mountain ranges aligned in a SW-NE direction, between which alternate deep valleys, plateaus and plains that spread towards the coast. Forty percent of the basin surface is below 500 m asl, being 81% below 1,000 m asl. The mountain ranges that occupy the largest part of the NW basin often exceed 1,000 m altitude and reach maximum heights over 2,000 m. The plateaus, with altitudes between 500–1,000 m, occupy large parts of the central basin, having a smooth topography and pronounced slopes on the edges. Around 32%

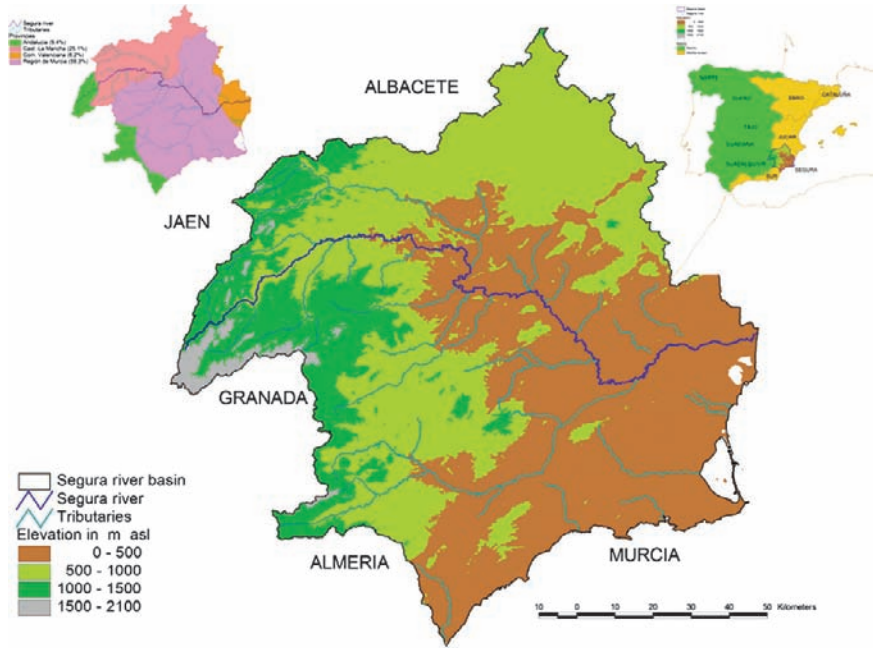

Fig. 9.1 The Segura river basin. Tributaries, ravines, altimetry and administrative provinces included in the basin. The small maps show the localization of the Segura basin in Spain and the Spanish region's territories included in the basin (MMA 1997; IGN 2000)

of the basin territory has a mean slope of less than 5% (coastal plateaus and tablelands), 42% of the basin has a mean slope between 5–20% (hedges and rangelands of the central basin), between 20–50% (the upland areas) close to 22% of the total basin and around 4% of the basin has a mean slope over 50% (high mountains).

The mean annual rainfall in the basin is around 400 mm, but the rainfall regime is very irregular. There are large spatial differences between the highest zones of the basin, where rainfall means exceed 1,000 mm year^{-1} and the lower coastal areas, where mean rainfall is around 300 mm year^{-1} and even lower (Fig. 9.2). The basin receives an annual mean water input of 7,000 hm^3 (equivalent to 370 mm m^{-2}); however, drought years are frequent, and agroforestry systems suffer shortages up to 50% of the time. The pastures of the Segura basin show a clear seasonality, determined by the distribution of the humid and dry periods, and by interruptions to vegetative growth during the winter freezing periods.

Torrential rains are frequent, especially at lower altitudes close to the sea, where rainfall intensities of 100 mm day^{-1} are usual, causing sudden and severe floods.

The lowest temperatures of the basin are found in the northwest mountain ranges, such as the Segura Range, where the mean annual isotherm is 10°C.

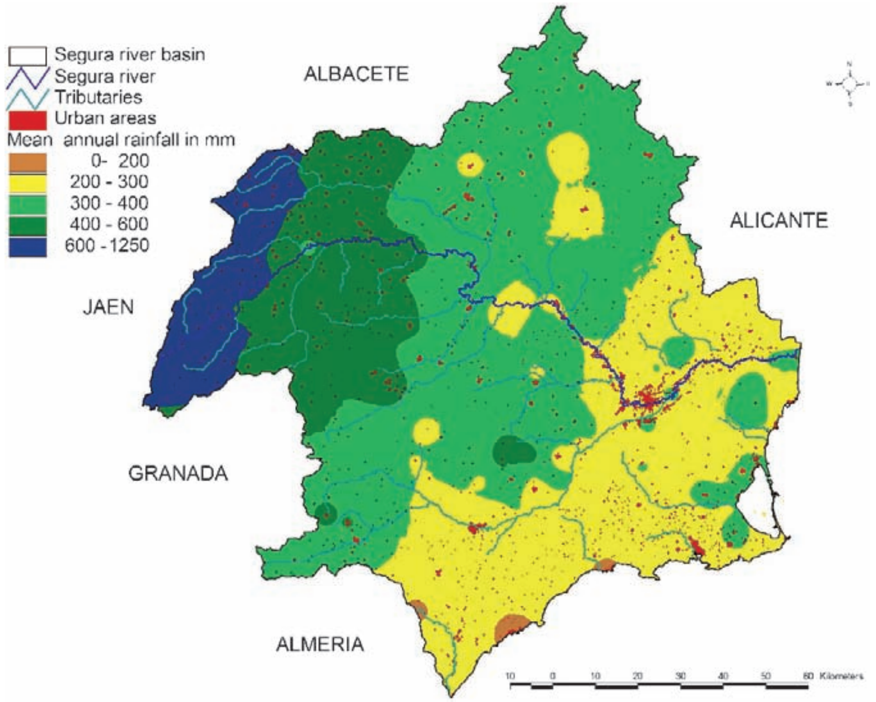

Fig. 9.2 Mean precipitation in the Segura basin (IMN 1961–1990)

Descending towards the coast the temperatures increase, reaching annual means of 18°C in the coastal areas (Table 9.1).

Land Use

Land use in the Segura basin, can be separated into forest and rangeland on one hand and croplands on the other. Rangelands include uncultivated grasslands, shrublands or forested lands with an herbaceous and/or shrubby understory. Agroforestry systems, that is to say the integration of trees and crops, can be found in both types mainly as silvopasture, agrosilvopasture and orchards.

Forest and Rangelands

Almost half (49.5%) of the basin consists of mountain zones and rangelands, occupied by forest species, shrubland and pastureland. The other half is cultivated and the rest (2.5%) is unproductive land (Fig. 9.3). The main forest cover is extensive

Table 9.1 Segura river basin environments: climatic characteristics, population distribution, livestock, and soil erosion, and main types of climax vegetation and agroforestry systems

Segura river basin environments	Cold and moist mountain zone	Dry and cold tablelands and rangelands	Dry and warm lower plateaus and coastal areas
% Basin	20	40	40
Altitude (m)	1,000–2,000	500–1,000	0–500
Pluviometry (mm)	600–1,000	400–600	200–400
Mean annual temper-ature (˚C)	10–12	12–16	16–18
% Population	1.2	16.0	82.8
% Livestock census	11.6	50.6	37.8
%Soil erosion losses	13	40	47
Main types of climax vegetation	1. Deciduous and evegreen oak forest 2. Pine-juniper open forest	1. Evergreen oak woodland 2. Pine open forest	Evergreen sclerophyllous matorral
Main types of agroforestry systems	1. Silvopasture 2. Forest farming 3. Riparian forest farming	1. Agrosilvo pasture 2. Fodder trees?	Fodder trees

pastures covered by trees (27% of the basin; 513,000 ha). Almost three quarters (73%) of the forest has more than 20% tree cover (373,000 ha), and the rest has a 5–20% tree cover (139,000 ha). Pastures with a shrub cover occupy 22.5% of the basin (513,000 ha). Natural, climax vegetation only covers 1% of the surface, giving an idea of what the final vegetation cover might be if man had not had such a huge influence on the original landscape.

In the vegetation of southeast Spain, woody species are dominant and herbaceous species are rare, except in the high mountain zones where pastures are more developed. Because of that, browsing of woody species is an important component of domestic and wild herbivorous diets. The original *Quercus* forest was transformed through long series of alternative burning and grazing episodes, into a continuous layer of leafy stems of high pastoral value. This woody fodder layer, dominated by species of the genus *Quercus, Pistacia*, *Phillyrea*, *Arbutus*, *Rhammus*, *Juniperus*, etc.(Quezel 1981), is known in different Mediterranean languages as 'mancha', 'sarda', 'machia', 'maquis' or 'matorral'.

Croplands

Croplands occupy 48% of the basin (908,000 ha), and about one quarter of the cropland is under irrigation (13% of the whole basin) occupying the valleys of

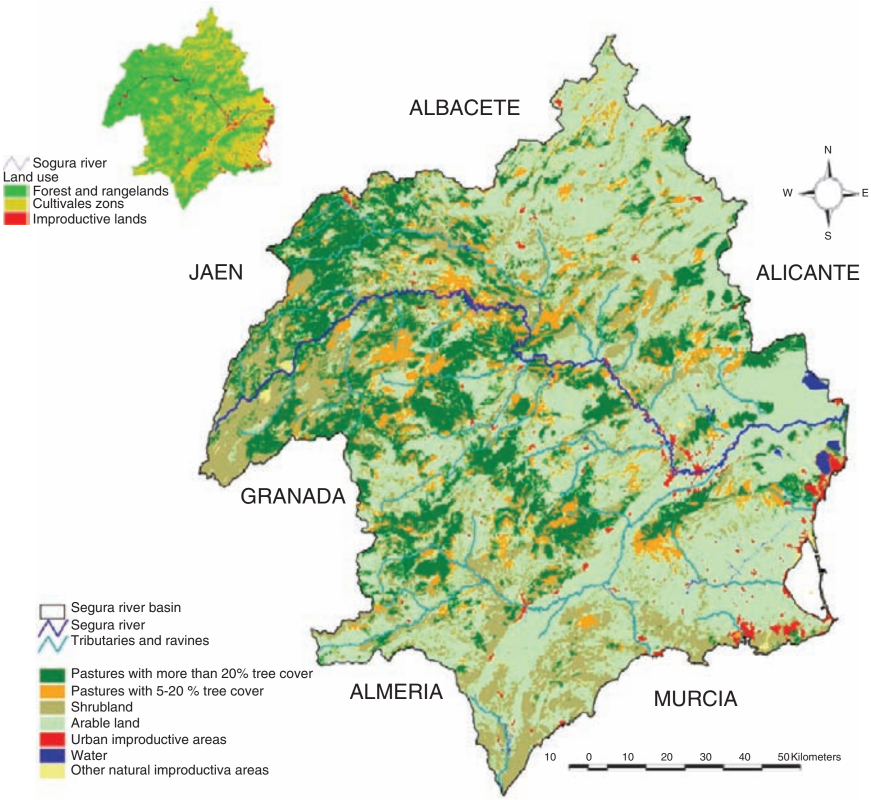

Fig. 9.3 Pasture resources in forest, rangelands and cultivated areas of the Segura basin (MMA 2000a)

the Segura river and its tributaries(Mundo, Quipar, Argos, Mula and Guadalentín) and the Cartagena coastal plain. The most widespread crops in the dryland areas are cereals but there are also some tree crops such as almond trees, vineyards and olives. In irrigated areas horticultural crops and citrus trees are more important.

Biodiversity Resources

The Segura basin has serious environment problems, such as the preservation of its biodiversity, desertification and a high risk of erosion.

It is one of the most biodiverse areas of the Iberian Peninsula despite its small size. The mixing of murcian-almeriense, andalusian, manchego, valencian and even north African elements, has been the basis of this high biodiversity (more than 3,000 plant taxa) (Valle et al. 1989; Pajarón and Escudero 1993; Alcaraz et al. 2000).

The agroforestry systems host the greatest biodiversity because the presence of mosaics creates numerous ecological niches and ecotones. Even the weed communities linked to soil cropping and dryland crops are very diverse. The shrub and pasture communities are particularly rich in species (genus *Teucrium*, *Thymus*, *Sideritis*, *Helianthemum*, etc.) especially in the semi-arid lower areas and in mountainous areas, where there are high levels of endemism.

Climatic stress and grazing pressure have had an important effect on the composition of many vegetation communities. They have led to frequent anti-nutritional adaptations which can be physical (thorns, inedible fibres, etc.) or chemical (poisons, rubbers, resins, etc.) all of which largely reduce their palatability (Ríos et al. 1989, 1991; Robledo et al. 1989).

New information on the faunal diversity is being added continuously, and invertebrate species new to the area are discovered annually. Man has had a long history of involvement in the region and there have been sudden historical changes and events during the Middle Ages when the basin area was a frontier border. This has resulted in the complete loss of large predators like the bear, wolf, lynx, etc. and the reduction to near extinction of many birds of prey during the 17th to 19th centuries (García-Abril et al. 1989). At present, the end of the trophic chain is occupied by man as hunter. Currently, some large herbivores such as indigenous wild goats and introduced species such as "arruí" Atlas goats (*Ammotragus lervia* Pallas) and mouflón wild sheep (*Ovis aries* L.) from Corsica are increasing in number to an extent that they pose a threat to the ecosystem.

The Segura basin is an important refuge for birds of prey such as the golden eagle (*Aquila chrysaetos* L.), partridge's eagle (*Hieraaetus fasciatus* Gmelin), booted eagle (*Hieraaetus pennatus* Gmelin), snake's eagle (*Circaetus gallicus* Gmelin), northern goshawk (*Accipiter gentiles* L.), owl (*Bubo bubo* L.), etc. Many steppe birds such as black-bellied sandgrouse (*Pterocles orientalis* L.), stone curlew (*Burhinus oedicnemus* L.), warblers (*Sylvia* spp.), trumpeter finch (*Bucanetes githagineus* Lichtenstein), Dupont lark (*Chersophilus duponti* Vieillot), etc. use the basin for nesting or overwintering. There are interesting species of vertebrates like amphibians and reptiles such as the Iberian midwife toad (*Alytes dickhilleni* Arntzen and García-Paris) or the dappled tortoise (*Testudo graeca* L.).

Approximately 29% of the basin (547,000 ha) is protected by the Natura 2000 Network (MMA 2000b) (Areas of Communal Interest – LICs – and Zones of Special Protection for Birds – ZEPA) under EU supervision, or by other designations like Regional Park, Ramsar Convention sites, etc. Nearly half of the protected area is in the Region of Murcia and the rest is mostly located in the mountainous areas of Albacete, Jaén and Almería, which form the upper part of the basin (Table 9.2).

Table 9.2 Protected territory in the Segura basin in relation to the area of the Segura basin

Provinces	Surface (ha)	% Protected	% Protected in relation to ASB
Murcia	264,437	14.0	48.3
Albacete	159,412	8.4	29.1
Jaén, Almería, Granada	109,707	5.8	20.0
Alicante	14,128	0.7	2.6
Totals	547,684	28.9	100.0
Area of the basin (ASB)	1,893,151		

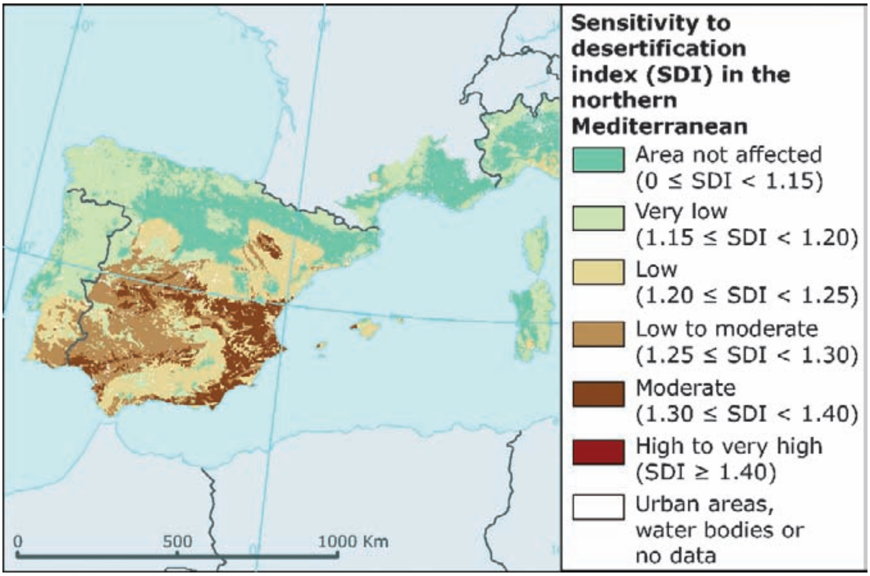

Fig. 9.4 Desertification risks in Spain and in the Segura basin (map copyright EEA, Copenhagen 2005)

Desertification Problems

The Segura basin is in the Northern Mediterranean area with the highest sensitivity to desertification index (SDI) (Fig. 9.4), an index derived from three datasets: vegetation, soil and climate sensitive indexes (EEA 2005).

Two thirds of the territory loses between 5 to 200 t ha^{-1} year^{-1} of soil, but 77% of the basin soil losses, estimated at 46 million tons year^{-1}, occur in a third of the territory.

The soil losses in the basin's reservoirs (mean of 3 t ha^{-1} year^{-1}) produce about 4 million tons of sediment which reduces the water storage capacity by, on average, 3.6 hm^3 year^{-1}. This reduction is equivalent to a 0.5% annual loss in capacity.

In the Region of Murcia, 47% of soil losses occur in coastal areas (between 0–500 m altitude), where torrential rains are more frequent and the vegetation cover is sparse. In the high table lands (500–1,000 m), where dry farming crops such as cereals, almond trees and vineyards predominate, another 40% of soil losses occur. More than 160,000 ha (14% of the surface of Murcia) have an arid terrain with clay-rich soil that has been extensively eroded by water (badlands) and where water erosion processes are very aggressive (López-Bermúdez 1990; MMA 2002).

Fire Risk

Between 1993–2004, around 28,000 ha of forest were burned in a total of 1,600 fires. However, a majority of the burned area (25,700 ha, two thirds covered by trees) was destroyed by one fire in 1994. This fire was accidentally started by a high tension electrical cable falling, followed by strong winds which quickly spread the fire from its initial site.

The abandonment of traditional forestry uses such as charcoal burning, selective felling and forest grazing is producing a denser forest structure more prone to fire and there is a recommendation by fire experts that the woods, pastures and paths need to be cleaned and cleared. During summer months, fire is common in many Spanish territories and it is known that fires are frequently started deliberately; but, this is not the case in south-east Spain.

Population; Social Situation; Rural Development

Most (83%) of the population of the Segura basin (1,587,706 inhabitants in 2000) live in villages, small towns and cities with more than 10,000 inhabitants (urban areas) mostly found in valleys and coastal areas. The other 17% live in small villages located in the mountain areas and hinterland (INE 2000) rural areas (Table 9.3). The population is distributed into 128 municipalities, half of these localised in the lower area of the basin (0–500 m). The territory of the Segura basin is very poorly

Table 9.3 Municipalities and population in the Segura basin by altitude range (INE 2000; IGN, 2000)

Mean altitude range of municipalities (m)	Municipalities		Population		
	Number	%	Number (n°)	%	n° ha^{-1}
<500 m	65	51	1,314,735	82.8	2.1
500–1000 m	39	30	255,742	16.0	0.6
1000–2000 m	24	19	17,229	1.2	0.1
Total number	128	100	1,587,706	100.0	

developed, very agrarian, Mediterranean and marginalised and is classified as an objective area 1 of the EU, where community structural funds can be implemented.

Economic Analysis; Productive Parameters

Around 68% of the forest lands in the Murcia Region are privately owned and the remaining 32% are in public ownership (Region and municipalities), mostly under the control of the City councils (63%). On average, 62% of the income generated from the forest area can be attributed to environmental aspects, 29% from recreational aspects and only 9% from productive aspects (CHS 1997). Less than 18% of the forest area has significant timber production because most of the trees in the basin (Aleppo pine) have no commercial value.

Sheep breeding, in general, is not profitable, even with the support of subsidies from the EU. For example, a sheep producer in the middle zone of NW Murcia (average of 265 sheep per flock) would need 50 euros per head more on top of the current subsidy of 31 euros per sheep to break even, while in the lower area of the basin (Cartagena plain), for example, where flocks are larger (400 sheep per flock), they only need a subsidy of 34 euros per sheep to break even (García et al. 2005).

Goat breeding is more profitable, particularly on goat farms that have invested to produce high quality cheese – the "Queso de Murcia al vino". This is a creamy cheese that is washed with the strong local red wine, providing a stark contrast between the white cheese and the crimson rind.

Goats have a unique ability to convert the poor quality grazing in such tough, arid landscapes into rich milk and meat. They have a highly developed sense of sight, smell, and taste and a very discerning palate. They will often eschew easily accessible fodder on the ground in favour of tender young shoots on trees which they must stand on their hind legs to reach.

We think the future of sheep farming relies on increasing the size of farms and flocks, and in the promotion of differentiated quality products. The agrarian policy of the EU grant environmental subsidies to maintain the landscape, enhances the biodiversity, reduces the risks of fires, etc. and for food production to conform to rigorous quality and welfare standards. Examples are organic livestock farming and subsidies linked to productive systems. Together these could justify an increase in subsidies for extensive livestock if they are bound to the preservation of rural life and environment in this marginal basin territory.

Biodiversity, Desertification, Sustainability

The high zone of the basin occupies 20% of the territory and contains a high biodiversity, but its population (1% of the total) and livestock activity (12% of the total) is very low. This scenario could favour a the future of this zone as a silvopastoral area, managed by a low number of people, who have the responsibility to shepherd livestock and manage seasonal grazing, plus achieving the general objectives of preserving the landscape, biodiversity and water resources.

The middle zone of the basin, (40% of the territory), has an intermediate level of biodiversity, a low population (16% of the total), but a high number of livestock (51% of the basin livestock units). Land use is economically marginal agrosilvopastoral systems with an associated risk of permanently overgrazing pasture resources and enhancing desertification processes. Finally, the lower zone of the basin has a relatively high biodiversity, but also the highest human density (83% total), and supports livestock. These result in a heavy pressure on land, vegetation and water resources, making this the zone with the largest desertification risk and one where the sustainability of productive systems is very fragile (Table 9.1).

Agroforestry Systems in the Segura River Basin

Agroforestry practices include not only the integration of the agricultural and tree components on the same land, but also the temporal integration of agricultural and forest land, as is found in the Segura basin.

There are three main types of agroforestry systems in the Segura basin: silvopasture, agrosilvopasture and uses of the forest areas not involving livestock. The system practised varies with the environment of the basin, being mostly extensive in the mountain zones, semi-intensive in tablelands and rangelands and intensive in the lower plateaus and coastal areas. Hence the agroforestry systems present in the Segura basin will be a function of the three environments already described in the introduction (Table 9.1).

High Mountain Zone

In the mountain zone of the Segura basin there are two types of forest: deciduous and evergreen oak forests and pine-juniper open forests. Within these forests, where the environment is moist and cold such as in the Segura and Alcaraz mountain ranges, there are pastures dominated by perennial grasses and spiny cushion plants, forming part of extensive silvopastoral systems. These pastures are used between June and September through the well known system called transhumance.

The main source of fodder for livestock is natural vegetation. Most of the biomass eaten is from browsing trees and shrubs and in open forest spaces, grasses and other forage plants make also a forage contribution. Extensive grazing with local breeds of sheep, goats and cows is practiced during the warm months (spring-summer) and there is seasonal migration in the coldest months (winter) when no supplementary feeding is used. The grazing area, approximately 80,000 ha, 85% rangelands and 15% cultivated land (mainly cereals), is surrounded by olive groves in a hilly countryside**.** Part of the cereal production and pruned olive branches are used for animal feed.

Livestock graze across a gradient of mountain-valley pastures according to seasonal variations of cold-warm and wet-dry regimes: river valleys during spring and autumn, and high altitude pastures ("agostaderos" at >1,500 m) during summer. In winter, livestock migrate to warm valleys or warmer neighbouring areas (e.g. Sierra Morena in Andalusia), and finally in spring, livestock return to the mountain ranges of the Segura basin. The whole process is supported by old grazing infrastructure facilities such as drinking troughs made with tree logs ('tornajos') or stones and cement ('abrevaderos'), livestock transit tracks ('cañadas') and shelters.

Local livestock breeds are used for meat production: Segureña sheep, White Celtibérica and Black Serrana goats, and cows similar to the Retinta and Avileña breeds of the western and central Spanish mountain areas. The "red" meat produced has high quality but it is bought and marketed by people from other areas. There are about 160,000 sheep and goats distributed in 15 villages and 3 provinces. Flocks of 100–200 sheep are common, but 500 ewes per shepherd are needed to make a living. The shepherds are the owners of the flocks

Around 80% of the forest pastures are communal and 20% private but the latter are also rented for grazing. Trees, mainly *Pinus nigra* subsp. *clusiana* and *Pinus pinaster* Aiton, are managed for timber production.

There is a seasonal and spatial pasture growth heterogeneity related to altitude(1,200–2,500 m,) and orientation (sunny southern slopes versus northern more shadowy slopes). Summer pastures are communally grazed in management units of 1,000–2,000 sheep and 300 cows, managed by local shepherds following a three months rotation. This involves flocks grazing freely during part of the time and when livestock has to be moved to a new grazing area, shepherds get together and, using horses and dogs to control livestock, move them to the new pastures.

The high Mediterranean mountains (e.g. Segura and Alcaraz Mountains with a maximum of 2,500 m in La Sagra peak) have been grazed for millennia. Formerly, the forests in these areas were dominated by oak trees forming woods of *Quercus ilex* L. subsp. *ballota* (Desf.) Samp. ('encinares'), *Quercus faginea* Lam. subsp. *faginea* ('quejigares'), and *Quercus pyrenaica* Wild. ('melojares'), as well as copses of *Corylus, Ulmus, Acer, Taxus* and *Ilex* in shaded and humid areas, and of *Sorbus aria* (L.) Crantzand *Amelanchier ovalis* Medicus ('mostajos') on the peaks and highest areas. However, nowadays forest covers a very limited surface area, being replaced by open copses of spiny shrubs ('espinares'), not higher than 3 m, dominated by *Crataegus monogyna* Jacq, y *C. laciniata* Ucria, and covered by several species of *Lonicera* and *Rosa*, etc. These copses are common in the Segura and Alcaraz mountains, and in other mountains of Alicante and Valencia such as 'Font Roja', and the Aitana and Mariola ranges. Beneath these copses pastures are composed of *Festuca* species (some endemic) which represent a summer pasture and forage reserve for many of Spain's domestic and wild ruminants in the east and southeast of the country.

Evergreen oak woods are more extensive under dry climate, where they represent the climax vegetation. In many areas, individual oaks are bushy and undersize, but produce sprouts and leaves of good forage value which are well browsed by livestock (acorn production is occasional). On stony ground, oak woods have open spaces occupied by a diversity of bushes and pastures.

In the calcareous oromediterranean areas (>1,700 m) vegetation cover is (i) pine juniper forest which forms an open formation with (ii) spiny cushion bushes and (iii) a pasture understorey. Species found are (i) *Pinus nigra* Arnoldsubsp. *clusiana* (Clemente *in* Arias et al.) Rivas-Martínez, *Juniperus sabina* L., *Juniperus communis* L. subsp. *hemisphaerica* (K. Presl) Nyman); (ii) genus *Genista, Erinacea, Ononis*, *Ptilotrichon, Vella*, *Prunus*); (iii) hard-leaf grasses (genus *Festuca, Poa, Koeleria, Dactylis*) and annual species such as legumes (genus *Medicago, Astragalus, Lotus*), and members of the *Compositae* and *Caryophyllaceae* families. All of these combined have a good pastoral value and are almost the only feed available at the end of the summer season in the highest areas of the southeast.

The high moorland continental areas are occupied by small juniper woods ('sabinares') of *Juniperus thurifera* L. (white 'sabina'), forming open copses where short-cropped pastures develop, under the influence of livestock grazing.

Livestock have been fed tree branches and leaves as a feed supplement in riparian zones (rivers and streams) where deciduous vegetation grows and in shady mountain areas. The hackberry (*Celtis australis* L.) and the elm (*Ulmus minor* Miller) are the species most eaten by many species of ruminants. Hence they were hand pruned to take advantage of their sprouts. The branches of wild olive trees (*Olea europaea* var. *sylvestris* Brot) which are present in rocky canyons and stony areas have also been used by livestock.

In the high mountains of Segura and Alcaraz, where there are frequent snowfalls, a mosaic of padded matorral, false brome 'lastonares' (*Brachypodium phoenicoides* (L.) Roem. & Schult), and hard leaf pastures, along with some meadows and deciduous spiny copses ('espinares') in small depressions or next to water points (springs and 'tornajos') is found. Pastures are grazed at a high stocking rate by mixed flocks of Segureña' sheep and Celtiberian white goats during the summer. In this situation, red deer and wild goats compete for the same pastoral territory.

The spatial distribution of flocks is unequal, more stock graze on pastures near inhabited areas and this livestock pressure causes soil erosion and loss of endemic and vulnerable species. The survival of potentially toxic wide leaved herbs (forbs), (e.g. *Arum alpinum* Schott & Kotschy, *Geum urbanum* L., *G. heterocarpum* Boiss, etc.) from the grazing pressure of herbivores under the cover of spiny species of the genus *Berberis, Crataegus, Rosa*, etc., while unpalatable species proliferate in the clearings (e.g. *Eryngium*) is an index of overgrazing.

Montane pastures are 2–3 times more productive than those from mid mountain areas. However, their current management is inadequate, because flocks are large (often with over 1,000 small ruminants) and are not moved off the area.

Non-livestock Uses of the High Mountain Forest Zone

Exploitation by the timber industry in the higher area of the Segura basin was very intense from early times until the 18th century, when there was a demand by the naval industry for high quality timber (*Quercus pyrenaica, Q. faginea, Pinus nigra* subsp. *clusiana*) for warship construction. Other tree species with high calorific value (e.g. *Quercus ilex* subsp. *ballota*) were used for charcoal, for heating, or as fuel for the iron, glass and resin factories located in the area at that time.

Nowadays wood for trees growing in the basin is scarce and of low quality, except that of the 'laricio' pine (*Pinus nigra* subsp. *clusiana*), which is used as a timber for furniture in the small area of forest at the head of the basin.

The extraction of resins from *Pinus pinaster* (Alcaraz Mountains) and 'miera', from the *Juniperus* spp. to caulk boats and ships, was an important economic activity until the mid 20th century.

Bee keeping for honey production is widespread throughout the entire mountainous and agricultural areas of the basin, producing high quality single and multi-flower honey.

Wild mushrooms, principally the genus *Lactarius*, represent an economic resource in the high areas of the basin. There is a significant harvest every 5–7 years, and this is an important area for tourism in autumn. However, there is no regulation of this activity, and in the long term it can cause an environmental problem. Something similar occurs with the harvest of wild snails across the territory.

During recent decades, one of the most important new economic activities has been the proliferation of limestone quarries in high and middle zones of the basin. This extraction of minerals sometimes conflicts with environmental regulation, for example, the gravel extraction from fluvial beds may cause destruction of the riparian vegetation.

Tablelands and Rangelands

In the semiarid cold plains (500–1,000 m altitude) of the Segura basin, the dominant agroforestry system is a semi-extensive *agrosilvopasture*, where crops and rangelands are grazed by extensive herds of livestock, except during periods when pasture is scarce and animals are fed in barns. The whole zone is economically marginal, and dryland agriculture and extensive livestock are under risk of extinction.

Depending on the contribution of woody and herbaceous species, the following rangeland pasture types can be identified:

Pastures with a Tree Cover

Pastures with a dense tree cover (>20%) represent about one half of the forest area. The main tree is Aleppo pine (*Pinus halepensis* Miller) which has expanded from the coast up to 1,100–1,200 m height due to human activity, either directly by reforesting or indirectly by management. When the pine density is low, it has a minimum influence on the botanical composition of the rest of the vegetation. In contrast to the holm oak, the Aleppo pine makes no contribution to livestock feed resources. The forage value of these pine woods is variable, depending on the diversity of the stratum of bushes and pastures growing below them. Most frequently, the understory stratum is dominated by shrubs of the *Labiatae*, *Cistaceae* and *Fabaceae* families, and by herbaceous pastures of *Brachypodium retusum* (Pers.) P. Beauv. Bulbous and rhizomatous species of the *Orquidaceae* and *Liliaceae* families also grow between them.

Shrubland Pastures

Shrubby pastures are those that support the highest livestock pressure in this area. The most abundant are the least evolved and include communities of high diversity and contain numerous endemic species. Usually, these pastures like light and have a good capacity to colonise disturbed soils, frequently representing the understory of a majority of pine woods, and its main pasture resource. These pastures are mainly formed by Labiatae (*Rosmarinus officinalis* L. and several species of the genus *Thymus*, *Sideritis*, *Teucrium* and *Satureja*), Cistaceae (genus *Cistus*, *Helianthemum*, *Fumana*), legumes (genus *Anthyllis*, *Coronilla*, *Onobrychis*, *Astragalus* and *Hedysarum*) and other genus (*Staehelina*, *Lithodora*, *Ruta* and *Haplophyllum*). In general, the feeding value of the species is medium, but due to the high botanical diversity of these pastures, herbivores can meet most of their requirements by consuming and selecting between a wide range of species, except during the summer months, when the browsing biomass of shrubland pastures is reduced by drought.

The ‘retamares’, shrubland communities dominated by broom species such as *Retama sphaerocarpa* (L.) Boiss. and genus *Cytisus*, *Genista* or by thorny shrubs (genus *Genista*, *Ulex*) belong to a later climax stage. They are spatial transition vegetation and although of low palatability, they encourage the establishment of good pastures.

The ‘coscojar’ is the most evolved shrubland community of these areas. It is a dense impenetrable matorral which is the climax vegetation in semi-arid areas. In dry climates it is a precursor to the oak woods community. The dominant species is *Quercus coccifera* L. (‘coscoja’), with *Rhamnus lycioides* L., *Rhamnus alaternus* L., *Juniperus oxycedrus* L. subsp. *oxycedrus, Phillyrea angustifolia* L., *Coronilla juncea* L., *Ephedra fragilis* Desf. subsp. *fragilis*, etc., and in lower warmer areas by *Pistacia lentiscus* L., *Rhamnus oleoides* L. subsp. *angustifolia* (Lange) Rivas Goday et Rivas Martínez. The forage value of this shrubland community is high, both that of the dominant species and the accompanying herbaceous species and bushes that grow among the shrubs. Together these contribute to their diversity and nutritional value which raises possibilities of feed complementation.

Productivity of Shrubland Pastures

Shrubland pastures provide fodder for livestock during the autumn-winter, when the fallow weeds have been eaten, or in spring, when the fallow land has been ploughed. They usually produce 1–2 t DM ha^{-1} of browseable dry material (DM), but it is mainly a volume feed, because most fodder shrub species are of low quality.

One of the most extensive formations in the ‘romerales’ is a low shrub community dominated by rosemary. Management affects its morphological structure and biomass yield (260–670 g plant^{-1}, 32–47% browse; 40–80% of canopy cover). On one hand, a moderate grazing increases the production of green matter, while on the other hand, keeping the shrubs from grazing favours their lignifications and reduces their productivity (Robledo et al. 2001). Formations dominated by *Anthyllis cytisoides* L. are widespread in the southern half and provide large quantity of browseable biomass (1.3–3.0 t DM ha^{-1}), an important feed resource for goats and sheep in dry areas. However, its herbage has a low protein level, contains tannins that reduce its digestibility, and leaves are lost during the summer (Robledo et al. 1991a).

Herbaceous Pastures

There is only a small area where herbaceous pastures are dominant vegetation. However they are a constituent part of other woody and shrubby aggregates. The most frequent pastures are those with *Brachypodium retusum*, which cover large areas below natural and reforested pine woods, mixed with low matorral like ‘tomillares’ (dominated by thyme) and middle matorral of *Q. coccifera*. As altitude and rainfall increases, they are displaced by pastures of *Festuca* and *Arrhenatherum*, of higher pastoral value.

The ‘esparto’ grass communities (*Stipa tenacissima* L.) cover large areas of the thermo and meso-Mediterranean belt, usually found at the overlap with the lower shrubland. Esparto fibre was one of the most important raw materials produced in southeast Spain until mid 20th century. Nowadays its use as a fibre has been mostly abandoned, and the stipa grass communities are slowly evolving into pine and shrubland communities. ‘Esparto’ has a low forage value. It tends to be only grazed during flowering and periods of feed scarcity, nevertheless it plays an important role in stabilising the soil and protecting it against water erosion. At high altitudes and on stony soils, it is displaced by *Helictotrichon filifolium* (Lag.) Henrard grass pastures, which are grazed by wild and domestic goats.

Meadows are only found around waterfalls, springs and humid ravines, and on high lands with clay soils remaining humid during a large part of the year. There are few of these meadows, but because of their quality and high yields they represent an “oasis” among the general aridity of the region. The most common meadows are those dominated by *Cynodon dactylon* L.*, Festuca arundinacea* Schreber subsp. *fenas* (Lag.) Arcangeli*, Brachypodium phoenicoides* (L.) Roemer et Schultes*, Lolium perenne* L.*, Agrostis stolonifera* L. on the particular soil and climatic conditions, but legume species *Medicago sativa* L.*, Lotus corniculatus* L.*, Ononis repens* L.*, Trifolium* diversity *fragiferum* L.*, T. repens* L. are also abundant.. These pastures should be carefully managed because excessive grazing pressure could degrade them, but an absence of grazing would make them evolve towards reed communities with lower diversity and palatability (Ríos et al. 1990).

Productivity of Herbaceous Pastures and Meadows

The most important pastures are formed by perennial tussock grasses of low palatability and poor nutritional value, such as the 'esparto' (*Stipa tenacissima*), 'albardín' (*Lygeum spartum* L.), 'lastón' (*Brachypodium retusum*) and *Helictotrichon filifolium*. In the *Brachypodium* pastures, most of the biomass is dead matter; hence they are often burnt to induce vigorous sprouting, which improves pasture quality. In the NW of Murcia accumulated yields of 2.6–8.6 t DM ha^{-1}, were measured. In a second cut a year later, yields were 0.7–1.7 t DM ha^{-1}.

Dactylis glomerata Roth pastures have good quality, but are only found in good soils, such as those underneath oak woods in NW Murcia, where yields between 0.7–2.0 t DM ha^{-1} have been measured.

In the tussock grass communities dominated by *Stipa tenacissima* (95% 'esparto') yields of 4.4 t DM ha^{-1}have been measured but only 1.5 t DM^{-1} of this is available, low quality fodder forage. There are other less frequent *Stipa* pastures such as those dominated by *Stipa celakovskyi* Martinovsky, in which yields of 1.2–3.7 t DM ha^{-1} have been measured.

The existing meadows (species of the genus *Festuca*, *Agrostis, Lolium, Hordeum, Trifolium, Medicago*, etc.) located in humid areas are very productive (8–12 t DM ha^{-1}) and of high quality.

Forage Resources from Dryland Crops

Forage crop resources from drylands consist of by-products from cereal crops (straw, stubble and fallows), herbaceous layer under almonds, vineyards and olive groves, and by-products from the trees such as fallen leaves, fruits and pruned branches.

In semiarid areas such as those found in the middle zone of the Segura basin, arable systems are low-yielding and winter cereals use fallowing, frequently in association with sheep rearing to maintain soil fertility. The proportion of fallow (30–80%) and the importance of livestock increases as rainfall decreases. The number of fallow years increases also in poor soils (2–3 years).

Higher labour costs and declining prices have contributed to the reduced viability of farming in these areas where forestation, marginalisation or complete abandonment can occur. Hence a loss of agricultural habitats associated with the drier, traditionally less intensive farming systems has been noted.

The combined use of sheep-cereal-rangeland is the dominant agrosilvopasture system; cereal stubbles are grazed in summer, cereal fallows in autumn and rangelands in winter. However, during periods of feed scarcity, rangelands are overgrazed, with the consequent degradation of vegetation and soil. Winter cereals are the best-yielding alternative to the potential biomass produced by dryland pastures and rangelands. For example, in semi-arid NW Murcia, where about 50% of the land is under cereal cultivation, the mean productivity of the twice yearly barley-fallow systems (2.7 t DM ha^{-1} $year^{-1}$) is very high compared to that of native rangelands (1.8 t DM ha^{-1} $year^{-1}$ in scrublands and steppes) and dry land pastures (1.2 t DM ha^{-1} $year^{-1}$) (Robledo 1991; Correal et al. 2006). A semi-extensive system which is becoming generally adopted is that of maintaining dry ewes on grazing residues from cereal crops and shrublands, but fattening lambs and supplementing animals with barley and other concentrate feeds during periods of high nutritional requirements.

Cereal Crops

Barley is the most widely cultivated species, only at higher altitudes it is replaced by wheat (white and hard) and rye. The dominant cultivation system is a crop-fallow biannual rotation. Sheep breeding is associated with cereal cultivation, animals grazing the cereal stubble during summer, and fallow pasture until spring (March–May), after which the fallow land is cultivated. In June–July, after the harvesters collect the grain and bale the straw, livestock moves into the stubble to eat the fallen grain, the standing straw and the opportunist weeds, remaining there during the whole summer (July to September).

Those barley grains, which fell to the ground during harvesting, start to germinate along with seeds of the native flora with the first autumn rains. The most important fallow species are *Lolium rigidum* Gaudin, *Bromus diandrus* Roth. and genus *Eruca, Moricandia, Biscutella, Papaver, Vicia*, *Trigonella* and *Medicago*. From March–April the germination of summer species (genus *Salsola, Chenopodium, Polygonum* and *Amaranthus* types) (Robledo et al. 1991b) begins. In general, most fallow weeds are well grazed, and are an important feed resource for livestock, which tend to overgraze rangeland pastures when feed is in short supply.

Productivity of Cereal Stubbles and Fallow Pastures

Once the cereal has been harvested, animals graze the stubble, where 0.9–1.7 t DM ha^{-1} have been measured in normal years, and 3.3 t DM ha^{-1} in rainy years. Animals also consume the cereal grain on the ground, which on average is 0.2 t DM ha^{-1}. After the summer, livestock eat the fallow weeds, which in the NW of Murcia produce 0.5–0.6 t DM ha^{-1} when cut fortnightly, and around 1.2 t DM ha^{-1} when only one harvest is made. In some cases yields of 0.9 t DM ha^{-1} have been measured with eight fortnightly cuttings and around 2.1 t DM ha^{-1}, when only one single final harvest is made. The more productive species are the grasses *Hordeum vulgare* L., *Lolium rigidum* and *Bromus diandrus*, barley (*H. vulgare*) which make the largest contribution – about half of the biomass produced during the fallow year (Robledo 1991).

Woody Crops

Among the dryland tree crops the almonds stand out as they can be used by livestock, which eat dry leaves, pruning leftovers and soil weeds. Other important crops are olive trees, whose pruning leftovers have been a traditional livestock feed in winter. Vineyards are grazed during autumn and winter, when they are dormant, consuming the dry leaves and the spontaneous weeds. Livestock also eat the pruned branches of olive trees (*Olea europea*) and vineyards (*Vitis vinifera* L.), and the leaves of mulberry (*Morus alba* L.), fig (*Ficus carica* L.), apricot (*Prunus armeniaca* L.), and peach trees (*Prunus persica* (L.) Batsch). In warmer areas, the fruits of the carob tree (*Ceratonia siliqua* L.) used to have a good economic value, (bought or leased). Nowadays, woody crop by-products have a very limited value, except for pruned olive branches which still have some commercial value for feeding animals.

In the case of irrigated tree crops, previously it was common to harvest the weeds and prunings from tree orchards to feed livestock, a practice that has disappeared due to the widespread use of insecticides. On the other hand, the food canning industry provides a large quantity of by-products consumed by livestock, such as pulps, discarded fruits, peelings and other leftovers from the food processing industries.

Non-livestock Uses of the Table Lands and Rangeland Forest Areas

The lower quality but abundant Aleppo pine has a certain economic value, yielding around 300,000 euros per year at loading point (30–40 euros m^{-3}) during the period 1995–1998.

The harvest of wild or cultivated aromatic and medicinal plants (rosemary, thyme, lavender, salvia, etc.) has been an important activity in the basin, where 600–700 t $year^{-1}$ are produced which, at 140 euros t^{-1}, yield an economic output of 86,000–97,000 euros $year^{-1}$ (period 1995–1998). Such extraction is not always sustainable and could create conservation problems, unless some of the species in most demand by the pharmaceutical and cosmetics industry are cultivated.

Esparto fibre (*Stipa tenacissima*), is still used in some lower areas of the basin, where the annual harvest is around 200 t $year^{-1}$ with a loading point value of 26,000 euros (1995–1997). This is considerably lower than before. Wild snails are also harvested in this part of the basin.

Lower Plateaus and Coastal Areas

In this basin environment, intensive agropasture systems are dominant because irrigation helps produce large quantities of fodder by-products to feed livestock, which are also fed concentrates. These intensive livestock systems do not have a tree component.

In this environment, small areas of dryland crops and rangelands are also found but their productivity is lower than in the middle zone of the Segura basin. As a result their forage contribution to agropasture systems is slighty smaller.

In the past, mulberries (planted along the irrigation channels) and carob trees (planted in the deep soils of the Cartagena plain) were an important source of income (silk and carob seeds and pods) and forage for livestock, but are currently in decline.

Livestock Numbers; Stocking Densities

Sheep are the ruminants that mostly graze montane pastures, rangelands, stubbles, fallows and forage by-products from agricultural areas. Goats and cows also make use of pasture resources in high mountain areas but most of them are localised in intensive dairy units where they are pen fed with fodder and concentrates. The same happens with other species like pigs, rabbits and chickens which are fed in pens and do not have any call on pastoral resources.

Approximately, 50% of sheep and 60% of goats are found in the middle zone of the basin (500–1,000 m altitude), and mostly associated with agrosilvopastoral systems (Table 9.4). More than 50% of cattle and about 25% of the sheep and goats are found in the lower zone of the basin (below 500 m), forming part of intensive livestock systems (dairy cattle and goats, and sheep for meat). Finally, the high area of the basin (1,000–2,000 m) maintains a small proportion of sheep (16% of the total census) and goats (12% of the census) and only 2% of the cattle. If we analyze the altitudinal distribution of all the ruminants using their total equivalent in livestock units (1 sheep or 1 goat, equivalent to 0.1 LU), the results are similar: 51% of the total LU are located in the middle area of the basin (500–1,000 m), where agrosilvopastoral systems are predominant, and 12% of the LU are in the highest zone (1,000–2,000 m) where silvopastoral systems prevail; 38% of the LU are located in the lower coastal area (0–500 m) where intensive livestock systems are dominant.

The mean stocking density in the districts of the basin is lower than 1 sheep per hectare per year. The mean sheep density (sheep per hectare) in the different municipalities of the basin is shown in Fig. 9.5. These are classified by their stocking densities, their numerical distribution and their position in the basin. Four categories can be recognized: (a) with less than 0.25 sheep per hectare, 42 dispersed municipalities through the whole basin only representing 7% of the sheep population; (b) with 0.25–0.5 sheep per hectare – (35% of the total) 50 municipalities like Lorca, located in the middle area of the basin, with an abundance of agricultural

Table 9.4 Distribution of sheep, goats and cows, by altitude of municipalities where livestock is registered

Altitude range (m)	Sheep	%	Goats	%	Cattle	%	LU	%
<500	300,216	33.1	56,867	28.5	21,263	53.2	56,971	37.8
500–1,000	465,080	51.2	118,073	59.3	17,947	44.9	76,262	50.6
1,000–2,000	142,685	15.7	24,322	12.2	742	1.9	17,442	11.6
Total	907,980	100.0	199,261	100.0	39,953	100.0	150,675	100.0

Legend: LU Large livestock units (cows or its equivalent; 1 sheep or goat = 0.1 cow)

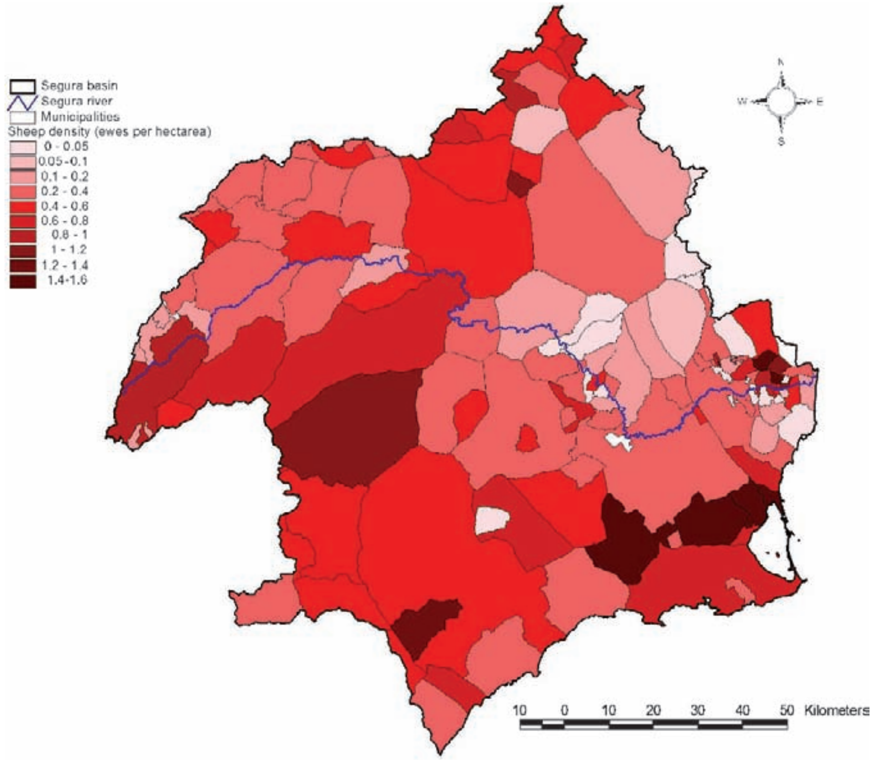

Fig. 9.5 Livestock densities (sheep per hectare) in the municipalities of the Segura basin (MAPA 1999)

by-products from rain-fed crops, such as cereals; (c) with 0.5–1 sheep per hectare (34% of sheep numbers) – 25 municipalities located in mountain areas such as Moratalla, or in highlands like Caravaca, with a mixture of rain fed crops, forest and rangelands and (d) with 1–2 sheep per hectare (24% of total sheep) – 10 municipalities located in the coastal plain of Cartagena, where large quantities of fodder by-products from intensive agriculture and agricultural industries are available. This is common in the municipalities of Torre Pacheco and Fuente Álamo (Erena et al. 2004).

Despite what has been said, seasonal variations of pasture resources generally mean that active stocking densities exceed the sustainable optimum as determined by the resources available in summer and winter months. The opposite happens during spring and autumn, when the available resources are usually higher than the requirements of the livestock population.

In 1999, there were 900,000 sheep in the Segura basin, representing 3.6% of the Spanish sheep population. This is similar to the area in the Segura basin (3.7% of Spain), where meat production (lamb and mutton) is the main agricultural output.

Current Land Use Changes and Future of the Agroforestry Systems

Changes in Soil Use (1990–2000)

To analyze the change in soil use, the "CORINE data base of land cover" from 1990 (revised) and 2000 have been used (IGN 2005). From these it can be concluded that:

1. 10.6% of the area evaluated (201,800 ha) has seen changes in the CORINE land cover classes and in 97% of the cases this means a loss of natural vegetation.
2. The biggest recorded changes were from agroforestry systems and extensive agriculture (Fig. 9.6). Altogether they lost 157,520 ha (25% of their area in 1990); Most (91%, 146,796 ha) of this loss was to intensive agriculture, which increased its cereal cover by 40% compared to 1990.

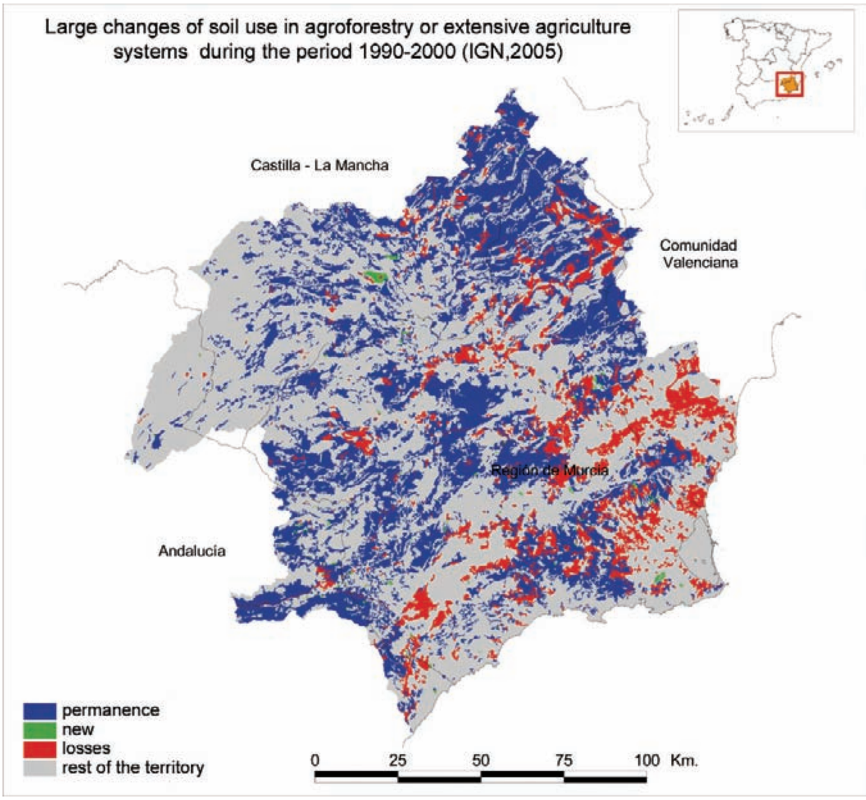

Fig. 9.6 Large changes of soil use in agroforestry or extensive agricultural systems during the period 1990–2000 (IGN 2005)

3. The lower plateaus and coastal areas of the Segura basin were those that suffered the greatest intensity of change. Land reclamation and man-made modification within 1 km of the coast is three times more than the basin average, and twice more than the average for the first 4 km. Similar values are obtained in the areas close to roads and highways.

In the Murcia Region (59% of the Segura basin), the forested area has increased from 41% in 1966 to 60% in 1999, probably due to the combined action of factors like reforestation, a reduction of pressure on forest and rangeland products (wood, fire woods and grazing), and to human abandonment in rural mountain areas. In contrast, the extent of rangelands (shrub communities, herbaceous pastures, etc.) has decreased by 53,000 ha during the same period, corresponding well with the 52,000 ha increase in the cultivated area.

Potential Future Improvements

People living in marginal areas like the Segura basin are faced with economic and ecological sustainability challenges (e.g. to make a living while preserving basic resources). However, only a small area of land is suitable for economically efficient agriculture, the rest is better suited for range and forest, and can only be used by grazing animals utilising areas which cannot be cultivated (Harlan 1975).

The following comments reflect on some potential improvements that could be introduced in the silvopastoral and agrosilvopastoral systemspresent in the Segura basin.

Annual Forage Utilisation Patterns to Match Resources with Sustainable Stocking Rates

The planning of annual feed calendars for livestock, to utilise all the potential fodder resources could reduce grazing pressure on degraded rangelands and improve the efficiency of animal production.

Forested areas of the Segura basin mountain area provide seasonal grazing during summer. This resource could be used to feed flocks of livestock from drier areas, like the middle zone of the Segura basin that have to sustain large stocking rate densities. This option is feasible as there is still a network of livestock transit tracks which would facilitate livestock movement between the middle and mountain zones. Additionally, these movements of livestock would help create biological corridors connecting different habitats.

Seasonal fluctuation in animal nutritional requirements and forage and pasture resources in Mediterranean environments like those prevailing in the Segura river basin must be matched in an optimal way. There are periods of fodder shortage but there are ways of improving the system, such as creating fodder banks or hedges with forage shrubs, which can also support biodiversity, or introducing infrastructures like fences, water points and animal shelters in parts of the farmland. These would confine animals grazing permanently during long periods, and thus reduce shepherding requirements and labour (Correal et al. 1988; Correal 1993).

Extensive livestock farming subsidies and Rural Development support should be linked to the territory and its productive systems (extensive, semi-extensive, organic farming, etc.), to see if livestock grazing degrades, maintains or improves the vegetation and other natural resources.

Promotion of Biodiversity

Agricultural policy in Europe is changing from supporting production to encouraging environmental benefits in the context of sustainable rural development.

In the mountain zones of the Segura basin, ecotourism from urban populations could partly justify economic investment to protect biodiversity. Seasonal summer grazing, maintaining low stocking densities, may help preserve the environment and natural habitats of forest zones, many of which are of particular interest to the EU (Red Natura 2000). Good grazing management can reduce shrubby biomass and with it the risk of fires while maintaining the biodiversity present in the forest layer. However, if mountain zones are not protected by law, overgrazing can damage valuable natural resources, as is happening in part of the mountain area.

In the middle zone of the Segura basin, the winter cereal-stubble-fallow system maintains a cereal-steppe landscape where an important part of the Mediterranean flora and fauna, especially steppe birds, depend on the habitat and feed resources generated by stubble and fallows (Suárez et al. 2004). Of all steppe birds, the great bustard (*Otis tarda* L.) and the little bustard (*Tetrax tetrax* L.) are the two most threatened species, and 50% of the world bustard population is found in the Iberian Peninsula. To protect steppe bustards, the following measures are suggested: maintain fallows and their rich flora; preserve or create borders and living hedges; stop herbicide and pesticide use, fertilize with organic manure; use native seeds; and maintain traditional cropping cycles (Alonso et al. 2003).

Organic Farming

Current EU policy on rural development promotes livestock systems oriented towards the production of quality food. Under such a policy, organic farming could be a means of sustaining silvopastoral and agrosilvopastoral systems in mountain and steppe rangelands of the Mediterranean Segura basin zones. In place of fertilizers and pesticides, organic farming relies on local biological resources. Synthetic fertilizers are replaced by animal manure or legume cover crops, natural weed control is practised, animals are reared outdoors with adequate space and natural medicinal practices are used. So organic farming could offer consumers food free of chemicals, and tasting better produced in an environmentally friendly manner. There is more manual labour with organic farming, but livestock are healthier and prices of animal products are usually higher. However, the high quality red meat produced in the silvopastoral zones of the Segura basin does not attract a premium and there is a need to organize the distribution and marketing of local products, such as meat, honey, aromatic plants, wood, resin and mushrooms to make it possible for the few people living in the zone to remain economically viable (Correal et al. 2006).

Use of Forage Cereals and Cereals as Forage in Sheep-Cereal-Rangeland Systems

When cereal yields are low, as in semiarid marginal areas, whole cereal crops like barley can be used as forage for livestock, either for winter and spring grazing, or cut and dried at the end of the cycle (milky grain stage) for later use in periods of forage scarcity, such as winter. Such a strategy might help the recovery and use of old cereal varieties and landraces, abandoned in the past because they had high straw yields.

Additionally, as the General Agreement on Trades and Tarrifs (GATT) agreements predict for the future, cereal production within EU countries will evolve towards a competitive open market and, in such a scenario, it seems logical that part of winter cereals, particularly barley, should be used for *in situ* consumption in extensive livestock systems.

Use of Woody Forage Species in Agrosilvopastoral Zones

Establishing crop hedges and field margins in environmentally sensitive areas could provide food and habitat for wild fauna and reduce soil erosion (Atkinson et al. 2002). Similarly, introducing woody forage species in natural fences and as protein feed supplements in cereal cropping areas, could improve the year round food availability profile and preserve biodiversity and protect soils.

Fodder shrub plantations can be used for several purposes: (a) to create fodder banks for annual and inter-annual feed scarcity periods, (b) as protein or mineral supplements to improve sheep intake of nutritionally deficient feeds (e.g. cereal straws, *Stipa* grasses, etc.), (c) to control soil erosion in cultivated areas with steep slopes, and (d) to provide refuge and food for wild fauna (Correal 1993).

Perennial woody legumes, like tree medics (*Medicago arborea* L., *Medicago citrina* (Font-Quer) Greuter) could be grown as fodder banks for winter-spring grazing. The introduction of cereal-*Atriplex* alley cropping (saltbushes planted in rows following widely spaced contour lines) could provide an *in situ* protein supplement to straw/stubble and protect the soil against erosion during heavy autumn rains (Correal et al. 1994).

Conclusions

The silvopastoral and agrosilvopastoral systems present in the upper and middle zones of the Segura river basin are important to maintain landscapes, biodiversity and rural life because they affect 60% of the territory. However, their economic output is marginal and the population living on them is relatively small (17%). Hence, their future is unclear, but it seems that the preservation and maintenance of the biodiversity and landscapes associated with them and the potential yield of quality products are reasons that might justify their economic support by EU agrarian policy.

In theory, the three zones of the Segura basin (high, middle and low) are complementary in terms of their fodder resources, because they are produced in different seasons and places, and hence annual forage calendars could be established to maintain sustainable extensive livestock systems, moving animals through the network of transit tracks connecting the different zones of the Segura basin, as was done in the past. However, this scenario is far from reality because the current trend is towards maintaining larger stocking densities in intensive farming systems close to coastal areas where a majority of the human population is concentrated, and in the semi-intensive systems in the middle zones of the basin. In contrast, the highest zones of the basin are experiencing abandonment of human population and livestock activity. In summary, there is a worrying trend towards depopulation in the upper zone of the basin and an increase of desertification risks in the lower and middle zones of the basin. All these combined will make sustainable management of the territory, the preservation of its biodiversity, the control of its erosion problems, and the long term development of the Segura basin very problematic.

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Chapter 10
Role of Livestock Grazing in Sustainable Use, Naturalness Promotion in Naturalization of Marginal Ecosystems of Southeastern Spain (Andalusia)

A.B. Robles*, J. Ruiz-Mirazo, M.E. Ramos, and J.L. González-Rebollar

Abstract Southeastern Spain is one of the driest regions in Europe, yet it is environmentally diverse, botanically rich, sensitive to wildfire, susceptible to erosion, and desertification, and in need of research, now that the Common Agricultural Policy is fundamentally changing the rural development paradigms. Our research group has been contributing to the development of methodologies and acquisition of knowledge to manage pastures and silvopastoral systems in this region since 1986. The proposed carrying-capacity methodology provides valuable information on rangeland diversity and the nutritive value of forage species (crude protein ranges from 4.02% in *Hyparrhenia hirta* (L.) Stapf to 27.17% in *Suaeda pruinosa* Lange; metabolizable energy varies between 4.22 MJ kg^{-1} DM for *Dorycnium pentaphyllum* Scop. and 11.30 MJ kg^{-1} DM for *Adenocarpus decorticans* Boiss.), forage production of rangeland and metabolizable energy, varied from 45 kg DM ha^{-1} year^{-1} and 127 MJ ha^{-1} year^{-1} for halophytic shrublands to 3,264 kg DM ha^{-1} year^{-1} and 11,415 MJ ha^{-1} year^{-1} for medium leguminous shrublands. Comparing these figures with small ruminants' energy requirement (4,841.36 MJ SRU^{-1} year^{-1} for local breeds), we calculated the corresponding carrying-capacity values. These are needed by rangeland grazing managers. Two agroforestry-management alternatives are offered within environmental and socioeconomic constraints. First, livestock and agriculture are integrated in practices such as browsing in fodder-shrub plantations or grazing on pastures in olive and almond orchards; and second, a silvopastoral system designed for the prevention of forest fires and the promotion of naturalness in ecosystems.

Keywords Mediterranean silvopastoralism, arid lands, shrubland grazing management, carrying capacity, sustainable livestock farming, grazed fuelbreaks

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A. Rigueiro-Rodríguez et al. (eds.), *Agroforestry in Europe: Current Status and Future Prospects*.

The Territory: Southeastern Spain

After Turkey, Spain is the European country with the largest area of arid lands (19% of the territory) (Le Houérou 1993). Within the Iberian Peninsula, the southeastern region has the Mediterranean climate with the lowest rainfall, including pockets with annual precipitations of less than 200 mm. A more detailed study of the climate shows that this is too much of a generalisation and a simple climatic classification such as the *Köppen-Geiger* (Köppen and Geiger 1954) reveals that there are wetter sectors in Almería, a province known for its aridity (Fig. 10.1).

Mediterranean climatic environments are characterised by irregular rainfall, summer drought and their high sensitivity to environmental variations (altitude, exposure, relief, soil, etc.). The sharp relief of southeastern Spain creates a diversity of environmental conditions and within only a few kilometres, warm environments and the mild coast or the cold, moist high mountains of the Sierra Nevada (3,482 m asl) can be found. Temporal heterogeneityisanother characteristic of the Mediterranean climate. The higher coefficient of variation for annual precipitation is found to the south-east of the peninsula (Fig. 10.2 – Montero de Burgos and González-Rebollar 1983). The monthly changes in the *De Martone Aridity Index* (De Martone 1926), as recorded at 17 weather stations of the region are presented (Fig. 10.3).

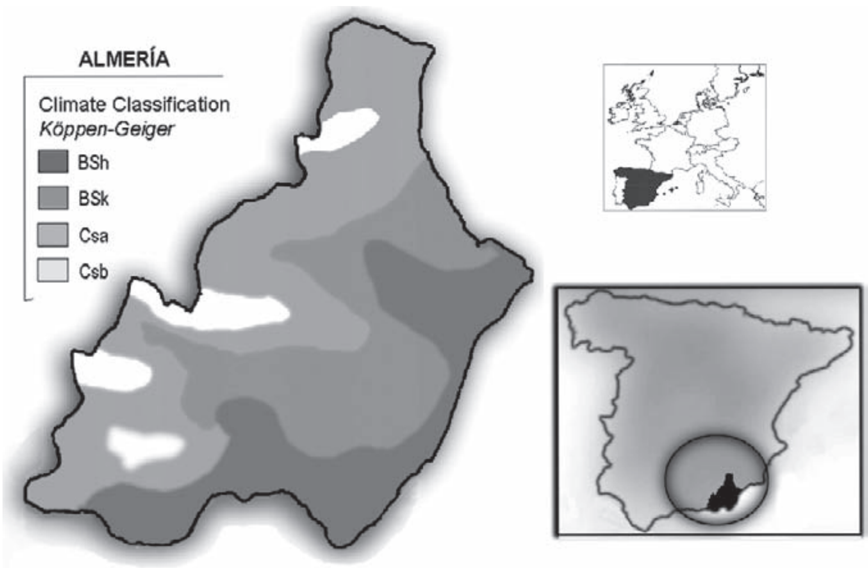

Fig. 10.1 Köppen–Geiger's climate classification in Almería. **Csa** – Mediterranean/hot summer; **Csb** – Mediterranean/cool summer; **BSh** – arid and semiarid/hot low-latitude steppe; **BSk** – arid and semiarid/cold mid-latitude steppe

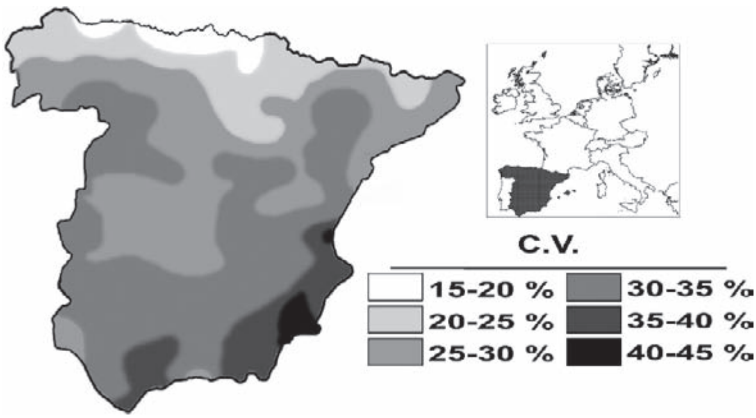

Fig. 10.2 Coefficient of variation for annual rainfall in the Iberian Peninsula (Montero de Burgos and González-Rebollar 1983)

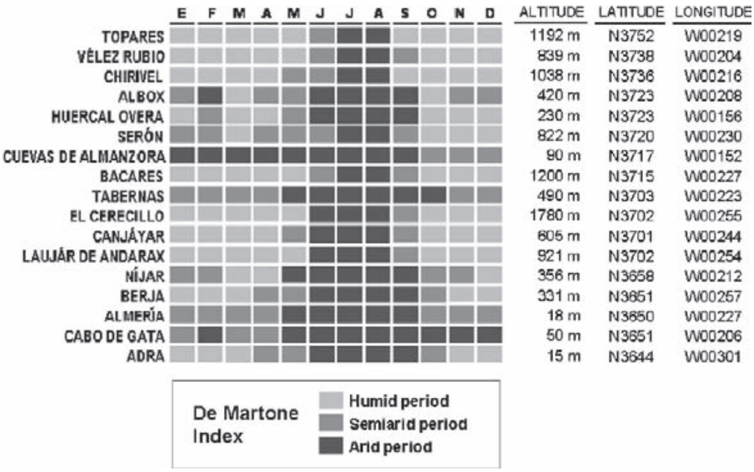

Fig. 10.3 Spatial and intra-annual heterogeneity of the De Martone Aridity Index in weather stations of southeastern Spain

These climatic characteristics, together with the rugged relief and the glacial and interglacial sequence of the Quaternary, have resulted in a mosaic of niches for the flora of this sector, representing a biogeographic ecotone between Africa and Europe. The flora of Andalusia (87,268 km^2, 17.3% of Spain) has some 4,000 taxa, representing more than half of the Spanish catalogue of plants (Blanca et al. 1999). Spain is the European Union (EU) country with the highest number of endemic species, 50% of these being concentrated in the arid and high-mountain zones of the southeast (Blanca et al. 1999). The Sierra Nevada, the main mountain range of this region, has not only the richest and most varied flora of the western Mediterranean but also the greatest concentration of endemic species in Western Europe (Gómez-Campo 1987).

In 1982, Pianka reported correlations between climatic diversity and the diversity of ecotypes. Observations from a Mediterranean environment occupy the uppermost part of the best-fit line which represents the most biologically and climatically diverse biomes (Fig. 10.4).

However, sustainable environment management should not be based exclusively on these environmental features. In this region, the landscape has been moulded by millennia of human influence. The 'natural' landscape in this area is, in fact, agrarian with human influence dating from as early as 1.3 million years (Gibert et al. 1998). The presence of large gregarious herbivores has been recorded in major palaeontological sites up until very recent (biochronological) times (Arribas et al. 2001). It is relevant to consider the balance between conservation of the 'natural' heritage and socioeconomic development that can damage the environment. This debate influences both conservation and development policies and the concepts of protection, exploitation, or disturbance are central to the debate.

Research on silvopastoral systems in southeastern Spain embraces both ecosystems adapted to extreme and changing climatic conditions and factors concerning history and evolutionary dynamics. There is a need for knowledge regarding the factors causing these circumstances, or having caused them in the past, such as fire, herbivore pressure, and human activities. From a socioeconomic perspective there is a need to understand the impact of market forces on the landscape.

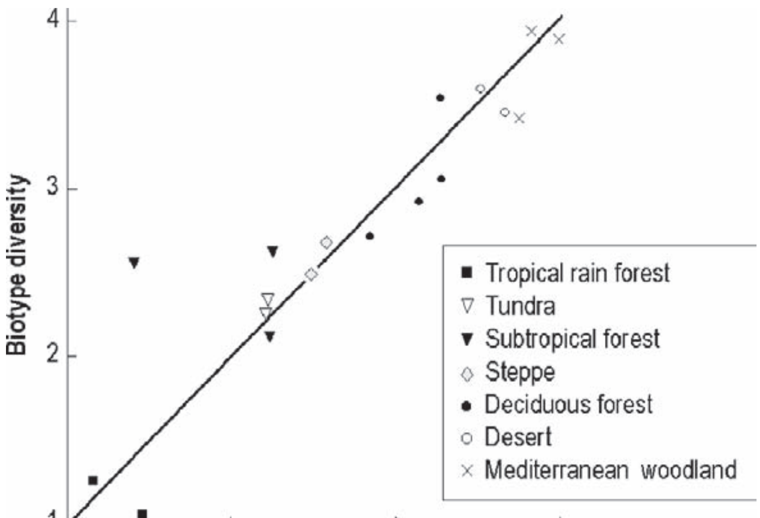

Fig. 10.4 The relationship between climatic diversity and biotype diversity in seven biomes of the world (Pianka 1982)

In this region, revenues from forestry do not exceed 2% of those for agriculture, but this figure does not reflect the true importance of *montes* (Salas et al. 1990). *Monte* is a Spanish term with an encompassing meaning, far broader than the English words 'forest', 'woodland', or 'shrubland', as it refers to all non-cultivated land covered with trees, shrubbery and undergrowth. Only 26.1% of the *monte* surface area are lands restricted to livestock grazing, the remaining being areas in which livestock is the main source of income (MMA 2000). Meanwhile, the *Forest Plan of Andalusia* (Salas et al. 1990) estimated that 26.2% of the market value of forest products was grazing, 26.0% hunting, 14.5% wild fruits, 8.1% cork, and only 14.7% lumber. Hence, the Mediterranean *monte* has very little to do with timber producing forests in Europe.

The application of the European Common Agricultural Policy (CAP) has reoriented agricultural trends in many deprived zones, bringing about significant changes in the scientific and technical conception of Mediterranean forest studies, specifically for its implications in other political arenas concerning environmental protection and quality of life. Research on silvopastoral systems of southeastern Spain currently requires good documentation of pasture resources. These are mainly shrublands which have frequently been neglected in the generalized definitions applied to pastures. This research requires the development of methodologies that are specific to these resources, effective in evaluating forage production and carrying capacity, and useful for the implementation of action plans. This implies considering both the local nature of the data and the limited breadth for generalization of the proposals. It should be borne in mind that forest research, as a tool for managing extensive resources is not a universal discipline and is highly dependent on environmental conditions and the cultural context of each place. Many of the mistakes in Spanish forestry policy are caused by not considering the broad range of conditions found in the management of Mediterranean *montes*.

In this general assessment of natural, cultural, and conceptual circumstances that historically identified the Mediterranean agroforestry sector, an additional factor has been the joining of the European Economic Community (EEC; today the EU) by Spain in 1985. When Spain entered the EEC, 63.7% of its usable agricultural area was qualified as 'less favoured', directly affecting 36.9% of the population (MAPA 1990) and in Andalusia, these figures rise to 69.9% and 49.7%, respectively. Most of the surface area of Andalusia is rural land, of which almost 50% is abandoned and covered with undergrowth. Most of this unused land corresponds to provinces of southeastern Spain.

The International Conference on Conservation and Sustainable Use of the Mediterranean *Monte* (Benalmádena, October 1998; MMA 2000) highlighted the need to: (a) outline a strategy for conservation and sustainable use of the Mediterranean *monte*, which would establish management models compatible with the maintenance of biodiversity; (b) formulate and put into practice silvopastoral models capable of optimizing the balanced use of the resources; (c) promote forestry policies and strategies in accordance with the particularities of the Mediterranean *monte*; (d) request the consideration of the Mediterranean *monte* as an essential reference in development policies; and (e) ensure conservation, sustainable management, and expansion of scientific as well as technical knowledge of the arid zones of the Mediterranean Basin. The single most paradigmatic question would perhaps be: What do we call ‘our landscape’? Landscape has become one of the fundamental values of peoples’ cultures, as well as a main element of cultural identity, constituting one of the indicators of quality of life (MMA 2000).

In the context described above, this paper gathers the most relevant aspects of our approach, information that our studies have been providing since 1986, methodologies developed in them, and our current proposals for action.

Resources and Methods

Extensive rearing of small ruminant livestock has historically been practised in the Mediterranean *monte* and it still has good development potential (Boza et al. 2000). The goat is the ruminant most adapted to the consumption of woody plants while the native sheep breed *segureña* have similar characteristics in southeastern Spain (Correal and Sotomayor 1998; Robles et al. 2001). Traditional livestock rearing uses varied indigenous plant resources, which is in agreement with the definition of ‘pasture’ that the Spanish Society for the Study of Grasslands (Ferrer et al. 2001) proposes: “any plant production (natural or artificial) that provides feed for domestic or wild animals, either as grazing or as forage”.

The pastures in southeastern Spain are mainly shrublands and perennial grasslands and have hardly been researched. Thus, early studies developed field techniques for evaluating shrub-community production and methods to determine the carrying capacity of pastures. The main objective was to develop a useful tool for managing livestock grazing in silvopastoral systems, which would enable the adjustment of the stocking rate to the carrying capacity of rangelands.

The terms ‘stocking rate’ and ‘carrying capacity’ are often misunderstood by forest and rangeland managers. Among the different definitions found in the literature, two clear and concise ones are (i) Stocking rate is the number of animal units allocated to a section of land for the yearly grazing period (Society for Range Management 1974); and (ii) Carrying capacity is the maximum stocking rate applicable under a conservative management (Holechek 1989). These terms represent the feed demand and forage supply in a grazed rangeland and both are often expressed as animal units per unit of land. The relation between stocking rate and carrying capacity indicates whether the pasture resource in being overgrazed or undergrazed.

The methodology developed by our research group to calculate the carrying capacity evaluates both forage production and animal requirements in energy terms. This methodology is based on diverse elements of silvopastoral systems: rangeland types (pastureland maps), floristic composition (plant richness and diversity), plant density and cover, forage production and nutritive value of plants (Robles 1990; González-Rebollar et al. 1993; Robles and Passera 1995).

Forage Production

Forage production (FP) was measured as dry-matter weight. Field sampling was stratified according to the biological forms, separating woody and herbaceous species. For the herbaceous stratum, destructive harvesting was used (12 to 24 plots at 50 × 50 cm). For woody plants, a non-destructive sampling method (Individual or Point-centred Quarter Methods; Cottan and Curtis 1956) was combined with the destructive harvesting of twenty individuals of each species to derive regression equations that relate allometric parameters to forage production (Robles et al. 2002). This was estimated for grazed species by simulating a conservative browsing of small ruminants (about 50% of the annual forage production within the animals' reach).

Nutritive Value

The value of pastures depends not only on their production but also on their quality (chemical content and nutritive value). Two commonly used parameters for characterizing pasture quality are crude protein (CP) and digestibility, which provide a reasonable approach to the nutritive value of forage species (Papanastasis 1993). Nevertheless, a high value of crude protein is not always indicative of quality, as many forbs and browse species have high tannin concentrations, which inhibit N digestion. Crude protein was determined using the Kjeldahl method, while dry (DM) and organic matter (OM) were measured according to AOAC (1990); *in vitro* dry-matter (IVDMD) and organic-matter digestibility (IVOMD) were determined using the rumen liquor-pepsin method (Tilley and Terry 1963) as modified by Molina (1981), which uses inoculums from the rumen of indigenous breeds (*segureña* sheep or *murciano-granadina* goat).

Carrying-Capacity Calculation Process

Metabolizable energy (ME) is very frequently used in animal-nutrition research. It can be estimated for each plant species regardless of the animal species (Pulina et al. 1999) by using the organic-matter (OM) content and digestibility of the plant (IVOMD), as proposed by the ARC (1980):

$$\mathrm{ME}(\mathrm{MJ\ kg^{-1}\ DM}) = \mathrm{OM}\ (\mathrm{gkg^{-1}DM}) \times \mathrm{IVOMD}\ (\%) \times 15.58 \times 10^{-5}$$

We can calculate the rangeland metabolizable energy available (RME) from the FP and ME of all species (i = 1 to i = n) that compose a certain rangeland, then adjust the result with two correction factors: animal preferences (PF) and availability period (AF) (Robles and Passera 1995).

Table 10.1 Carrying capacity regression equations. Annual rainfall (x = mm); plant cover (z = %); rangeland ME (y = MJ ha^{-1} year^{-1}); adjusted regression coefficients (adj. r^2); accuracy level (p) and number of samples (n) (Passera et al. 2001)

Rangeland type	Regression equation	adj. r^2	*P*	n
All rangelands	y = −701.036 + 0.269 × + 88.214 z	0.55	<0.001	63
All shrublands	y = −2198.151 + 1.61 × + 101.22 z	0.71	<0.001	48
High mountain shrublands	y = −2253.357 + 2.916 × + 76.863 z	0.85	<0.001	17
Low mountain shrublands	y = −2938.221 + 0.963 × + 129.819 z	0.80	<0.001	21

$$\text{RME (MJ ha}^{-1}\text{ year}^{-1}) = \sum_{1}^{n} \text{FP}_i \text{ (kg DM ha}^{-1}\text{ year}^{-1}) \times \text{ME}_i \text{ (MJ kg}^{-1}\text{DM)} \times \text{PF}_i \text{x AF}_i$$

According to Barroso et al. (1995), who studied animals' preferences in the region, PF ranges from 0 (null preference) to 1 (very high preference). AF was estimated as the portion of the year (from 0 to 1) in which the species is offered and consumed by the animal.

The energy requirements for small ruminants can be found in the literature (INRA 1988 for sheep; Prieto et al. 1990 and Aguilera et al. 1990, 1991 for goats). Considering that the energy requirements are determined by different physiological factors affecting animals (growth, pregnancy, lactation; NRC 1981), we can estimate the energy needs (in terms of metabolizable energy) of a Small Ruminant Unit (SRU) as the average of the requirements of all animals in the herd (80% adult-females, 2% adult-males, 18% young). For local breeds of small ruminants, we calculated 4,841.36 MJ SRU^{-1} year^{-1} (Robles 1990). Thus, if we divide the metabolizable energy of the rangeland (MJ ha^{-1} year^{-1}) by the metabolizable energy required per animal (MJ SRU^{-1} year^{-1}), we get the annual carrying capacity of the rangeland (SRU ha^{-1}).

The overall carrying capacity for a complex management unit can be calculated as the aggregate of each rangeland's carrying capacity adjusted to the area it occupies. This method is laborious and involves much field and laboratory work. Data collected over several years of research have enabled the rangeland ME determination through regression equations. Metabolizable energy is estimated from annual mean rainfall and plant cover (Table 10.1, Passera et al. 2001). The best fits are achieved when only shrublands are considered. Therefore, it seems more adequate to establish and use regression equations which are specific for each range type.

Nutritive Value of Forage Species

Table 10.2a, b, c shows the nutritional data for the most abundant perennial forage species in our region. Analyses have been made for 113 species of 21 different families, chiefly Leguminosae (22%), Gramineae (19%), Compositae (18%) and Labiatae (10%). Among the studied species, *Adenocarpus decorticans* Boiss. and *Ephedra fragilis* Desf. had the highest and lowest nutritive values, respectively.

Table 10.2a Nutritive values of forage species (spring sampling): dry mater (DM, %), organic matter (OM, %), crude protein (CP, %), *in vitro* dry mater digestibility (IVDMD, %), *in vitro* organic mater digestibility (IVOMD, %) and metabolizable energy (ME, MJ kg^{-1} DM) (Robles 1990; Robles and Boza 1993; Fernández 1995; Boza et al. 1998; Barroso et al. 2005)

Species	DM	OM	CP	IVDMD	IVOMD	ME
TREES (leaves and thin twigs)						
Average	44.77	92.98	9.30	37.99	41.09	6.91
Oleaceae						
Olea europaea L.	42.90	91.00	9.90	42.40	51.60	8.00
Fagaceae						
Quercus ilex ssp. *ballota* (Desf.) Samp.	46.64	94.96	8.70	33.58	30.58	5.82
SHRUBS (leaves and thin twigs, some flowers)						
Average	37.38	91.07	11.45	53.51	50.77	7.59
Anacardiaceae						
Periploca angustifolia Labill.	27.15	89.75	n/a	50.62	44.98	6.99
Compositae						
Artemisia barrelieri Besser	31.30	92.00	17.10	68.10	66.10	9.33
Artemisia campestris L.	27.30	92.80	15.70	59.60	57.10	8.32
Helichrysum stoechas (L.) Moench	30.60	93.60	6.34	68.40	65.60	9.44
Launaea arborescens (Batt.) Murb.	37.60	92.58	n/a	42.73	39.33	6.59
Launaea lanifera Pau	30.50	94.40	8.19	30.50	26.40	4.69
Phagnalon saxatile (L.) Cass.	43.20	92.70	8.00	53.30	52.00	7.70
Santolina chamaecyparissus L.	40.00	93.70	7.60	52.20	49.50	7.80
Staehelina dubia L.	52.90	92.20	4.80	51.40	49.70	7.70
Chenopodiaceae						
Atriplex glauca L.	34.09	71.49	16.11	69.73	68.76	7.66
Atriplex halimus L.	31.90	75.53	15.71	57.40	56.50	6.58
Salsola genistoides Juss. ex Poir.	43.18	91.00	19.21	45.13	45.13	8.17
Salsola oppositifolia Desf.	24.74	76.18	13.97	71.72	64.21	7.66
Suaeda pruinosa Lange	36.82	83.00	27.17	59.52	56.23	7.27
Cistaceae						
Cistus albidus L.	48.10	92.20	6.80	30.80	25.60	5.10
Cistus clusii Dunal	42.40	92.00	7.50	32.80	28.30	5.40
Fumana ericoides (Cav.) Gand	42.00	90.50	6.20	34.20	29.00	5.40
Fumana laevipes (L.) Spach	42.00	93.70	7.76	40.30	38.20	6.09
Fumana thymifolia (L.) Webb	50.70	87.80	6.94	34.40	30.00	4.77
Helianthemum almeriense Pau	28.20	92.86	n/a	53.72	52.08	8.01
Helianthemum apenninum (L.) Mill.	43.90	91.30	16.60	52.80	49.30	7.60
Crasulaceae						
Opuntia maxima Mill.	7.90	84.00	10.80	90.60	89.70	11.11

A certain species can be considered a good-quality pasture: when metabolizable energy is over 8 MJ kg^{-1} DM and crude-protein content is close to 12% (Boza et al. 2000). When each plant type is studied separately, only annual plants (grasses and forbs) exceed these values, due to the high proportion of leguminous species in this

Table 10.2b Nutritive values of forage species (spring sampling): dry mater (DM, %), organic matter (OM, %), crude protein (CP, %), *in vitro* dry mater digestibility (IVDMD, %), *in vitro* organic mater digestibility (IVOMD, %) and metabolizable energy (ME, MJ kg^{-1} DM) (Robles 1990; Robles and Boza 1993; Fernández 1995; Boza et al. 1998)

Species	DM	OM	CP	IVDMD	IVOMD	ME
SHRUBS (leaves and thin twigs, some flowers)						
Ephedraceae						
Ephedra fragilis Desf.	36.30	93.40	14.70	23.30	18.60	3.68
Fagaceae						
Quercus coccifera L.	44.20	95.98	6.60	47.50	45.50	7.50
Labiatae						
Ballota hirsuta Benth.	33.60	93.00	10.90	48.10	42.60	6.59
Lavandula lanata Boiss.	36.30	89.30	7.30	38.40	32.70	5.70
Lavandula multifida L.	28.60	90.10	9.75	47.80	43.00	6.43
Lavandula stoechas L.	33.70	93.20	7.98	49.50	46.90	7.12
Rosmarinus officinalis L.	31.50	93.70	10.30	30.10	26.30	4.64
Teucrium capitatum L.	41.70	94.00	8.36	55.80	53.70	8.01
Teucrium compactum Clemente ex Lag.	43.00	81.70	6.50	62.20	67.70	8.60
Teucrium polium L.	42.40	90.30	7.60	55.70	54.30	8.00
Thymus baeticus Boiss. ex Lacaita	31.70	92.40	8.46	54.10	50.90	7.54
Thymus serpylloides Bory	41.40	89.10	8.30	44.30	44.10	6.70
Thymus zygis Loefl. ex L.	40.80	91.40	10.20	59.30	56.50	8.40
Leguminosae						
Adenocarpus decorticans Boiss.	37.80	95.30	18.00	79.40	79.00	11.30
Anthyllis cytisoides L.	30.70	90.50	10.70	32.30	25.90	4.43
Coronilla juncea L.	38.84	87.63	n/a	65.93	65.93	10.49
Cytisus fontanesii Spach ex Ball ssp. *fontanesii*	56.20	97.00	14.90	64.30	63.10	9.47
Cytisus galianoi Talavera & P.E. Gibbs	32.80	95.30	15.90	67.10	66.20	8.20
Cytisus scoparius L. subsp. *Reverchonii*						
(Degen & Hervier) Rivas Goday & Rivas Mart.	35.50	95.47	n/a	77.80	76.60	11.00
Dorycnium pentaphyllum Scop.	36.30	95.10	13.50	26.50	22.40	4.22
Erinacea anthyllis Link	49.90	95.50	8.80	63.10	62.70	9.40
Genista cinerea (Vill.) DC.	46.30	95.70	13.50	67.30	66.50	9.70
Genista scorpius (L.) DC.	46.50	93.50	12.40	53.00	50.10	8.20
Genista spartioides Spach	54.89	96.60	n/a	37.06	35.36	6.43
Genista umbellata (L'Hér) Dum. Cours.	38.40	96.00	12.50	51.10	47.10	7.39
Genista versicolor Boiss.	44.10	96.40	13.00	63.60	63.30	9.50
Onobrychis stenorhiza DC.	29.80	90.65	n/a	54.70	51.30	7.74
Ononis tridentata L.	27.50	89.93	n/a	65.13	64.58	9.09
Retama sphaerocarpa (L.) Boiss.	40.80	96.70	15.90	72.10	70.80	10.41
Ulex parviflorus Pourr.	42.90	95.40	13.50	51.60	49.70	8.00
Liliaceae						
Asparagus albus L.	18.60	93.80	17.30	59.40	56.90	8.40

Table 10.2c Nutritive values of forage species (spring sampling): dry mater (DM, %), organic matter (OM, %), crude protein (CP, %), *in vitro* dry mater digestibility (IVDMD, %), *in vitro* organic mater digestibility (IVOMD, %) and metabolizable energy (ME, MJ kg^{-1} DM) (Robles 1990; Robles and Boza 1993; Fernández 1995; Boza et al. 1998)

Species	DM	OM	CP	IVDMD	IVOMD	ME
SHRUBS (leaves and thin twigs, some flowers)						
Arecaceae						
Chamaerops humilis L.	50.56	94.90	n/a	35.26	33.58	7.46
Rosaceae						
Crataegus monogyna Jacq.	36.80	92.30	12.30	52.60	50.00	7.70
Rhamnaceae						
Rhamnus lycioides L.	45.40	92.40	11.50	42.80	40.30	6.27
Zizyphus lotus (L.) Lam.	36.81	94.53	n/a	62.59	60.43	9.09
Solanaceae						
Lycium intricatum Boiss.	11.37	72.51	n/a	75.28	65.91	7.44
Withania frutescens (L.) Pauquy	27.80	84.72	n/a	77.71	75.03	9.61
Umbelliferae						
Bupleurum fruticescens Loelf. ex L. subsp. *spinosum* (Gouan) O. Bolòs & Vigo	52.30	90.60	7.70	55.00	50.70	7.70
PERENNIAL GRASSES AND FORBS ***Average***	41.06	92.79	8.50	52.64	50.93	7.77
Cruciferae						
Erucastrum virgatum C. Presl	17.30	86.20	20.60	69.30	65.20	8.65
Compositae						
Carthamus arborescens L.	25.00	91.00	9.40	50.60	46.20	6.87
Gramineae						
Agrostis castellana Boiss. & Reut.	42.60	93.80	8.50	69.90	68.10	9.90
Avenula bromoides (Gouan) H. Scholz	41.30	89.60	7.00	48.00	46.70	7.20
Brachypodium retusum (Pers.) Beauv.	39.30	90.60	8.82	63.20	63.50	8.89
Corynephorus canescens (L.) P. Beauv.	54.60	94.00	5.20	46.50	45.50	7.40
Cynodon dactylon (L.) Pers.	29.00	91.00	9.40	62.30	55.30	8.30
Dactylis glomerata L.	41.90	92.70	8.90	60.50	59.30	8.80
Festuca elegans Boiss.	62.10	95.60	5.10	47.70	46.40	7.60
Festuca indigesta Boiss.	56.30	96.50	n/a	36.10	34.40	6.30
Festuca lemanii Bastard	51.50	95.30	6.00	40.50	39.10	6.80
Festuca scariosa (Lag.) Asch. & Graebn.	53.40	96.10	9.10	34.40	32.50	6.10
Festuca trichophylla (Ducros ex Gaudin) K. Richter	44.70	90.40	5.30	44.60	45.00	7.10
Hyparrhenia hirta (L.) Stapf	43.00	92.20	4.02	55.10	53.20	7.81
Stipa tenacissima L.	39.30	98.00	7.60	41.10	44.10	6.74
Liliaceae						
Asphodelus albus Miller	15.70	91.60	12.60	72.50	70.40	9.80
ANNUAL GRASSES AND FORBS: Average	29.76	88.33	12.68	58.60	55.63	8.00

Grasses: leaves and thin twigs; Forbs: leaves and thin twigs some flowers group. In fact, when the Leguminosae family is evaluated, its shrubby species have the second highest nutritive value (CP 13.35%, IVDMD 58.35%, IVOMD 56.28%, and ME 8.50 MJ kg^{-1} DM), surpassed only by Chenopodiaceae (CP 18.43%, IVDMD 60.70%, IVOMD 58.17%, and ME 7.47 MJ kg^{-1} DM). The high CP content that this family shows can also be found in the literature (Barroso et al. 2005). Shrubs of these two families can be used in fodder plantations for livestock feeding and in land restoration, e.g. *A. decorticans*, *Coronilla juncea* L.*, Retama sphaerocarpa* (L.) Boiss.*, Cytisus fontanesii* Spach ex Ball. ssp. *fontanesii Cytisus scoparius* L. subsp. *Reverchonii* (Degen & Hervier) Rivas Goday & Rivas Mart., *Atriplex halimus* L., *Atriplex glauca* L., *Salsola oppositifolia* Desf.*, Suaeda pruinosa* Lange.

Some of the shrubs analysed had a surprisingly low nutritive value, even though they are heavily consumed by livestock, e.g. *Anthyllis cytisoides* L., *Fumana* spp., *Helianthemum* spp., *E. fragilis* or *Plantago albicans* L.

Rangeland Types

Pastures in southeastern Spain vary between esparto-grass (*Stipa tenacissima* L.) on dry steppes and mountain forests with undergrowth. The following vegetation types were differentiated and measured (Ferrer et al. 2001): forest pastures, shrub pastures, grasslands (including steppes) and *Opuntia maxima* Mill. Communities.

Table 10.3 Rangeland characteristics: plant cover (%, woodlands and shrublands: woody species; grasslands: herbaceous species), forage production (FP, kg DM ha^{-1} $year^{-1}$), metabolizable energy (RME, MJ ha^{-1} $year^{-1}$) and carrying capacity (CC, SRU[a] ha^{-1}) (Robles 1990; Fernández 1995; Boza et al. 1998; Passera et al. 2001; Robles et al. 2001)

Rangeland type	Cover	FP	RME	CC
Woodlands (Holm oak forests)	18–56	412–2,613	2,820–4,669	0.6–1.0
Tall shrublands	45–71	170–1,951	486–4,780	0.1–1.0
Medium and low shrublands				
Mountain leguminous shrublands	62–81	1,843–2,955	4,151–4,459	0.9
Medium leguminous shrublands	40–84	823–3,264	7,090–11,415	1.5–2.4
Low leguminous shrublands	34–66	371–2,454	1,233–5,708	0.3–1.2
Medium labiate shrublands	37–54	287–1,575	486–3,714	0.1–0.8
Low labiate shrublands	12–49	96–1,456	825–4,076	0.2–1.0
Halophytic shrublands	19–77	45–1,107	127–5,192	<0.1–1.1
Grasslands				
Esparto–grass steppes	25–51	211–521	560–1,457	0.1–0.3
Perennial xeromesophytic grasslands	20–80	327–1,103	1,423–4,801	0.3–1.0
Annual terophytic grasslands	n/a	156–2,403	236–5,498	<0.1–1.1
Cold and dry mountain grasslands	18–20	466–638	1,557–3,076	0.3–0.6
Cold and wet mountain grasslands	92	2,245	6,062	1.3
Opuntia maxima communities	20	3,544	10,583	2.2

[a] Small ruminant (sheep or goat) unit

Opuntia maxima is a naturalized species in the region. Forage production (kg DM ha^{-1} year^{-1}), metabolizable energy (MJ ha^{-1} year^{-1}) and carrying capacity (SRU ha^{-1}) of the most representative natural pastures are presented (Table 10.3).

Woodlands

The most abundant woody vegetation is sclerophyllous, dominated by the Holm oak (*Quercus ilex* subsp. *ballota* (Desf.) Samp.). They usually form open forests with tall shrubs (>2 m), including species such as *Olea europaea* L. var. *sylvestris* (Miller) Lehr and *Quercus coccifera* L., which are heavily consumed by livestock. The understory is shrubs and grasses of good pastoral value. The Holm oak is an important feed source for livestock and wildlife in the Mediterranean region because it offers acorns in autumn and winter and browse throughout the year. Although its nutritive value is low to medium for browse (4.5–6 MJ kg^{-1} DM), its acorns have higher energy values (9.5–11.1 MJ kg^{-1} DM). Our studies show that acorn production fluctuates between 84 and 200 kg ha^{-1} year^{-1}, while browse production ranges from 140 to 318 kg ha^{-1} year^{-1}. These values are lower than those reported in *dehesas* of wetter locations (Montero et al. 1998). Total forage production in Holm oak forests of the southeastern region, including the undergrowth, varies from 1,047 kg ha in open forests to 2,613 kg ha^{-1} year^{-1} in dense ones (Fernández-García 1995). In degraded forests (with low tree density and coverage, and overgrazed), total production is lower (412 kg ha^{-1} year^{-1}, Passera et al. 1993) than this.

Tall Shrublands

These communities are composed of tall evergreen shrubs (>2.5 m) with an understory of low shrubs and perennial grasses (Le Houérou 1993). The species that become dominant are: *Q. coccifera*, *Rhamnus lycioides* L., *Pistacia lentiscus* L., *O. europaea*, *Chamaerops humilis* L. and *Zizyphus lotus* (L.) Lam. Most have a medium or low nutritive value, except for *Z. lotus* (Table 10.2). Total forage production varies commonly between 170 and 540 kg DM ha^{-1} year^{-1}, and the carrying capacity values are 0.1–0.5 SRU ha^{-1} year^{-1}. Only certain dense shrublands, such as those dominated by *C. humilis*, can reach a production of 1,951 kg ha^{-1} year^{-1}.

Medium and Low Shrublands

These communities consist mainly of sclerophyllous and xerophytic shrubs 0.5–2 m high (nanophanerophytes and chamaephytes), with a plant cover of 12–84%. Plants from the families Leguminosae, Labiatae and Cistaceae dominate these communities. Leguminous species have good nutritive values (*A. decorticans, R. sphaerocarpa, C. juncea, Genista* spp., *Cytisus* spp.) whereas the Labiatae and Cistaceae species (*Rosmarinus officinalis* L., *Thymus* spp., *Lavanda* spp., *Cistus* spp., *Fumana* spp., *Helianthemum* spp., etc.) have low to medium nutritive values. Many abandoned agricultural areas are dominated by nitrophilous species (*Artemisia* spp., *Helichrysum* spp., *Santolina* spp.) of low to medium nutritive value and are rarely consumed by livestock.

Mountain shrublands can be found above 1,400 m, characterized by cushion-like and spiny shrubs. The dominant species are *Erinacea anthyllis* Link., *Cytisus galianoi* Talavera & P.E. Gibbs, *Genista versicolor* Boiss., *Bupleurum fruticescens Loelf. ex* L. subsp. *spinosum* (Gouan) O. Bolòs & Vigo, *Vella spinosa* Boiss. and *Hormathophylla spinosa* (L.) P. Küpfer. Many leguminous species have good grazing values while a diverse stratum of herbaceous species (especially perennial grasses, *Corynephorus canescens* (L.) P. Beauv., *Koeleria* spp., *Festuca* spp.) is very important for transhumance flocks in summer.

Medium leguminous shrublands dominated by either *Genista cinerea* (Vill.) DC., *Cytisus scoparius* L. or *R. sphaerocarpa* have the highest forage production and carrying capacity. Accompanying herbaceous species, which have production levels approaching 900 kg DM ha^{-1} year^{-1}, make an important contribution to production.

On the other hand, low leguminous shrublands are dominated by species as *Genista umbellata* (L'Hér.) Dum. Cours. or *A. cytisoides* and have variable grazing values (0.2–0.9 SRU ha^{-1} year^{-1}). The labiate medium and low shrublands are highly variable inproduction and carrying capacity (0.1–0.8 SRU ha^{-1} year^{-1} for *R. officinalis* and 0.2–0.7 SRU ha^{-1} year^{-1} for *Thymus* spp.). These differences depend on the plant cover and the herbaceous species in the understory.

Halophilous shrublands are very frequent in arid regions. These azonal communities are distributed on saline soils of marshes, wadis and depressions, where fleshy Chenopodiaceae species predominate. On average, this family has a high crude-protein value (see Table 10.2) and some species is intensely consumed by livestock (*A. halimus, S. oppositifolia, Suaeda vera* Forssk. ex J.F. Gmel.), while others as *Arthrocnemum macrostachyum* (Moric.) Moris and *Sarcocornia fruticosa* (L.) A.J. Schott are unpalatable or only occasionally eaten. Despite their very low forage production and carrying capacity, they are a key resource for livestock in summer (Le Houérou 1993). In rainy years, production increases due to the growth of the accompanying annual grasses (700 kg DM ha^{-1} year^{-1}, Boza et al. 1998).

Grasslands

Esparto-grass steppes are dominated by *Stipa tenacissima* including sparse perennial grasses(*Dactylis glomerata* L., *Avenula bromoides* (Gouan) H. Scholz, *Piptatherum coerulescens* (Desf.) P. Beauv., *Brachypodium retusum* (Pers.) Beauv., etc.) and chamaephytes (*Thymus* spp., *Lavanda* spp., *Helianthemum* spp., *Fumana* spp., etc.). These plants cover large areas in the Spanish south-east. *S. tenacissima* provides the highest total phytomass but the lowest amount of consumable herbage (Robles and Passera 1995), and has a low nutritive value. Livestock only consume young floral stems that are available only during winter. The carrying capacity is very low.

Grasslands dominated by *Lygeum spartum* Loefl. ex L., which is an unpalatable species consumed by livestock only in overgrazing situations, have a negligible carrying capacity (0.03–0.10 SRU ha^{-1} $year^{-1}$). Other perennial xeromesophytic grasslands are those dominated by *D. glomerata, B. retusum, A. bromoides, Festuca scariosa* (Lag.) Asch. & Graebn. or *Piptatherum miliaceum* (L.) Cosson.Except for *D. glomerata*, all species have a low to medium nutritive value. These species are also frequent in forests, shrublands and steppes with production of between 70 and 500 kg DM ha^{-1} $year^{-1}$. In rainier mountain areas, they reach 1,390 kg DM ha^{-1} $year^{-1}$.

Many annual terophytic grasslands are ephemeral communities with very unpalatable plants such as *Helianthemum* spp., *Filago* spp., *Evax* spp., *Loegflingia* spp., *Tolpis* spp. or *Xolhanta* spp., and these are not grazed. When altered by agricultural practices, the composition is totally different, the dominant families being Gramineae (*Bromus* spp., *Aegilops* spp., *Lolium rigidum* Gaudin, *Stipa capensis* Thunb., *Cynodon dactylon* (L.) Pers., *Hordeum murinum* L., etc.), Compositae (*Crepis* spp., *Hedypnois* spp., *Leontodon* spp., *Sonchus* spp., etc.) and Leguminosae (*Medicago* spp., *Trifolium* spp., *Trigonella* spp., *Scorpiurus* spp., etc). These constitute a good forage resource in spring (CP is 15% and ME, 8 MJ kg^{-1} DM).

In mountain areas located over 1,800 m, communities of rough perennial grasses with low palatability occur. Cold and dry grasslands cover stony grounds, which are dominated by *Festuca* spp. (*F. indigesta* Boiss., *F. lemanii* Bastard, *F. clementei* Boiss., etc.)and have a low nutritive and pastoral value. Cold and wet grasslands can be found in places with permanent moisture during summer, supplied by melting snow. Dominated by *Nardus stricta* L., their forage production can reach over 2,000 kg DM ha^{-1} $year^{-1}$. Both types of grassland play an important role in transhumance livestock systems.

Opuntia Maxima Communities

In the 1950s, the Ministry of Agriculture encouraged the plantation of this cactus in the arid southeastern Spain, as animal feed flour can be made out of its fruits. After some years the plantations were abandoned and *O. maxima* became naturalized in local shrublands, which are now grazed by livestock. Cladode production is 2,500–3,000 kg DM ha^{-1} $year^{-1}$ and in rainy years, grasses increase the overall rangeland values by up to 690 kg DM ha^{-1} $year^{-1}$. Nevertheless, the carrying capacity is not as high as it could be expected, as an excessive consumption of *O. maxima* creates digestive problems for livestock.

Proposals

Integration of Livestock and Crops

Farming activities in arid environments are diminishing, mainly due to depopulation and the abandonment of arable lands. The main causes of this desertion are the low profitability from agriculture and the loss of social, cultural and environmental values of agriculture and livestock farming. Low rainfalls, extreme temperatures and intrinsic characteristics of soils are responsible for low or very low yields in Mediterranean arid environments.

For profitability in these lands to increase, production costs must be reduced by using conservative practices such as minimum tillage and, if possible, decreasing or even eliminating the use of agrochemicals. However, the greatest economic, environmental and social profits arise from the integration of crops and livestock farming.

Sheep are a key component of Spanish arid environments due to the great adaptation and hardiness of indigenous breeds, which allow the integration of sheep in agricultural activities. An agropastoral research project is being carried out in the highlands of northern Granada, which have a continental arid climate. This region has been qualified as 'Less Favoured Area' by the CAP. Here we present a number of farming practices that are being tested in the current project. All are designed to be integrated with ovine livestock as they are benefited by livestock activities and/or contribute to its feeding.

Cereal Grazing in Winter

Grazing green cereals (*Avena sativa* L. and *Hordeum vulgare* L.) at the end of winter is a traditional practice in many Mediterranean countries (Robledo 1991). It may reduce or even eliminate grain yields, depending on the phenological status during grazing and on the influence of climatic factors. In any case, this practice offers high-quality livestock feed in winter, the season of severest feed scarcity. Farmers must balance the benefits and losses of this practice in each case.

Pastoral Stubble

Grain and straw in the stubbles of cereal are the main source of feed for extensive sheep during summer, with production that is between 1,250 and 1,870 kg DM ha^{-1} (Robledo 1991). Soil, organic-matter content and fertility are increased by livestock excreta released while grazing.

Fallows

Fallow crops begin to re-sprout after the first rains of autumn, due to the germination of early weeds and seeds of cereals that remained in the soil after harvest. The annual biomass production may vary between 1,100 and 1,200 kg DM ha^{-1} (Robledo 1991), representing most of the winter food for extensive livestock, together with rangeland grazing and without taking into account supplements. As for pastoral stubbles, sheep dung enriches the soil.

Browsing in Fodder-Shrub Plantations

A few studies have examined plantations of fodder shrubs in arid environments. This is a recent but profitable way to produce food in low-productivity areas, where livestock feeding over the winter is a serious problem. There are various species that can be used as fodder shrubs because of their nutritive value and good adaptation to the severe climate, e.g. *Medicago strasseri* Greuter et al., *Bituminaria bituminosa* (L.) C.H. Stirt, *Coronilla glauca* L., *Atriplex nummularia* Lindl., *Atriplex canescens* (Pursh) Nutt., *Atriplex lentiformis* (Torr.) S. Wats and *A. halimus* (Papanastasis 1993).

Herbage Grazing in Olive and Almond Orchards

There is usually a cover of grass under olive and almond orchards. It protects the soil against erosion and helps preserve biological activity and organic-matter content. Livestock grazing reduces the competition between the grass and the trees. Unfortunately, the interpretation of some of the CAP rules result in the continuous tillage of the orchards as a qualification for subsidies; consequently, no cover can be established and, therefore, soil protection and livestock use are not possible. Our group has studied the productivity of natural grass covers in almond orchards. Biomass production ranged from 1,820 kg DM ha^{-1} in a particularly rainy year (2004, 508 mm) to 860 kg DM ha^{-1} in a markedly dry year (2005, 214 mm). The species comprising the cover were *L. rigidum* (50%), *H. murinum* (25%), *Bromus diandrus* Roth (6%), *Medicago minima* L. (3%) and *Trigonella polyceratia* L.(3%). All of these are consumed by livestock.

Fencing

Mediterranean semiarid soils usually have low levels of organic matter (García et al. 2005) and livestock dung is an excellent source of organic matter and nutrients. Several studies have shown that numerous seeds of species of pastoral interest and/or soil improvers are spread by sheep in their dung pellets (Russi et al. 1992; Manzano et al. 2005). As these seeds often grow where they are deposited, concentrating a number of sheep in a fenced area for several days is an inexpensive way to provide a good amount of organic matter to arable lands or degraded pastures, while spreading seeds of different species. Seeds can be ingested while grazing or they can be intermingled with concentrated feed. In general, wild varieties of legumes are most successfully spread in this manner.

In conclusion, research on a number of practices which integrate crop and livestock farming is underway. All of these may enhance the profitability of farming activities (Correal and Sotomayor 1998) in the south east of Spain and, thus, help avoid rural abandonment.

Promotion of Naturalness in Ecosystems Through Grazed Fuelbreaks

Many people use the term ‘natural’ as the opposite of ‘artificial’, which can be defined as “made by humans rather than natural in origin”. So it is considered that a ‘natural’ ecosystem is one which has scarcely been affected by human activities. In this section, we propose a redefinition of this concept, incorporating people and livestock as key agents in promoting naturalness of ecosystems.

Historical Facts

In recent times, agriculture and the ensuing accelerated development have severely altered our landscapes. However, well before Neolithic times, humans hunted wild animals and used fire in their territory for very long periods of time. In fact, the genus *Homo* in southeastern Spain dates at least to 1.1 or 1.3 million years (Gibert et al. 1998). Therefore, a permanent and long-lasting intervention of humans in Iberian ecosystems must be acknowledged.

At the Fonelas site, in the Guadix-Baza basin (Granada province), fossils of large mammals such as hyenas, wild river boars, elephants, giraffes, wolf ancestors and sabre-toothed tigers have been found, these having inhabited the Andalusian savannah some 1.8 million years ago (Arribas et al. 2001).

Large gregarious herbivores have coexisted and coevolved with the present flora of the region which has developed mechanisms for reproduction and growth that ensure the persistence of certain species when subjected to intense grazing. Reductions in stocking rates could bring about the disappearance of many of these species which have a long adaptation to grazing. It must be accepted that humans have long been part of our natural ecosystems and that livestock play a key role in the conservation of certain elements of our flora.

Suggested Management

Extensive reforestation programmes have led to many areas which lack the heterogeneity and diversity of natural forests. These have little market value and should be managed for conservation to create a more natural habitat. The naturalness amelioration actions should include, firstly, the reintroduction of livestock in certain parts of the forest to restore the intense grazing dynamics that wild herbivores fail to keep at present. Animals can help spread species of pastoral or ecological value (Manzano et al. 2005). Moreover, extensive livestock farming maintains a sustainable economic activity in rural areas, which stimulates the interest of local people in the preservation of forest resources.

Secondly, areas of low tree density must be created to achieve greater plant diversity (Robles et al. 2001) and promote pastoral use. This will increase forest structural diversity and, hence, biodiversity. These areas also become fuelbreaks in an otherwise homogeneous forest, resulting in an ecosystem which is less vulnerable to severe forest fires, one of the main threats to the conservation of European Mediterranean forests. Such a silvopastoral activity is fully compatible with the protection and improvement of the environment, as encouraged by current European Union policies.

Field Research

Grazed fuelbreaks are not a new concept in international forest research and management programmes (Etienne et al. 1995), but had not been widely put into practice in Spain. Since 2003 research has encouraged the adoption of this silvopastoral fire prevention system all over the region of Andalusia.

A 45-ha experimental fuelbreak has been established in an 11-year-old *Pinus halepensis* Miller plantation located in the province of Granada. The original forest has been pruned and thinned along an irregularly shaped strip, resulting in a progressively decreasing density of 1,700, 800, 400 and 250 trees per hectare towards the central axis of the fuelbreak. Through random felling, an irregular distribution of the trees has been achieved, increasing structural diversity.

To estimate the biomass of trees left standing from their diameter at breast height, regression equations have been calculated. Annual and seasonal pasture production is being evaluated under the canopy of each of the different tree density strips. In the same plots, plant cover and diversity measurements are being carried out. The effect of grazing on the lessening of shrub and grass height and biomass is being analysed and compared with other fuel-control management techniques. The evolution of growth and structure of the tree stratum after the different intensity thinning is being monitored. Pastoral improvements through sowings of indigenous palatable species are being performed. All this research is intended to evaluate the possibilities and limitations in the application of this silvopastoral system as a useful tool for the prevention of forest fires and the promotion of biodiversity in Andalusia.

In the frame of the environmental and socioeconomic conditions that characterize southeastern Spain, we believe that these two agroforestry research and development proposals fulfil the demands of national and international institutions for a renewed integrated management. New insights into issues such as environmental protection, naturalness of ecosystems, rural development or sustainable management of agrarian resources are all on the political agenda for the coming years.

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Chapter 11
Role of Various Woody Species in Spanish Mediterranean Forest and Scrubland as Food Resources for Spanish Ibex *(Capra pyrenaica* Schinz) and Red Deer *(Cervus elaphus* L.)

T. Martínez

Abstract Spanish ibex (*Capra pyrenaica* Sinhinz) and red deer (*Cervus elaphus* L.) are highly abundant in Mediterranean habitats and are of major economic importance, primarily due to their value as game but also, in the case of red deer, for their meat. This study analyses the importance of nine woody species in the diet of two wild herbivores with browser and browser-grazer feeding habits: Spanish ibex in south-eastern and eastern Spain and red deer in south-eastern and central Spain. In south-eastern Spain, altitude (low and high zone), sex and age classes (males, females and animals younger than 2 years) and season were recorded for the whole Spanish ibex study area. Availability, selection index and specific nutritional parameters were recorded for the woody species (four) studied in south-eastern Spain. *Arbutus unedo* L., *Juniperus oxycedrus* L., *J. phoenicea* L., *Phillyrea angustifolia* L., *Ph. latifolia* L., *Pinus nigra* J.F. Arnold, *Quercus faginea* Lam., *Quercus ilex* L. and *Rosmarinus officinalis* L. were the species most eaten by Spanish ibex and red deer in the different areas studied.

Keywords Consumption, selection index, browsing, food quality, *Quercus ilex*

Introduction

Most wild herbivores diversify their diet in accordance with various types of ecological and physiological influences: unfavourable periods, limited highest quality resources, needs for specific nutrients and potential overlaps in habitats and trophic resources. Flexibility and plasticity in the feeding habits of both Spanish ibex and red deer allow them to easily adapt their consumption of the

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various plant categories based on changes in the availability of food resources in space and time (Martínez 1992, 1996; Garín et al.2001). The energy and protein content of a wide range of plant species is also one of the most important restrictions for animal productivity (Holechek et al. 2004). In Mediterranean areas, caprine and cervid diet usually contains a high richness of plant species (Álvarez and Ramos 1991; Cuartas 1992; Martínez 1992, 1994b, 1996, 2001, 2002a; Heroldová 1997). However, only a small number of species plants form a substantial part of their diets. Both Spanish ibex (*Capra pyrenaica* Sinhinz) and red deer (*Cervus elaphus* L.) are grazers and browsers according to Hofmann's (1989) definition. Both types of feeding behaviour have been observed, with a varying tendency towards one type of behaviour or other (Maillard and Casanova 1994; Groot-Bruinderink and Hazebroek 1995; Heroldová 1997; Martínez 2000, 2001, 2002a). In Mediterranean forests, and particularly in the Iberian Peninsula, browsing tendencies become much more obvious than in other type of forests developed in other type of environments different from Mediterranean area and woody vegetation is an important food resource for both studied animal species as well as for other ruminants (Boza and Robles 1988; Palacios et al. 1989; Álvarez et al. 1991; García-González and Cuartas 1992; Martínez 1992, 1994a, 1996, 2002a; Aldezabal 2001). Consequently, knowledge about and evaluation of woody species in terms of their diet contribution, availability, chemical composition and degree of selection by consuming ruminants can provide accurate information towards sustainability of the natural environment and the silvopastoral systems that they use. Thus, within the mosaic of vegetation formations making up the woody vegetation in Mediterranean environments (*Quercus ilex* woodlands, pine forests, dehesas, open hills and scrubland), several species have been found to play a particularly important role in Spanish ibex and red deer feeding patterns. This paper analyses the importance or role played by nine woody species in the feeding habits of Spanish ibex and red deer in three large areas of Mediterranean forest in the Iberian Peninsula. The plant species studied were *Arbutus unedo* L. (strawberry tree), *Juniperus oxycedrus* L. (cade), *Juniperus phoenicea* L. (sabina negral), *Phillyrea angustifolia* L. (labiernago blanco), *Phillyrea latifolia* L. (jasmine box), *Pinus nigra* J.F. Arnold subsp. *salzmammii* (Dunal) Franco (black pine), *Quercus faginea* Lam. (lusitanian oak), *Quercus ilex* subsp. *ballota* (Desf.) Samp. (holm oak) (from now named *Quercus ilex* L.) and *Rosmarinus officinalis* L.(rosemary). These species are native to Spanish Mediterranean forests and scrubland. This study quantifies and evaluates the consumption of the four most relevant woody species in the Spanish ibex and red deer total and woody diet in southeastern, eastern and central Spain. In addition to the consumption of these species, availability, the selection index of each species by the Spanish ibex and red deer, and specific nutritional parameters that explain energy and protein content were studied in south-eastern Spain.

Spanish ibex goat is an endemic species of high interest in the Iberian Peninsula due to its unique spatial distribution as it lives in meta-populations of the main Spanish mountain systems (Soriguer et al. 1992). In the two mountain massifs, Spanish ibex is well represented and it is a very important species from a hunting and ecological point of view. The domestic goat *Capra hircus* aeagrus Erxleben has similar and higher browser behaviour than Spanish ibex in the studied areas.

Red deer is a Eurasian animal, with natural distribution from west Europe to central Asia, including islands of Córcega and Cerdeña and the MAGREB (Geist 1998). Nowadays, red deer occupies most of the Iberian Peninsular land, with the exception of the west of Galicia (NW Spain) and the Levante coast (SW Spain) (Carranza 2002).

The main distribution and ecology of the main plant species evaluated based on Polunin (1982) and López (2002) are now described.

Quercus ilex is a Mediterranean species which can be found as a tree or a perennial shrub. It is abundant in the Mediterranean part of the Iberian Peninsula and it grows in all types of soils, from the coast parts (where the subspecies ilex is more frequent) to the inner parts of the country with extreme and continental climate (where the sub species ballota is more frequent) from sea level up to 1,400 m. Small shrub individuals can be found as high as 1,900–2,000 m above sea level. *Quercus faginea* is a medium size marcescent (with leaves that wither but do not fall) tree, which lives in the most part of the Iberian Peninsula and in the NW of Africa. It can be found in areas with submediterranean or continental Mediterranean (not very extreme) climate, on all type of soils.

Arbutus unedo is a perennial shrub or small tree which grows in the Mediterranean West Europe and in Ireland. It is found in temperate climates associated with *Quercus ilex* and *Quercus suber* forests and in the degraded shrubland areas derived from both forest types, mainly in calcareous and siliceous soils, and it can be found in the South mountains up to 1,200 m of altitude.

Juniperus oxycedrus is also a shrub or small tree of the Mediterranean region, found on most of the Iberian Peninsula as in the mountains and forest, dry and stony soils from the sea level over to 1,000 m and it is associated with *Quercus ilex* and other sclerophilus Mediterranean forests. A similar species, *J. communis* L., is found in all types of soils from sea level up to 2,000 m across Europe. *Juniperus phoenicea* is also a shrub or small tree of the Mediterranean region, found on all types of lands and conditions from sea level up to 1,400 m.

The genus *Phillyrea* is represented by shrubs and small perennial trees in woodlands and stony areas of the Mediterranean countries. *Ph. angustifolia* can be found in the west part of the Mediterranean region. In the Iberian Peninsula it is not found in some parts of the north and northwestern area. It is found in the shrublands of the *Quercus ilex* and *Quercus suber*, being a thermophilus plant. *Ph. latifolia* is found in the Mediterranean region, located from the southern part of the Iberian Peninsula to the east part of Cataluña and in the northeast of Galicia. It can be found in *Quercus ilex* and other sclerophilus forests, and the shrubland which appear after the destruction of these forests. It can be found in siliceous and calcareous soils.

Pinus nigra is a tree species distributed and planted in many European countries. Its natural habitats in the Iberian Peninsula in central and eastern mountains reaching 800 and 1,500 m of altitude.

Rosmarinus officinalis is a perennial aromatic shrub which is naturally distributed in the Mediterranean part of Europe. In the Iberian Peninsula, it is very frequent in the lowlands where the climate is warm. It can be found in all types of soils, but prefers calcareous soil, from sea level up to 1,500 m of altitude in the warmest mountains.

Study Area

The study area included three huge different zones (south eastern, eastern and central areas) of the Iberian Peninsula covered by Mediterranean forest and scrubland (Fig. 11.1).

The south-eastern area, the major source of information of this study, was in the in the Cazorla, Segura and Las Villas Nature Park (37°45 N and 2°40 W), where two zones with different altitudes were defined: low (800–1,500 m) and high (1,500–2,000 m). The local climate has extremely hot summers and frequent frosts in winter, with snow at the highest altitudes. Temperature and precipitation at an altitude of 1,360 m is usually around 9.8°C and 1,129 mm (10 years mean). There are two bioclimatic sub-regions: Supramediterranean, defined by the Betic Supramesomediterranean, basophyle-*Quercus faginea* and Betic Supramediterranean basophyle-*Q. rotundifolia* vegetation series, and the Oromediterranean defined by the Betic Oromediterranean basophyle-*Juniperus sabina* series (Rivas-Martínez 1987).

Fig. 11.1 Location of the studied areas

The eastern area is located in the Tortosa and Beceite Passes (40°45′ N and 0°). The area is dominated by calcareous soils, warm and dry weather with a Mediterranean tendency and continental influence. It has been recorded a mean annual temperature around 11.6°C and a precipitation mean of around 580.8 mm (Morella weather station placed at 1,000 m asl) The altitude of this area ranges between 700 and 1,340 m asl and it is a typical Mediterranean hill landscape with a range of plant formations (holm oaks, pine forests and scrubland), this vegetation formations are described by Rivas Martínez (1987).

The central area is located in the Montes de Toledo range (39°25′ N and 4°04′ W). Two zones were defined: Zone I, Quintos de Mora (Toledo) and Zone II, Retuerta de Bullaque (Ciudad Real), with a characteristic dry Mediterranean climate, mild winters and a mesomediterranean bioclimate (Rivas Martínez 1987). Mean annual registered temperature of most closed weather station (Navahermosa) was around 14.8°C, being mean annual precipitation around 508 mm. The altitude of this area ranges between 800 and 1,200 m asl. The vegetation is characteristically a mixture of *Quercus ilex*, *Q. faginea* and shrub layer of *Phillyrea angustifolia*, *Arbutus unedo*, *Cistus ladanifer*, *Rosmarinus officinalis*, *Erica arborea*, *E.australis*, and also, several pine plantations (*Pinus pinea* and *P. pinaster*).

Methodology

This paper analyses and summarises the results from a number of studies, primarily by the author but also by other researchers in south-eastern, eastern and central Spain (Palacios et al.1989; Álvarez et al. 1991; Martínez 1992, 1994a, b, 1996, 1997, 2002a). The Spanish ibex studies were conducted in south-eastern and eastern Spain, while those for red deer were conducted in south-eastern and central Spain.

Several methods and techniques used to determine a large number of parameters, are described in Martínez (1992, 1994a, 2000, 2001, 2002a). The method used to evaluate Spanish ibex diet in south-eastern Spain involved the botanical analyses of stomach contents (Martínez 1992, 2001; Klansek and Vavra 1992), while Spanish ibex diet in eastern Spain was studied using faecal analysis (Álvarez and Ramos 1991; Martínez 1988, 1994a, 2000; Heroldová 1997).

In south-eastern Spain, the study of the four most heavily consumed woody plant species by Spanish ibex was carried out for the whole studied area by altitude (low and high zone), sex and age classes (males, females and animals younger than 2 years) and season (number of samples rumen, see Table 11.2). The plant species studied were *Quercus ilex*, *Phillyrea latifolia*, *Juniperus oxycedrus* and *Rosmarinus officinalis*. In the eastern zone, consumption of the four woody plant species with highest consumption by Spanish ibex was evaluated for overall diet (225 faecal samples) and three seasons (spring (75 samples), summer (75 samples) and winter (75 samples)). The plant species studied were *Quercus ilex*, *Juniperus phoenicea*, *J. oxycedrus* and *Pinus nigra*.

Table 11.1 Availability (% biomass) and chemical composition of some plant species in south-eastern Spain

Woody species	Availability (%) Total zone	Low zone	High zone	Components (%) PROT	CC	LIG	DDM
Quercus ilex	23.7	31.0	11.0	7.5	53.2	38.5	33.8
Phillyrea latifolia	11.5	18.0	0.0	7.2	41.9	12.8	47.5
Juniperus oxycedrus	7.7	11.1	0.0	7.5	64.2	11.5	59.3
Rosmarinus officinalis	5.0	7.9	0.0	9.5	58.8	18.0	51.7
Juniperus phoenicea		–	–	6.4	75.5	18.6	64.1
Pinus nigra	–	–	–	5.0	60.2	13.6	55.8
Arbutus unedo	–	–	–	7.8	70.2	10.9	62.4
Phillyrea angustifolia	–	–	–	5.1	62.7	12.5	55.0
Quercus faginea	–	–	–	9.8	58.8	8.1	58.9

PROT = protein, CC = cellular content, LIG = lignin, DDM = apparent digestibility of dry matter

The method used to evaluate red deer diet involved the botanical analysis of stomach contents (Martínez 1992, 2001; Klansek and Vavra 1992). The study of overall red deer diet in south-eastern Spain used 16 rumen samples collected in spring, summer and winter. Red deer diet in central Spain (Montes de Toledo) was analysed using 42 samples collected in winter (December and January) in Quintos de Mora (zone I), and 16 samples from Retuerta de Bullaque (zone II) collected in autumn. The plant species studied were *Quercus ilex*, *Arbutus unedo* and *Phillyrea angustifolia* (zone I and II), *Rosmarinus officinalis* (zone I) and *Quercus faginea* (zone II).

The available vegetation in south-eastern Spain (Cazorla and Segura ranges), was sampled systematically using sampling plots set in different types of vegetation in accordance with altitudinal gradient and heterogeneity. The method described by Walker (1976) with certain modifications was used. The availability (biomass) of the woody species was evaluated on the basis of their volume and weight using regression equations (Martínez 1992).

In order to estimate availability (biomass) of shrubby and tree vegetation 11 transects were established in sampling plots of 240 m of length and 5 m width, where 4 sub-plots of 50m^2 were established and all woody plants were measured. Transects were selected taking into account the distribution of the vegetation used in the diet analyses and the higher diversity-complexity of the vegetation. Following Walker (1976) the volume of each plant was estimated. Volume was estimated from the height and higher and smaller canopy diameter. Height was estimated as below or up to 2.5 m, because this height was standardised as the maximum ungulate shrub grazing height. In order to obtain dry biomass the volume/weight ratio was calculated from regression equations which predict plant biomass from volume. The regression equation was calculated by harvesting between 10 and 20 plants of the most relevant species in the diet and vegetation. These plants were measured, fresh weight determined; cut and stored in paper bags, air dried (they were periodically weighted for 60 days until constant weight was obtained). Data were analyses with lineal regression (y = a + b x). Regression coefficients were high and significant. Confidence intervals were around 95% and the F test was used to adjust the regression. Samplings were made at the end of May.

Plant species selection was estimated by Ivlev's Selectivity Index, ISI = (D – A)/ D + A), where D – diet (consumption) and A – Availability. The values of this index lay in the −1 and + 1 range. Values close to 1 indicated high selection of plant species by the animals, negative values indicated negative selection or avoidance of the species. Values close to 0 indicated a very close relationship between species consumption and availability

Food quality in the Cazorla and Segura ranges was evaluated using chemical analysis of the different organic parameters of plant species (Martínez 1992). The plant samples consisted of leaves and stem with less than 0.5 cm collected in May. Each plant sample was analysed for four organic parameters. Crude protein content (PROT) was estimated using the Kjeldahl method with a Bouat-Afora air-dragging device and the results being multiplied by 6.25. Other parameters: cellular content (CC), lignin (LIG) and apparent digestibility of dry matter (DDM) were determined by the method of Goering and Van Soest (1970) with modifications suggested by García-Criado (1974).

Availability, Consumption and Selection Index of the Four Most Relevant Woody Plant Species in the Spanish Ibex Diet in South-Eastern Spain

The availability of the four studied species can be seen in Table 11.1. It *Quercus ilex* was the most abundant species, representing around 23.7% of the woody vegetation evaluated (40 species) (Martínez 1992). Out of the four species studied *Rosmarinus officinalis* was the least abundant (5%) of the woody plants. The availability of the resources in the low area ranged from the 31% of *Quercus ilex* to 7.9% of *Rosmarinus officinalis. Phillyrea latifolia* and *Juniperus oxycedrus* were intermediate (Table 11.1). In the high land area, only *Quercus ilex* was found with lower availability than in the low area (around 11%). The other three species in the high zone were very scarce, being found close to the limit with the low zone, where goats eat them.

Most important woody species consumed by Spanish Ibex in south east Spain were *Quercus ilex*, *Phillyrea latifolia*, *Juniperus oxyedrus* and *Rosmarinus officinalis*. They explained around 32.2% of Spanish ibex annual diet and 52.7% of all consumed woody resources (Table 11.2). *Quercus ilex* was the most consumed, followed by *Phillyrea latifolia* and *Juniperus oxycedrus*. *Rosmarinus officinalis* was considerably less consumed than the former species. *Phillyrea latifolia* and *Juniperus oxycedrus* had a positive selection index (Table 11.3).

Quercus ilex represented 14.1% and 11.2% of the diet in the low and high zonesrespectively (Table 11.2). However, the selection index was considerably

Table 11.2 Proportion (%) in the biomass of the four most relevant woody plant species in the Spanish ibex diet and red deer diet in south-eastern Spain, 2(a) percentage of total diet, 2(b) percentages within the consumed woody vegetation or woody component of the diet (WV)

2(a)	Diet (biomass %)										
	Spanish ibex										Red deer
	Annual	Low Z	High Z	♂	♀	Y	Spring	Summer	Autumn	Winter	Annual
Samples (n)	105	57	38	52	34	19	22	28	20	35	16
Woody species											
Quercus ilex	13.4	14.1	11.2	16.6	11.6	4.1	7.3	7.6	24.7	14.0	29.0
Phillyrea latifolia	9.2	17.0	0.2	9.8	5.9	15.2	9.6	7.1	10.5	10.0	9.5
Juniperus oxycedrus	6.8	8.2	5.4	5.5	10.0	5.2	1.2	0.5	4.6	16.8	3,0
Rosmarinus officinalis	2.8	2.2	3.4	3.5	2.1	2.8	2,0	1.3	1.8	5.1	12.5
Total (4 species)	32.2	41.5	20.2	35.4	29.6	27.3	20.1	16.5	41.6	45.9	54.0
WV	61.3	64.0	51.2	63.0	58.3	58.1	41.6	59.0	66.6	77.6	73.7

WV = Woody vegetation consumed, Z = Zone, Y = Young, Samples (n) = rumen samples

2(b)	WV (biomass %)										
	Spanish ibex										Red deer
Woody species	Annual	Low Z	High Z	♂	♀	Y	Spring	Summer	Autumn	Winter	Annual
Quercus ilex	22.0	22.0	21.9	26.4	19.9	7.1	17.5	12.9	37.1	18,0	39.3
Phillyrea latifolia	15.0	26.6	0.4	15.6	10.1	26.2	23.1	12,0	15.8	12.9	13.0
Juniperus oxycedrus	11.1	12.8	10.5	8.7	17.2	9,0	2.9	0.8	6.9	21.7	4.0
Rosmarinus officinalis	4.6	3.4	6.6	5.6	3.6	4.8	4.8	2.2	2.7	6.6	17.0
Total (four species)	52.7	64.8	39.4	56.3	50.8	47.0	48.3	27.9	62.5	59.2	73.3
TWV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TWV = Total woody vegetation

Table 11.3 Selection index of 4 species of plants consumed by Spanish ibex and red deer in south-eastern Spain

	Spanish ibex										Red deer
Woody species	Annual	Low Z	High Z	♂	♀	Y	Spring	Summer	Autumn	Winter	Annual
Qi	−0.04	−0.17	0.33	0.05	0.08	−0.54	−0.15	−0.29	0.22	−0.13	0.25
Pl	0.13	0.19	1.00	0.15	−0.06	0.40	0.34	0.02	0.16	0.06	0.03
Jo	0.21	0.07	1.00	0.09	0.41	0.10	−0.43	−0.80	−0.03	0.50	−0.30
Ro	−0.04	−0.40	1.00	0.06	−0.16	−0.02	−0.02	−0.39	−0.30	0.14	0.55

Z = zone, Y = young, Qi = *Quercus ilex*, Pl = *Phillyrea latifolia*, Jo = *Juniperus oxycedrus*, Ro = *Rosmarinus officinalis*

higher in the high zone than in the low zone. *Phillyrea latifolia* was the most heavily consumed and selected trophic resource in the low zone and made up 26.6%, of the woody plants. However, in the high zone this species was scarcely detected in the rumens analysed due to its absence in the high altitudinal areas (Table 11.1). *Juniperus oxycedrus* was the third most heavily consumed woody species by Spanish ibex, being intake also higher in low zones than in high zones (Table 11.2). This species was selected in both zones, but particularly at high altitudes where *Juniperus oxycedrus* is scarce. Finally, *Rosmarinus officinalis* was less eaten in the low zones than in high areas. Its selection by Spanish ibex was greater in the high zone where it is very scarce, and, as happened with *Juniperus oxyedrus* was also not found in the sampled plots. In the low zone, *Rosmarinus officinalis* was relatively abundant (Table 11.1) but was not positively selected by Ibex (Table 11.3).

In the male, female and young diets, the four studied species comprised amounts ranging from 27.3% in young to 35.4% in the case of males (Table 11.2). They comprised more than 50% of the consumed woody resources for both males and females and 47% for the young groups. Males consumed most *Quercus ilex* and showed a positive selection index. The other three species of plants also proved to be of interest in the male diet and showed a positive selection index. Female *Quercus ilex* consumption was lower than for males, but was also important as food resource for this group. Females showed an index selection close to zero, indicating that resource consumption and availability were similar (Tables 11.1 and 11.2). *Juniperus oxycedrus* was consumed by females in similar amounts to *Quercus ilex* and the selection index was positive (Tables 11.2 and 11.3). *Phillyrea latifolia* was also interesting in the female diet; meanwhile *Rosmarinus officinalis* is consumed in a lower degree (Table 11.2). The selection index for female of both plant species was negative. On the other hand, young age groups consumed much less *Quercus ilex* than male and female groups and showed a negative selection index. On the contrary, the young group primarily consumed *Phillyrea latifolia*, with a positive selection index (0.4). Finally, *Juniperus oxycedrus* was also selected by this group, and *Rosmarinus officinalis* was barely consumed (Table 11.3).

The group of four analysed species comprised from 45.9% to 16.5% of the seasonal diet, in winter and summer, respectively (Table 11.2a). This range was between 62.5% in autumn and 27.9% in summer when only woody vegetation is evaluated (Table 11.2b). In spring, the most eaten species was *Phillyrea latifolia*, followed by *Quercus ilex*. However, *Phillyrea latifolia* had a relatively high selection index, while *Quercus ilex* was rejected during this season. *Juniperus oxycedrus* and *Rosmarinus officinalis* were also rejected and their consumption was considerably lower than the previously mentioned species. The lower consumption for the four species happened during the summer, as their sum represented 16.5% of diet and 27.9% of the woody component. The most heavily consumed species were *Quercus ilex* and *Phillyrea latifolia*. As in spring, *Rosmarinus officinalis* and *Juniperus oxycedrus* were considerably less eaten. *Phillyrea latifolia* was the only species that had a positive selection index.

In autumn and winter the group of the four evaluated species represented an important component of the Spanish ibex diet (Table 11.2a). In autumn, they comprised 41.6% of total diet and 62.5% of the woody vegetation consumed. *Quercus ilex* and *Phillyrea latifolia* had a high level of consumption and positive selection index. *Juniperus oxycedrus* was consumed more in autumn than in spring and summer, and *Rosmarinus officinalis* was scarcely consumed in autumn, as occurred in spring and summer. *Juniperus oxycedrus* and *Rosmarinus officinalis* showed a negative selection index. Finally, in winter, the four analysed resources represented almost 60% of the woody vegetation consumed. In this period, *Juniperus oxycedrus* was the most heavily consumed species, surpassing its consumption in the rest of the seasons. *Quercus ilex* and *Phillyrea latifolia* were also appreciated (Table 11.2). *Rosmarinus officinalis* consumption was more than double in winter compared with the rest of the seasons. All species, with the exception of *Quercus ilex*, showed positive selection indexes, with a quite high index (0.50) for *Juniperus oxycedrus* (Table 11.3).

Consumption of the Four Most Important Woody Plant Species in the Spanish Ibex Diet in Eastern Spain

In the overall or general Spanish ibex diet, the four plant species formed 46.3% of the diet and 65.6% of all woody resources consumed. *Quercus ilex* was particularly important in the diet, followed by *Juniperus oxycedrus*, *J. phoenicea* and *Pinus nigra* (Table 11.4).

Quercus ilex was the most heavily consumed species over the three seasons studied, only being surpassed by *Pinus nigra* in the summer. Within a season, *Juniperus oxycedrus*, *J. phoenicea* and *Quercus ilex* showed a similar degree of intake. *Quercus ilex* consumption peaked in winter (25%), although it only represented around 28.4% of the woody component. This was a minor portion, considering that 88% of Spanish ibex consumption was woody vegetation in this

Table 11.4 Proportion (%) in the biomass of the four most relevant woody plant species in the total diet and in terms of the woody vegetation consumed by Spanish ibex in eastern Spain

	Annual	Spring	Summer	Winter	Annual	Spring	Summer	Winter
Woody species	Diet (Biomass %)				WV (Biomass %)			
Qi	17.3	17.0	10.0	25.0	24.5	29.5	15.1	28.4
Jp	9.7	10.3	8.5	10.0	13.7	17.9	12.8	11.4
Jo	12.2	9.9	8.5	18.0	17.3	17.2	12.8	20.5
Pn	7.1	4.0	13.8	3.5	10.1	6.9	20.9	4.0
Total	46.3	41.2	40.8	56.5	65.6	71.5	61.6	64.2
WV	70.6	57.7	66.2	88.0	100.0	100.0	100.0	100.0

WV = Woody vegetation consumed, Qi = *Quercus ilex*, Jp = *Juniperus phoenicea*, Jo = *Juniperus oxycedrus*, Pn = *Pinus nigra*, Total = Four species

period. In spring, on the other hand, this plant species constituted around the 17% of total Spanish ibex intake and 29.5% of woody matter, an indication of the importance of *Quercus ilex* in comparison to the rest of the woody species consumed in this season. Both, *Juniperus oxycedrus* and *J. phoenicea* consumption were also quite heavy in spring. In winter, the second ranking species after *Quercus ilex* was *Juniperus oxycedrus* (Table 11.4).

Consumption and Selection Index of the Four Most Relevant Woody Plant Species in Red Deer Diet in South-Eastern and Central Spain

In south-eastern Spain, overall red deer diet included 73.7% of woody plants (Table 11.2), with the four analysed species comprising 54% of the diet and 73.3% of woody resources consumed (Table 11.2) *Quercus ilex* was consumed most with 39.3% of the total woody vegetation. It was followed, to a lesser degree, by *Rosmarinus officinalis* (17%) and *Phillyrea latifolia* (13%). These three species were selected positively by red deer, with a particularly high index for *Rosmarinus officinalis* (Table 11.3). *Juniperus oxycedrus* was less consumed than the other species and showed a negative selection index by red deer.

In central Spain, red deer diet was studied in I and II zones. In zone I there was a high consumption of woody plants (95.7% of diet), with the four studied species comprising 71.5% of the total woody vegetation consumed. The most abundant species in the diet was *Quercus ilex*, followed by *Arbutus unedo*. Consumption of *Rosmarinus officinalis* and *Phillyrea angustifolia* was considerably lower (Table 11.5). In zone II, the four species comprised 61.1% of the diet and 87.3% of the woody vegetation consumed (Table 11.5). *Quercus ilex* consumption was

Table 11.5 Proportion (%) in the biomass of the four most relevant woody plant species in the total diet and in terms of the woody vegetation consumed by red deer in central Spain in winter and autumn

	Zone I		Zone II	
Woody species	Diet (%)	WV (%)	Diet (%)	WV (%)
Quercus ilex	35.4	37.0	23.1	33.0
Arbutus unedo	19.7	20.6	11.6	16.6
Phyllirea latifolia	–	–	–	–
Juniperus oxycedrus	–	–	–	–
Rosmarinus officinalis	9.4	9.8	–	–
Phillyrea angustifolia	7.0	7.3	19.4	27.7
Quercus faginea	–	–	7.0	10.0
Total (four species)	71.5	74.7	61.1	87.3
WV	95.7	100.0	70.0	100.0

WV = Woody vegetation consumed

slightly lower than in the two previous zones (23.1%), although constituted it the highest percentage of the species studied. *Phillyrea angustifolia* was consumed considerably more than in zone I (Table 11.5) but *Arbutus unedo* was consumed less in lower proportion, and *Rosmarinus officinalis* was not detected in the diet. The fourth most heavily consumed species in this zone was *Quercus faginea*.

Role or Importance of the Analysed Woody Species

Quercus ilex

In both south-eastern and eastern Spain, *Quercus ilex* has played an important role in the diet of Spanish ibex in the different periods and zones, and primarily for males and female in south-eastern area. The interest of this species has been widely reported in literature for C*apra* sp. (Schaller 1977; Cuartas and García-González 1992; Martínez 1992, 1994a, 2005; Soriguer et al. 1992).

In south-eastern Spain, *Quercus ilex* consisted of 22% of the woody vegetation consumed in the annual Spanish ibex diet (Table 11.2b), a large amount considering the high floristic richness (40) of the scrubland in this area (Martínez 1992). A close relationship was found between *Quercus ilex* consumption and availability, 22% and 23.7% respectively (Tables 11.1 and 11.2b respectively). The interest in *Quercus ilex* can also be seen in both study zones (low and high), where it was eaten a lot and had positive selection in the high zone. In the low zone, although consumption was substantial, the selection index was negative given the abundance of *Quercus ilex*. The male group consumed the largest amount of *Quercus ilex*, which also formed by far its most heavily consumed trophic resource in comparison with the rest of the ingested plant species. The male group showed positive selection for the species, indicating the interest of males in this resource, which it consumed in larger amounts than its availability. Females consumed considerable amounts of *Quercus ilex* but less than males, possibly to optimize the energy level in the diet in relation to the use of the habitat (Nudds 1980; Mangel and Clark 1986). The peak consumption periods for females were autumn (46% of woody vegetation) and winter (14.5%) (Martínez 1992), the periods of greatest resource scarcity due to low availability of herbaceous plants and limitations of many woody deciduous species. *Quercus ilex* was less relevant for young ibex as it was consumed in third place and showed a negative selection index. The young group seemed to particularly prefer *Phillyrea latifolia* and also other species of plants with relatively high digestibility and protein content (Martínez 1992). They seemed to use the same feeding strategies as those of small ungulates, i.e., consumption of highly digestible food with a high nutrient concentration, thus facilitating ingestion of new food given their smaller rumen size (Hofmann 1989).

In south-eastern Spain, *Quercus ilex* played an important role in all seasons and was practically the most heavily consumed species amongst both woody and herbaceous species. In spring its consumption was only surpassed by *Phillyrea latifolia* and in winter by *Juniperus oxycedrus*. Spanish ibex showed a high consumption of *Quercus ilex* and a positive selection index in autumn, when variety and diversity of diet was the lowest in the year. In spring, *Quercus ilex* formed a large part of the woody component of the diet (17.5%), similar to winter when woody vegetation was consumed much more (77.6% in contrast to 41.6% in spring).

In the eastern zone, *Quercus ilex* comprised 17% of the spring diet but 29.5% of the consumed woody resources, suggesting that *Quercus ilex* was important in spring in comparison with the rest of the woody species eaten (Table 11.4) and (Martínez 1994b). The relative importance of *Quercus ilex* in spring in relation to other woody species is linked to the consumption of new shoots with a higher quality (higher protein content and digestibility) than in other periods (Soriguer et al. 1992; Baraza 2004). In the summer, *Quercus ilex* was consumed in similar amounts to spring, but this was the least relevant period in terms of consumed woody vegetation. Spanish ibex diet in summer had the highest species richness, a way of compensating for the lower efficiency of digestion of heavily lignified fodder.

Quercus ilex was the species most eaten by red deer in both study areas. In south-eastern Spain it amounted to almost 40% of consumed woody vegetation, a considerable amount given that woody resources make up practically three quarters of its diet. In addition, the species was positively selected. Red deer preference for *Quercus ilex* has also been noted by other authors (Álvarez and Ramos 1991; García-González and Cuartas 1992). It has been shown that *Quercus ilex* is also very important for high browser ruminants like the domestic goat (Cuartas 1992) or even for animal species with grazing habits such as mouflon, fallow deer (Cuartas and García-González 1992; Martínez 2002a) and even sheep (Cuartas 1992).

Heavy *Quercus ilex* consumption by ruminants is linked to its abundance in many Mediterranean zones, but is also related to it nutritional value which, in comparison to other woody species, particularly with respect to its protein content, is medium quality (Martínez 1992; Baraza 2004). Its medium-low quality is primarily reflected in a high lignin content and low digestibility (Table 11.1). However, Milchunaset al. (1978) suggest that lignin-rich food facilitates gut passage, which helps to permit the ingestion of larger amounts of food and thus are of more nutritional value.

Phillyrea latifolia, Ph. angustifolia, Arbutus unedo and Quercus faginea

Phillyrea latifolia was positively selected by Spanish ibex in south-eastern Spain. In the low zone it was the most heavily consumed species and had the highest selection index of any of the four species studied in the southeast. However, in the high zone this species was scarcely detected in the analysed rumens because it does not grow or is extremely scarce in this zone. *Phillyrea latifolia* was the most heavily consumed species by the young age group, which had the highest selection index for this species. In spring, *Phillyrea latifolia* had also a positive selection by males, partially due to this group's browsing tendency. Our results show that *Phillyrea latifolia* can be regarded as a medium quality resource due to its low-medium lignin and protein content and its medium-low cellular content and digestibility (Table 11.1). The genus *Phillyrea* was a relevant diet resource for red deer. *Phillyrea latifolia* was selected positively in south-eastern Spain, while in the central zone, *Ph. angustifolia* made up a large part of the woody component of the diet (Table 11.5). *Arbutus unedo* was the second ranking species in consumption after *Quercus ilex* in Montes de Toledo (central zone). It was heavily selected by red deer, with consumption also seen in other zones (Martínez 1996). The quality of the species was relatively high given its high digestibility and medium-high protein content in data obtained for the species in the southeastern zone (Martínez 1992). Álvarez and Ramos (1991) also detected high *Phillyrea angustifolia* and *Arbutus unedo* consumption and preference amongst deer in winter in the Montes de Toledo area.

Quercus faginea showed high consumption in zone II of central Spain, forming 10% of the woody component. It was also found to be consumed by red deer and Spanish ibex in other areas, albeit in much smaller quantities (Martínez 2002a). It is a high quality resource with a high protein content and high digestibility according to data published in southeast Spain (Martínez 1992), although its tannin content is also high (Garín et al. 1996). Tannins can precipitate proteins and reduce the amount available (Robbins 1993; González-Hernández et al. 1999; González-Hernández 2005). However, herbivores adapted to the consumption of tannin-rich foods may produce salivary proteins that surround them in a highly specific way as a defence mechanism (Hagerman et al. 1992). Browsing herbivores may thus be better adapted to these tannins, as the parotid saliva gland is larger in browsers than in grazers (Hofmann 1989; Austin et al. 1989).

Rosmarinus officinalis

Rosmarinus officinalis is found in the Mediterranean region, being very frequent in the lowlands with warm climate in the Iberian Peninsula (López 2002). It should be regarded as an interesting food resource in forest and shrub environments, decreasing in accordance to the season, the geographic area and the herbivore in question. In southeast Spain, *Rosmarinus officinalis* was the least consumed resource by Spanish ibex of the four analysed, having a negative selection index, albeit close to zero. In high zones where the species was scarce, it was considerably more desirable than in low zones where it was relatively abundant, and showed a negative selection index. Its heaviest consumption was in winter, when the animals are distributed across lower areas and other herbaceous and woody resources are more limited (species that have lost their leaves and part or all of their fruits). *Rosmarinus officinalis* was avoided by females and young, while males had a higher consumption and showed positive selection (Table 11.3).

Rosmarinus officinalis was important in the diet of red deer diet, both in south-eastern and central Spain (zone I). In south-eastern zone it was the second most heavily consumed species after *Quercus ilex* and it had a particularly high selection index, suggesting a considerable preference for this resource. This is surprising considering its moderate availability in comparison with the rest of the woody resources. Its consumption could be linked to its availability, which in some areas is abundant, and to its nutritional value. Within the group of woody resources, it may be regarded as medium quality due to its relatively high cellular content and its protein content, which was higher than the other species analysed (Table 11.1).

Juniperus oxycedrus

In eastern Spain *Juniperus oxycedrus* was the second most consumed species by Spanish ibex after *Quercus ilex*. It was important in all seasons but most specially in winter. In south-eastern Spain, in both zones, Spanish ibex consumed a lot of *Juniperus oxycedrus* (with positive selection index), more so in the low zones than in the high zones, where it is scarce. *Juniperus oxycedrus* was selected in south-eastern Spain by females, who consumed similar quantities of this species to *Quercus ilex*. The three animal groups (males, females and young) showed positive selection for *Juniperus oxycedrus*. In winter, *Juniperus oxycedrus* was consumed more than at any other time. In this season, *Juniperus* spp. has a lower concentration of volatile oils and is more palatable (Riddle et al. 1996). *Juniperus oxycedrus* was less eaten in summer, probably because wider food resource diversity (flowers and fruits of rosacea and other species) was available, and because *Juniperus oxycedrus* is scarce (has low availability) in the high zone where Spanish ibex is more abundant in this season. *Juniperus* *oxycedrus* may be bromatologically regarded as medium quality (Table 11.1), given that its cellular content and digestibility are relatively high for a woody plant. This may be because its consumption was high and the species was selected positively, particularly in winter when there is more qualitative and quantitative limitation of food resources. Both protein content and digestibility passed the minimum nutritional threshold required for ruminants (ARC 1968). Several *Juniperus* spp. species are more palatable in autumn and winter than in the other seasons, due to their lower content of volatile oils (Riddle et al. 1996), and probably also due to lower tannin content. In general, plants containing tannin tend to reach their peak levels in the growth season, after which they decline until the end of winter (González-Hernández et al. 2003). *Juniperus* spp. was selected by Spanish ibex in Mediterranean areas and also in alpine zones (Sierra Nevada) where, although it ate mainly pasture, *Juniperus communis* was one of the three most heavily consumed woody species and produced high selection indices (Martínez 2002b). Domestic goats in Texas also have abundant consumption of several *Juniperus* ssp., species which in fact are used in their control in several areas (Riddle et al. 1996).

Juniperus oxycedrus consumption by red deer is a controversial issue and varies between populations (Garín et al.2001). *J. communis* is a significant part of red deer diet in some areas of the Aragon Pyrenees (Garín et al. 2001). In our Mediterranean study areas, however, *Juniperus oxycedrus* consumption was practically nonexistent in central Spain, while in the southeast zone it was considerably less important for red deer than for Spanish ibex (Tables 11.2 and 11.5). This might be due to the patchy distribution of *Juniperus oxycedrus* in the study area, which does not always coincide with the distribution of the red deer population, or to its greater preference for more abundant and similar or better quality resources in its grazing area. Red deer thus seems to only use *Juniperus oxycedrus* in periods or situations of limited food supply, as shown by its lowest percentage in the red deer diet and its negative selection index.

Juniperus phoenicea

Juniperus phoenicea was the third most important plant species consumed in the Spanish ibex diet in eastern Spain, with uniform consumption throughout the three study seasons. It tended to be slightly less eaten in summer when species richness in the diet was greater (Martínez 1994b). In the high zones of Sierra Nevada, *Juniperus sabina* was also eaten and selected with a relatively high selection index (Martínez 2001). *Juniperus phoenicea* had low protein content, high lignin and cellular content (Table 11.1), and high digestibility (64.1%) compared with other woody species. The latter factor had a positive effect on consumption, with *Juniperus phoenicea* helping to meet the animal's energy requirements. High *Juniperus phoenicea* consumption by Spanish ibex in eastern Spain may be linked to its availability and food stress suffered by herbivores in various Mediterranean zones as a consequence of high stocking rates (wild and domestic) and shortage or limitation of trophic resources in unfavourable periods or years triggered by climate conditions. In eastern Spain, all species that played a major dietary role (*Quercus ilex*, *Juniperus oxycedrus*, *J. phoenicea* and *Pinus nigra*) were of medium or medium-low quality, a reflection of the Ibex's efficiency in processing trophic resources. Some species are ranked as low quality as they contain terpenoids that may reduce the digestion of other feed through an inhibition effect on the microbial activity of the rumen (Schwartz et al. 1980; Maizeret and Tran Manh 1984).

Pinus nigra

Pinus spp. is a resource which, according to literature (Cuartas 1992; Martínez 1994b, 1996, 2002a; Heroldová 1997; Garínet al. 2001) is usually found to some degree in wild ungulate diets. However, *Pinus* spp. consumption fluctuates greatly between species, seasons and the availability of resources that are more preferred. In eastern Spain it was consumed most in summer (20.9% of woody vegetation) and in largest amounts by males (Martínez 1994a). In the south-eastern zone, Cuartas(1992) also observed large amounts of *Pinus nigra* in red deer and fallow deer diets, as well as in domestic goat and sheep. *Pinus nigra* showed a very low protein content with medium values for the rest of the analysed parameters (Table 11.1). These results were similar to the results found by Garín et al. (1996) for the same species in the Pyrenees. At medium-high altitudes in Sierra Nevada, *Pinus sylvestris* was consumed by Spanish ibex in July, forming 5.7% of its diet in a zone where grazing was the primary feeding habit, and woody plants were less than 19% of the diet (Martínez 2000). Spanish ibex used *Pinus nigra* shoots in spring, when the protein content is highest (Garín et al. 1996), but particularly in summer, the least favourable season for quality of other resources, and less used in winter, when *Quercus ilex* was most frequently eaten and consumed more by males. All of these results show that *Pinus* spp. can meet certain food requirements and is a recurrent resource for Spanish Ibex and other large herbivores, particularly in unfavourable zones and seasons.

Conclusions

Arbutus unedo, *Juniperus oxycedrus*, *J. phoenicea*, *Phillyrea angustifolia*, *Ph. latifolia*, *Pinus nigra*, *Quercus faginea*, *Quercus ilex* and *Rosmarinus officinalis* were the species most eaten by Spanish ibex and red deer in the different Spanish areas studied. *Quercus ilex* was specially eaten by both ungulates and particularly by red deer. *Phillyrea latifolia*, *Juniperus oxycedrus* and *J. phoenicea* were the most eaten species by Spanish ibex after *Quercus ilex*. In contrast, red deer ate *Arbutus unedo*, *Phillyrea angustifolia*, *Ph. latifolia* and *Rosmarinus officinalis*.

The selection index of the fourth most important species eaten by Spanish ibex in south-east Spain was a different and depended on the area (lowlands and highlands), on seasons, and type of animals (males, females and young). Red deer positively selected the three most consumed species, but the fourth (*Juniperus oxycedrus*) had a negative selection index.

The importance of the analysed plant species for Spanish ibex and red deer diets depended largely on their availability and nutritive quality. Many of these species do not have an optimum nutritive quality, given that they are heavily lignified plants with medium-low digestibility and medium-low protein content. Consequently, Spanish ibex and red deer seem to maximise the capacity for obtaining energy from these plants species, given that they are an important part of their diet.

The exploitation of these species studied would be mainly by cervids and caprines (especially red deer and goats) as they consume those most, primarily in critical periods when herbaceous vegetation is in very limited supply and deciduous woody species have lost their leaves.

Potential pressure of herbivores on certain plant species, together with a tendency towards lower rainfall and higher temperatures in the semiarid Mediterranean zone may lead to a degradation of plant cover with less biomass production in the natural ecosystems. In this context, forest and grassland management trends should focus on re-defining the optimum densities of both wild and domestic ungulates to a sustainable level in the environment.

Given the crucial role of *Quercus ilex* as a food species for Spanish ibex and red deer in the Mediterranean habitats, its importance for domestic goats and, albeit on a smaller scale, other wild and domestic herbivores, optimum control of stocking rates of the various ruminants is a recommendable management strategy with a view to protecting *Quercus ilex* from heavy browsing impact and taking into account possible negative effects on tree regeneration. This policy will benefit the silvopastoral systems through appropriate management of herbivore populations, encourage regrowth and prevent exhaustion and stripping of plants that are accessible to large herbivores.

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Chapter 12
Agroforestry Systems in Italy: Traditions Towards Modern Management

A. Pardini

Abstract The long history of civilization and the passage of several different cultures have produced slow changes in the Italian landscape. Changes in land use have created a large number of agroforestry systems, comprising natural or planted tree stands and shrub species with different densities in which botanical composition, productivity and management are much diversified. The traditional integration of pasture and woody plants has been disrupted by modern agriculture. However, this disruption did not spread in marginal areas and has never resulted in complete separation of the different resources. The result has been complex systems which are difficult, expensive to manage and non-competitive, although they are more resilient to environmental changes than specialized ones. The current concerns of people about their quality of life (including food quality and nature conservation) and the development of new economic sectors related to recreational activities (including farm tourism, game hunting, educational services and valorisation of local genetic resources) have opened up new opportunities for the integration of rural economies into the wider regional economy. Modern techniques for integrated, modern management of pasture, forest and cropped areas can be further integrated to increase multiple uses of the territory and integrated economic development. In Italy, landscape diversity can nowadays be valued more highly than in areas with specialized land uses. Some examples of agroforestry systems from mountains and plains are given and some opportunities for their integration in the developing economy are discussed.

Keywords Trees and pasture, land management, eco-tourism, natural resource tourism

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A. Rigueiro-Rodríguez et al. (eds.), *Agroforestry in Europe: Current Status and Future Prospects*.

Introduction

The countries around the Mediterranean Basin have about 121 million hectares of pastures and 88 million hectares of forest (FAO 2006; Pardini 2006). The area is home to over 450 million people and it is characterized by diversity of economic and social development. A large number of people have been living in rural areas and engaging in rural activities for over two millennia creating a continuing evolving natural landscape in Mediterranean Europe (Talamucci and Chaulet 1989). In Italy the areas of forest, pasture and cropped fields have undergone changes over time (Sereni 1987): forests were reduced and cropped fields increased until the 16th century, after this a new equilibrium was reached and maintained until the mid 18th century when a massive increase in population number resulted in land reclamation and crop growing spread into marginal areas. At that time farming was always linked to livestock production: cattle were reared for meat and milk, manure was used as fertiliser for cropped fields and draft animals used to plough the soil. Sheep produced meat, milk and wool and herds were reared mainly on family farms which depended on transhumance.

For a long time forests were harvested for wood, the understory vegetation was grazed and branches were cut to provide green leaves to livestock during summer. In Italy, at the beginning of the 20th century, forest contribution to livestock forage was around 50% of the diet (Pontecorvo 1933; Vignati 1936). This high stocking rate damaged the forest resource. However, forest grazing remained unregulated until a Forest Law of 1923 (GURI 1924), which finally legalized and set important limitations to this practice (Gambi 1982; Talamucci 1991).

Current Types of Pastoral Systems in Italy

Many changes have taken place since the 1950s (Fig. 12.1): urbanization and reduced human birth rates have resulted in concentration of agriculture and animal rearing in intensive areas. The number of enterprises with extensive rearing decreased, consequently land conservation was reduced, pastures were encroached by shrubs and risk of fires were increased (Talamucci 1993). These problems led to the need for tree reintroduction in complex systems, and at the same time integration of conventional agriculture with modern ecosystem services were sought in integrated systems.

Currently, agriculture is subsidised in Italy to limit further land abandonment. At present it is estimated land abandonment (Fig. 12.2) is about 30–75% in different Alpine areas and 25–70% in the Apennines. Within the mosaic of diversified conditions, although pasture undergrazing is very common, there are overgrazed patches within undergrazed pastures. Damage to the nearby forest vegetation usually happens when grazing in nearby pastures exceeds the carrying capacity. The area of Italy is around 29 million hectares, of which two thirds are arable and the rest is rocky mountains or poor forests on steep slopes. Agricultural land has lost 5 million hectares from

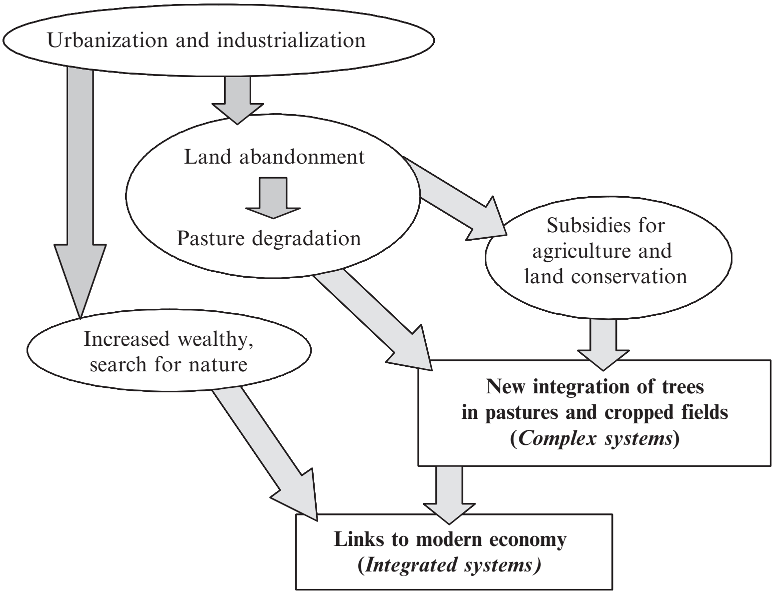

Fig. 12.1 Dynamics of recent changes in Italian pastoral systems

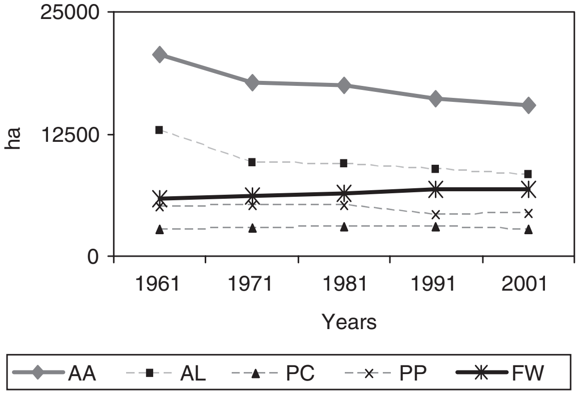

Fig. 12.2 Changes in agricultural area (AA, grey) and forests and woodlands (FW, black) area in Italy from 1961 to 2001. Agricultural area comprises arable land (AL) permanent crops (PC) and permanent pastures (PP). Hectares × 1,000 (FAO 2006)

1961 to 2006, in the same period the pasture area increased as a proportion of the agricultural area from 24.5% to 28.2%, but it was reduced as percentage of the total area. In the same period, the forest area increased by around 913,000 ha and the arable land was reduced by 8,000 ha (FAO 2006). The result of the expansion of pasture and forest land has meant the return of trees and shrubs in pastures and the new conversion of pastures and cropped fields to early stages of forest.

Environmental diversity as well as the different management systems introduced in different historical periods contributed to enhancing the variability of farming and of pastoral systems in Italy (Pardini and Rossini 1997; Pardini 2002). These systems are more extensive in Italy than in countries with shorter history. Examples are pastures with scattered trees (pastures with a few trees left, usually less than 50 per hectare), park-forests (forests managed for recreation, usually near to towns, thinned out and cleared of most of the understory), thinned out forests (forests cleared with selective or geometrical tree removal, with density reduced to also allow grazing), tree plantations (usually fast growing tree species or valuable hardwoods planted in rows, where the competition from pasture is reduced by periodical mowing or by grazing) and forage shrub plantations (usually in the form of alley-cropping). All these resources integrate trees, animal grazing and usually cropped fields depending on farm structure. Motor-vehicle transhumance with service herds that graze abandoned pastures in Alpine areas to maintain their beauty is a possibility to link traditional and modern practices. These integrations have resulted in conventional complex pastoral systems (Table 12.1) as well as integrated pastoral systems that comprise farm tourism, game hunting, and educational activities. Although both the traditional and conventional complex systems use the same resources as the integrated systems, the latter offers opportunity to diversify income and to make the survival of marginal farms possible. Hence, integrated systems need different overall management than conventional complex systems as their outputs are different.

The need for management changes is understood, and will benefit the increase of biodiversity and modern management by helping to develop links with the modern economy through in-farm sale of quality foods, farm-tourism and educational activities. In turn these changes will help develop new approaches to land care and to improve environmental protection.

In this classification, the agro-silvo-pastoral systems are found within traditional complex systems and in integrated systems. Complex and integrated systems have

Table 12.1 Classification of pastoral systems on the basis of the level of complexity, according to number and type of resources in the system (Pardini 2005)

System	Complexity	Number and type of resources		Examples of resources
Traditional	Simple	1	Pastures	Native and sown pastures, pasture mixtures with diversified heading dates
	Medium	2	Pastures, forage crops	+ Forage crops for hay or silage
	Complex	>3	Pastures, forage crops, resources else than forage	+ Forest, shrub plantations, sown firebreaks and ski lanes
Integrated	Very complex	+	Integration with different economic resources	+ Links to game hunting, farm-tourism, environmental education

Table 12.2 Possible factors for improvement of the four types of pastoral systems

System type		Possibile interventions
Traditional	Simple	Traditional improvements to pasture management
	Medium	Traditional improvement to pasture and forage crops
	Complex	(Comprise agro-silvo-pastoral systems). Integration of pasture plants and trees, including resources placed in distant part of the territory by transhumance on motor-vehicles
	Integrated	(Comprise agro-silvo-pastoral systems) Development of links with other economic sectors

higher ecological stability and more sustainable productivity than simple systems; in fact their higher biodiversity buffers them against occasional fluctuations in climate and the economy (Pardini 2005). Considerable management input is necessary in both complex and integrated systems. Management does not mean reduced ecological stability. This depends on the ecological basis underpinning the management. A strong but sustainable management is preferable to a low input bad management. Integrated systems can be more stable than complex systems because all conventional systems are geared to the maximum productivity of the resource that consequently is managed at the limit of its sustainability. In contrast, integrated systems are aimed at sustainable productivity and diversified incomes through services that are favoured by the maintenance of natural conditions that reduce the exploitation of the vegetation. Different strategies for improvement apply to systems with different level of complexity (Table 12.2).

Geographical Distribution of Agroforestry Systems in Italy

Oak, pine and larch stands are the most important existing complex and integrated systems which could support further development in Italy (Fig. 12.3):

1. *Quercus pubescens* Wild., *Q. cerris* L., *Q. suber* L. and *Q. ilex* L. are found in mixed forests in central and southern Italy and on the main islands. These forests cover about 279,263 ha (Bernetti 1995) and they frequently exist as components of silvopastoral systems that integrate several resources within the farm. Some of these forests are thinned out to allow cattle or sheep grazing, others are being converted to parkland forests. The understorey comprises many palatable species of small size like *Acer campestre* L., *Acer monspessulanum* L., *Alnus cordata* C. (Loisel.) Dub., *Crataegus monogyna* Jacq., *Quercus cerris* L. and some unpalatable shrubs (like *Cistus salvifolius* L., *Erica arborea* L., *E. scoparia* L., *Juniperus communis* L. and *Spartium junceum* L.) but, usually, not much herbage species as little light reaches the lowest layer. These forests are grazed in summer, when livestock seeks green leaves and shade, and in winter when the tree stands protects the animals from cold winds.

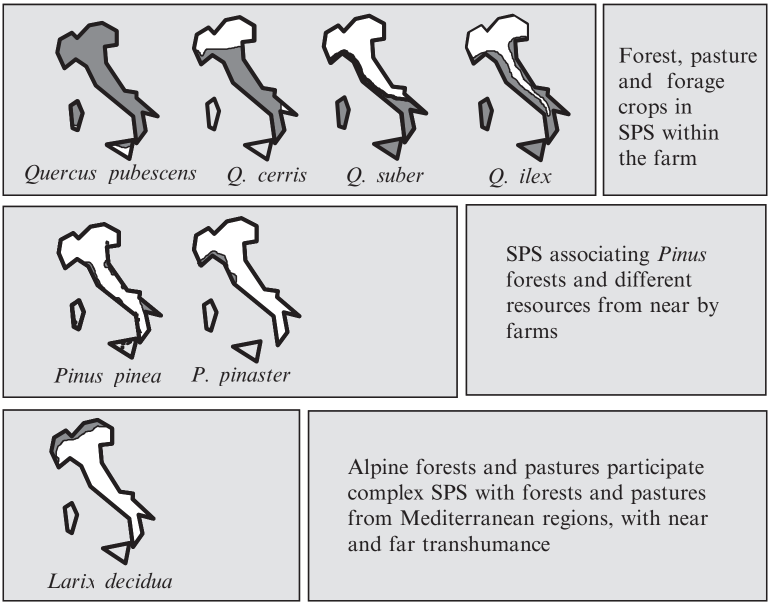

Fig. 12.3 Area of the main forest species associated with different kinds of silvopastoral systems (SPS) in Italy

2. *Pinus pinea* L. and *P. pinaster* Ait. park forests. Pine species cover about 362,126 ha and are mainly distributed in Central Italy. The understorey normally consists of unpalatable shrubs (mostly the same species found in oak forests) and very little herbage. Hence they are visited only occasionally by livestock. These forests, owned either by private farms or public administrations, are part of silvopastoral systems as an external farm component. They support horse riding and trekking from nearby farms and, so generate important complementary incomes for local farms. Also public administrations benefit from tourism in their municipalities.
3. *Larix decidua* forests cover 102,319 ha mainly in northern Italy. Some of these forests have pastures under low tree density stands. Pastures are normally native, comprise 30–60 herbage species and so are very important for biological diversity conservation. These pastures are grazed in summer by cattle or sheep moving from the valleys or sometimes as part of mechanized transhumance from Mediterranean regions.

Despite the variability due to the physical environment, forage production of forest understorey remains low in all the forest types considered in this article (Table 12.3). The annual dry matter production of forage from the understorey is frequently between 0.1 and 4 t ha^{-1} and consequently is too low to feed high stocking rates of

Table 12.3 Productivity of the understorey (herbage and palatable shrub leaves) and periods of presence of animals (Pardini, unpublished data)

Species	Forage yield (DM t ha^{-1})	Type and periods of grazing
Quercus pubescens, *Q. cerris*, Q. ilex, Q. suber	3–6	Seasonal (summer, winter) and occasional
Pinus pinea, *P. pinaster*	0.1–1	Occasional
Larix deciduas	1–4	Seasonal (summer)

livestock all the year round (Pardini et al. 1987) The forest ameliorates forage availability in the hot and the cold season, provides shade in summer and shelter from wind in winter.

Pasture production in oak forests is low (1–2 t DM ha^{-1}) but shrubs can contribute with 2–4 t DM of leaves per hectarewhich are palatable, especially for native cattle breeds (examples are *Chianina* and *Maremmana*) while sheep eat only young and low-growing shrubs. The livestock spend most of the year on farm pastures and move into the forests in summer and winter. During these seasons they are also fed with hay and silage that is normally produced from forage crops on the same farm.

Pine forests are rarely grazed, however they are important for land conservation (reduction of soil erosion) and because they support rural tourism. They can generate important income for private farms and local administrations that have developed organized horse back riding and trekking. Livestock presence is only occasional, limited to tourists' horses, or to temporary visitors from herds of nearby farms. Tourists pay for the trekking service and they can stop and rest in the farm where they buy local products. A better integration of these forests in animal rearing systems, with periodical grazing, could limit the growth of the understory and consequently reduce fire risk. On the other hand grazing could reduce the costs of periodical mechanical cutting that is done in some cases.

Larch forests frequently have sparse trees and productive pasture that is grazed in summer. Livestock move from the valleys (a short transhumance) to graze and sometimes there is also grazing by service herds from the Mediterranean regions (involving long transhumance in trucks). Service herds are needed by some Alpine municipalities to maintain abandoned pastures with minimal grazing (Staglianò et al. 2000).

In most of the described forest cases, timber, firewood and herbage alone cannot generate sufficient income to keep people on their land. Consequently, many managers have favoured the reduction of forest density (selective cutting or regular clearing) or the planting of trees into pastures (20–30% of soil cover) to develop new income sources from farm-tourism, educational services for school classes and game hunting. It is understood that new management plans for pastures and forests will be integrated and traditional practices will be linked to modern ones.

From Traditional to Integrated Management

Oak Forests

In the Mediterranean region of Italy oak forests are mainly *Quercus cerris*, *Q. ilex*, *Q. pubescens*, *Q. suber*. and they grow in mixed forest with other *Quercus* species and trees of many other genera. Except for the cork oak, the other oak forests derive from old coppices used for firewood up until the 1950s. Tall *Q. pubescens* trees were left to grow in coppices to provide acorns for grazing pigs. Nowadays these forests are home to species such as boar (*Sus scrofa* L.), red deer (*Cervus elaphus* L.), mouflon (*Ovis musimon* Schr.) and many other animals. Some forests are now being left to grow and convert to high stands and some will be thinned out to make parkland forests in which farm tourism with trekking and horseback riding can be promoted.

Many oak forests in private or public lands are grazed by livestock and wild game is common (Gambi 1982; Bagnaresi et al. 1984). Livestock is frequently cattle or sheep whilst mixed herds are rare. Forest grazing takes place in summer when animals seek shadow and green leaves and in winter when the trees provide shelter from cold winds (Talamucci et al. 1995, 1996b). During the highly productive seasons (spring and autumn) livestock graze on farm pastures or they stay part of the day in stables (Fig. 12.4). Livestock used are frequently native rustic breeds (Chianina is the most common, Maremmana is probably the most resistant, other native breeds can also be found) because these are better adapted to the harsh conditions of the physical environment in comparison to the breeds from northern Europe. However, other beef breeds can also be found. Sheep do not usually graze into the tree stand unless the forest has been thinned out and also the understorey density reduced in a high degree.

Traditional complex systems on the same farm are frequent and they are composed of pastures, forage crops, forest and sown firebreaks (Table 12.4). Modern integrated systems are already frequent as many farms have started nature-tourism activities which include horseback riding, four wheel driving, trekking and game hunting. In addition, some farms receive payment from regional institutions for

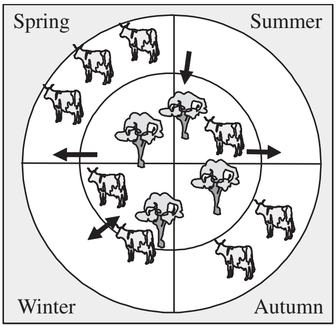

Fig. 12.4 Livestock movements during the four seasons are shown clockwise. Livestock moves within the farm from pastures (outer circle) into forests (inner circle) during summer and winter and back to pastures in the milder seasons

Table 12.4 Traditional and modern management objectives of Mediterranean oak forests

Forest	Traditional objectives	Modern objectives
Quercus spp.	Firewood + timber + extensive animal rearing during summer and winter	Links with on-farm sale of produce, quality products, links with other economic activities, (game hunting, horseback riding, trekking, farm tourism, educational activities
Q. suber	Cork, occasional grazing	Cork, occasional tourism

educational activities in which school classes participate in some of the farm work. These links can be further developed but there is a need for land management changes, mainly better nature conservation dealing with increasing biodiversity, increasing of land use diversity, increasing land care, paying special attention to tourism facilities and to the natural beauty of the territory (Pardini et al. 2002). Fortunately, the shift to integrated systems usually reduces the impact on the natural environment by creating better conditions for conservation of plant and animal diversity and for tree regeneration. Moreover, the reduced impact of these practices on forests should allow tall stands to grow, replacing younger and smaller trees derived from abandoned coppices, thus producing better timber products.

Pine Forests in the Mediterranean Italy

Italian pine forests comprise *P. pinaster* and *Pinus pinea* stands along the coast and in hilly areas inland.

P. pinaster is native to the Western Mediterranean area and is nowadays naturalized in many parts of Italy, where it frequently forms the forests nearest to the sea due to its salt tolerance. However excessive salinity and air and aerosol pollution have caused consistent damage to this kind of forest which is also prone to wildfires (Mondino and Bernetti 1998). Moreover, *P. pinaster* is attacked by the parasite *Matsucoccus feytaudi* Duc. that has spread to Italy since the 1950s and is devastating this species to such an extent that *P. pinaster* could become just an occasional tree in mixed stand oak forests. *P. pinea* (stone pine) parkland forests are found more on the coast than *P. pinaster* and they are traditionally used for recreation tourism and pine nut harvesting (1 kg of pine nut costs about €50 in any local market). Stone Pine has been planted inland in pure stands or mixed with other coniferous species (*P. pinea*, *Cupressus sempervirens* L.) and several broadleaves (*Quercus* spp.). The wood from these pines is used for woodchips, some timber is used to build facilities for the visitors to the forest itself (picnic tables, benches, paths, fences and information boards). The forest understorey is made up of shrubs (mainly species of *Erica arborea* L., *E. scoparia* L., *Juniperus communis* L., *Cistus* spp. *Spartium junceum* L., *Cytisus scoparius* L. W.D.J. Koch) rather than pasture or herbs, consequently no livestock is brought in except than for horse rid-

Fig. 12.5 Livestock movements during the four seasons are shown clockwise. Occasional incursions of horses and herds of cattle or sheep coming from nearby farms (small external circles) cause moderate grazing into pine forests (large circle). This can happen in any season

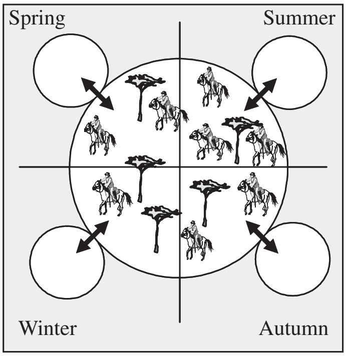

Table 12.5 Traditional and modern management objectives of Mediterranean pine forests

Forest	Traditional objectives	Modern objectives
Pinus pinaster	Woodchip	Environmental protection (mainly coasts). Links with farm tourism
Pinus pinea	Woodchip + pine nuts	Pine nut. Environmental protection. Links with farm tourism

ing. Wild game enters occasionally from nearby forests. However, these forests are part of a diversified economy of neighbouring farms that integrate agriculture, forestry and pastoralism with nature tourism (Fig. 12.5). Fire risks are usually higher in these pine stands than in oak or larch forests, mainly because pines contain lots of inflammable resins and grow in climates with dry hot summers more than larch or some oaks.

Traditional complex silvopastoral systems are not possible as these forests do not support animal grazing. However; there are opportunities for further development of modern integrated systems as these forests are beautiful and of value in supporting tourism on nearby farms (Table 12.5). Silvicultural practices (Bianchi et al. 2005) aim to eliminate the oldest trees (the average age of *P. pinea* in Tuscany is 85 years with some trees 140 years old) and favour progressive renovation of opened stands in which pine nuts can be harvested and farm tourism will contribute to diversification of the rural economy. The occasional presence of livestock from nearby farms can help to limit the growth of shrubs that could encroach and become obstacles to nut harvesting and to reduce risks of wildfires (Pardini et al. 1999).

Larix Decidua Mill. Forest

Larch is found in the Alps, frequently associated with *Pinus cembra* L. at high altitudes or in pure stands grazed by dairy cattle or sheep at lower altitudes. Low forests can produce good timber, however there is also grazing where the understory is rich enough to sustain herds (Giordano 1955) that move from the pasture valley during summer. Although *Larix decidua* is an Alpine species, some forests of this type are linked to the Mediterranean as part of the summer transhumance system (Fig. 12.6). Sheep herds are carried on trucks to graze on green pastures during summer and, in some cases, the Alpine Municipalities organize and pay to get the pastures grazed by Mediterranean sheep to limit shrub encroachment. The animals used for this practice are called "service herds" (Talamucci et al. 1996a) and their effect is to maintain short pasture, preventing the spread of fires. Most importantly, they prevent tall common species *Deschampsia caespitosa* (L.) Beauv. and *Trisetum flavescens* (L.) Beauv. competing excessively with smaller species such as *Trifolium repens* L., *T. badium* Schreber, *Lotus corniculatus* L. and other small species that are known as officinals (*Alchemilla vulgaris* L., *Gentiana* spp., *Campanula* spp.) many of which need high intensity of light.

In the traditional system sheep graze pastures at lower stocking rate than optimal and they frequently also enter *Larix* forests (Table 12.6). This kind of system comprises elements of the traditional complex system (integration of Alpine forest and Mediterranean pastures) and others of the modern integrated system (integration with on-farm sale of milk and cheese for tourists).

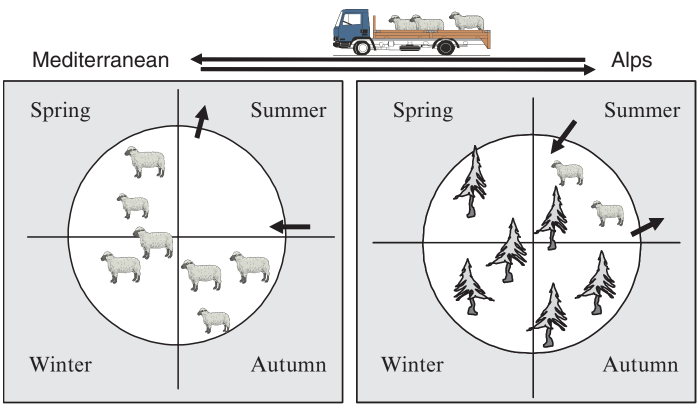

Fig. 12.6 Livestock movements during the four seasons are shown clockwise. Summer transhumance from Mediterranean regions (left circle) bringing livestock to graze in forests of the Alpine chain (right circle), and back to the Mediterranean at the end of Summer. Black arrows show livestock arrival or departure from the system

Table 12.6 Traditional and modern management objectives for mountain pine forests

Forest	Traditional objectives	Modern objectives
Larix decidua (Alps)	Timber + extensive animal rearing during summer	Links with on-farm sale of produce, quality products, links with other economic activities

The presence of small herds makes it impossible to attempt to increase pasture productivity for example by fertilising due to the low profitability of this management practice. This management – the lack of fertilization – does however help maintain higher levels of plant diversity.

One of the main problems of herd and pasture management in the Alps is the difficulty in finding shepherds. Even if they are offered lucrative payments, only emigrants from eastern Europe or north Africa are available for this specialized work that obliges people to remain a whole season in marginal areas far away from their own towns.

Conclusions

The present condition of Italian forests is complex. Despite the many agronomic and pastoral tools available to increase productivity and quality of pastures, traditional animal rearing in Italy cannot generate enough income for rural people living in marginal areas. Land abandonment will occur unless new income sources are found by linking traditional activities with emerging sectors of the economy. It is important to highlight that rural economies are linked to regional and national development programmes. These links will cause management changes which will probably highlight the production of non-market goods and traditional production for timber, firewood, other forest products, forage and animal products as being secondary in many areas of the country. These changes are favoured by diversification of land uses and the integration of pastures, forage crops, forage trees and shrubs and forests to form complex agro-silvo pastoral systems. The organization of integrated pastoral systems can be a further step in the economic diversification of rural activities. Such integrated systems can embrace on-farm sale of quality foods, farm tourism, game hunting and the organisation of educational activities that will be carried out on farms by local schools. Many examples of these integrated management systems already exist in Italy and they can be developed further.

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Chapter 13
Economics of Multiple Use Cork Oak Woodlands: Two Case Studies of Agroforestry Systems

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Abstract Jerez (Spain) and Iteimia (Tunisia) cork oak agroforestry systems have close natural environments but they differ in land property rights, labour market and economic development contexts. These human induced differences result in similarities and dissimilarities on natural resources multiple use management. In this study we apply a simplified agroforestry accounting system (AAS) in two publicly owned cork oak agroforestry systems (COAS) for an average year, assuming steady state situation, without considering both environmental outputs (private and public) and government expenditures. The study objectives are to analyse the multiple Jerez and Iteimia agroforestry system activities intra-relationships taking into account intermediate outputs and to estimate a set of on-site cork oak agroforestry economic indicators related to single activity and the COAS as whole aggregated activities. In addition, in order to estimate separately the Iteimia open access grazing resource rent and the household's self-employed labour cost, we propose a simulated pricing approach trade-off as an alternative to close substitute goods pricing method. The study results show that Jerez generates a commercial capital income loss and employees receive competitive wage rate, while undertakes a significant investment on agroforestry natural resources conservation and improvements. Opposite to Jerez, Iteimia actual management offers a positive capital income and a high household self-employed labour income on hectare basis, mainly from livestock and, in a less extent, other agroforestry land uses carried out in the local subsistence-economy. The noteworthy dependence of Iteimia households on cork oak multiple use, with a current negative impact on that resources conservation, make household subsistence-economy highly sensitive to nature conservationist policies and measures.

Keywords Agroforestry accounting system, income, Jerez, Spain, Iteimia, Tunisia

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Introduction

Cork oak (*Quercus suber* L.) extends through the Mediterranean basin of Western Europe (Italy, France, Spain and Portugal) and North Africa (Tunisia, Algeria and Morocco), with an area of 2.3 million hectares (37% in Africa and 63% in Europe). Spanish cork oak woodlands cover almost 500×10^3 ha and most are privately owned, while Tunisia has 99×10^3 ha of cork oak forests which are publicly owned (DGF 2006).

Cork oak agroforestry system (COAS) conservation problems and economic issues can be better understood if the differences in socioeconomic development and institutional regimes across Mediterranean region are analysed. Thus, the distinction between the northern sub-region – south-western Europe – and the southern sub-region – North African countries – is useful (Scarascia-Mugnozza et al. 2000; Campos 2004).

Insufficient natural regeneration of cork oaks is commonplace in both European and African sites of the Mediterranean region (Torres and Montero 2000; Pulido and Díaz 2003; Stiti et al. 2004). As former authors state, this process might be a consequence of overgrazing, inappropriate silvicultural treatments, severe pruning, careless brush clearing and tree health problems. Grazing in European COAS is unrestricted, except in government subsidized plantations, and overgrazing has been accentuated in the last four decades by a drastic decrease in seasonal migration of herds (transhumance) and a rapid increase in cattle numbers (Campos 2004). In Maghreb COAS countries, degradation through over-pruning affects a large part of those forests (Ellatifi 2005) and overgrazing has led to “a total absence of natural regeneration of woodland” (FAO 2001).

The complex mosaic of land uses and vegetations patches of COAS reflects the ways in which human influence has shaped the natural endowment of resources. Traditionally, two of the main commercial uses of COAS have been livestock grazing and cork stripping. Cereal and pulse crops usually occupy a small share of COASs surface. Wood use for energy is still of key importance in the rural homes of the Maghreb, particularly brushwood fuel, while there are many other non-timber goods gathered by rural populations. On the northern side of COAS, there is growing importance of woodland environmental services used by private landowners (Campos and Caparrós 2006), as well as the significance of the services the oak ecosystem delivers to the public on both sides of the Mediterranean basin.

The shortcomings of the economic system whereby agriculture and forestry resources are registered nationally (Eurostat 2000; Campos et al. 2005a) and the lack of statistical data leads to incomplete estimations of commercial incomes at farm and national levels (Campos and Caparrós 2006; European Commission 2006). In the area of multiple land use, much economic data needs to be generated by the analyst for its specific purpose. These official statistical shortcomings on missing relevant agroforestry system market land outputs and costs could be offset by applying a more comprehensives agroforestry accounting system (AAS) pilot exercises. These would illustrate the operative feasibility of measuring total commercial incomes objectively from multiple land uses. In this study we apply a simplified AAS in two publicly owned cork oak agroforestry systems (COAS) for an average year, assuming a steady state situation, without considering both environmental outputs (private and public) and government expenditures.

The study objectives are to measure multiple agroforestry system activities and intra-relationships (taking into account intermediate outputs), and to estimate a set of on-site cork oak agroforestry economic indicators related to single activity and the COAS as multiple aggregated activities.

Householder free-access grazing property rights and self-employment limit the options to value single grazing resource rent and self-employed compensation costs objectively. Therefore, to estimate separately the open access grazing resource rent and the household's self-employed labour cost we propose a simulated pricing approach trade-off as an alternative to the closed substitute goods pricing method. The household steady state private total commercial income is an objective residual measurement, except for intermediate outputs, and we make use of this simulated trade-off pricing approach to measure the single incomes from forestry, animal and cropping activities.

In this study a simplified AAS is applied to two cork oak woodlands case studies located in *Jerez* (Spain) and *Iteimia* (Tunisia), which exemplify the COAS multiple land use, economic trends, similarities and dissimilarities in the northern and southern sides of the Mediterranean basin. Ignoring unique characteristics of the areas – and most COAS have some unique features – those case studies are not statistically representative. They do, however, illustrate how property rights, labour market and local socioeconomic conditions generate notable differences in respect to the type and the amount of commercial benefits produced by those ecosystems and their distribution within the economic agents that profit from COAS natural resources use.

Materials and Methods

Jerez and Iteimia Cork Oak Agroforestry System Case Studies Description

In Spain, the case study was carried out in *Montes de Propios* estate of *Jerez de la Frontera* (south-west of Spain).[1] In Tunisia, the study was conducted in *Iteimia* (north-west of Tunisia).[2] The area of the Jerez and Iteimia COASs are 7,035 and 634 ha, respectively (Campos et al. 2005b; Chebil et al. in press).

[1] Jerez COAS is located inside *Alcornocales* Natural Park (ANP). ANP has 1,677 km^2 where private landowners own 75% of the area (BOJA 2004).

[2] Iteimia COAS is located inside *Ain Snoussi* region (AS), with an area of 32.3 km^2, under public ownership regime.

Jerez and Iteimia COASs have similar natural environments, but huge dissimilarities in institutional and economic contexts. Both are mountainous areas with an altitude range between 200–650 m in Jerez and 400–642 m in Iteimia, as well as, both have a humid Mediterranean climate with an annual average rainfall of 882 mm (period 1994–2002) and 1,006 mm (period 1999–2002), respectively.

In Jerez the forest area is dominated by cork oak. Other forest species are Andalusian oak (*Quercus canariensis* Willd.) and wild olive (*Olea europaea* L. var. sylvestris Brot). Cork oak is the only forest species in Iteimia. A forest inventory of Jerez in 1976 showed a density of 149 trees per hectare of wooded land[3] with 67 cork oaks, 34 Andalusian oaks, 41 wild olive and 7 other species different from pines (Campos and Salgado 1987). In Iteimia the average cork oak trees' density increases to 583 trees per hectare on wooded land (Stiti et al. 2004). In both areas, the main brush species are the mastic tree (*Pistacia lentiscus* L.), myrtle (*Myrtus communis* L.) and strawberry tree (*Arbutus unedo* L.). Red deer (*Cervus elaphus hispanicus Erxleben* 1777) and roe deer (*Capreolus capreolus* L.) are the main species hunted for game in Jerez, and wild boar *(Sus scrofa* L.) and hare (*Lepus* sp.) in Iteimia.

More than two thirds of the total Jerez area is made up of pure and mixed stands of cork oaks and by pure stands of cork oak in Iteimia (Fig. 13.1). There is less cropland in Jerez than in Iteimia. In the latter, this consists of subsistence crops over small treeless parcels inside the forestland. In Iteimia, shrub biomass is used for fodder, firewood, charcoal and shelter. Hence, subsistence-economy in Iteimia reduces the cork oak woodland under-storey to a minimum. On the other hand, standing brush biomass is increasing in Jerez as a consequence of lower grazing pressures and lack of fuel wood uses.

Jerez is a public property which belongs to the Jerez municipality, where the owner holds the right to exclude other users from the resources of *Montes de Propios* estate, including public entry. The land ownership of Iteimia belongs to the Tunisian State, but local inhabitants have specific use rights. The Tunisian State is engaged in the forestry management operations from which it gets commercial benefits, mainly from cork, firewood, mushrooms, myrtle and hunting rent. Tunisian Forest law maintains livestock grazing among the list of usage rights that can be freely practiced by the local population (Ben-Mansoura et al. 2001). Households-subsistence economy in Iteimia generates diverse uses of woody vegetation other than cork stripping (opposite of Jerez[4]) the self-consumption of different tradable goods and services provided by the COAS being highly relevant.

The socioeconomic contexts of Jerez and Iteimia diverge substantially in the case of labour market regulation. The Jerez work force is regulated in a competitive labour market and all positions are for permanent or temporary employees. Iteimia

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[3] Trees were counted as greater than 10 cm diameter.

[4] The ANP private landowners may incur an opportunity cost for ensuring environmental private amenities self-consumption (Campos and Caparrós 2006). However, in the case of Jerez the nature of public landownership impedes the realization of private environmental self-consumption.

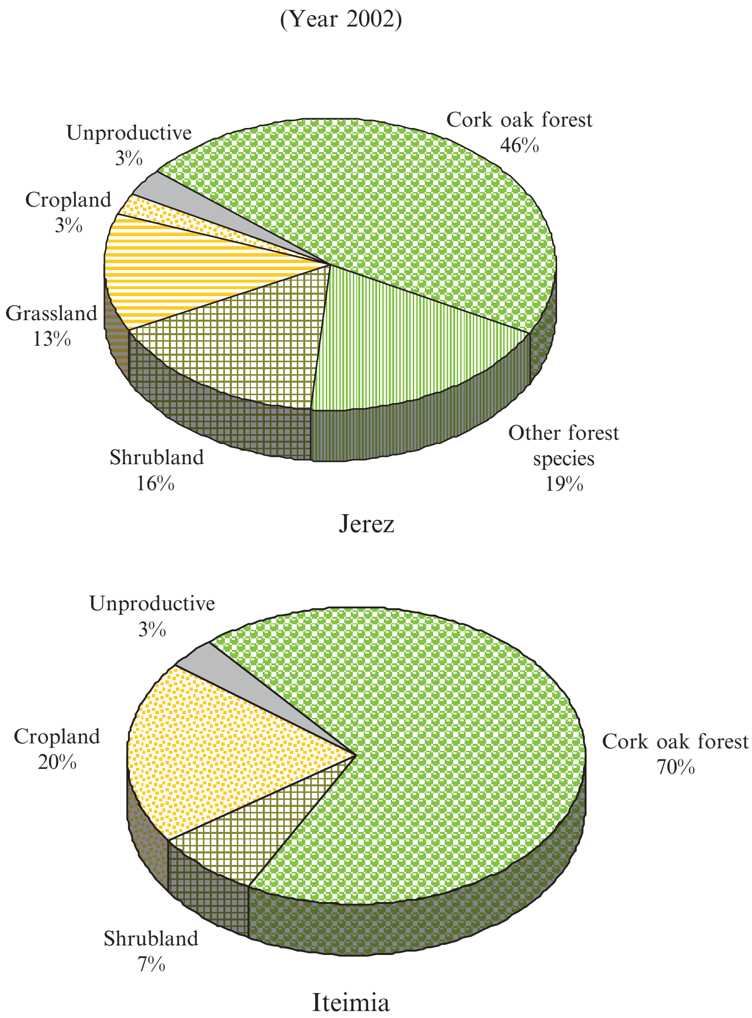

Fig. 13.1 Cork oak agroforestry land uses for Jerez and Iteimia

has weak labour market regulation and most of the operations, except cork stripping and tree thinning, are performed by family workers on their own account (self-employed). In Jerez, because the whole labour force is made up of employees, the economic risk is only borne by the Jerez Municipality. In Iteimia, the economic risk is shared by both families and the Tunisian State. Moreover, both cases differ considerably in the working time devoted to agroforestry-based activities. In Iteimia, households spent (in this case self-employed) 532 hours per hectare and year[5] in

2002 whilst in Jerez, employees worked an average of 19 hours per hectare and year between 1994 and 2002.

Management criteria in Jerez are concentrated on nature conservation and social guidance, which generates a relatively high demand for permanent and temporary employment. This management operates on the basis of financial transfers from Jerez municipality, Andalusia government, Spanish government and the European Union.

Management criteria in Iteimia are geared to avoiding negative annual cash-flow to the owner (Tunisian State) and developing subsistence-economies of local families on the basis of mitigating natural capital loss and improving livestock productivity by introducing exotic mix meat-milk cow races (*Schwitz* and *Tarentaise* races). Women and children play a major contribution to livestock rearing and crops. Households use the agroforestry natural resources with the aim of maximising the whole families' self-employed income in a context where alternative family employment opportunities in the area are low.

Income Indicators

Private Total and Capital Commercial Income

In our COASs case studies we have assumed a hypothetical forestry, livestock and crops steady state situation, which means that results do not reflect any year in particular, rather an average year at which it is supposed that the cork and crops yields, as well as herds, are in a stable situation. This steady state assumption makes it possible to estimate private single and total commercial income (TI) as the difference between a reduced number of private benefits and costs accrued from the management of those cork oak woodlands. Applying complete and simplified agroforestry accounting systems (AAS) give the same single and total incomes results (Appendix 1).

In terms of *benefits*, this study considers the intermediate outputs (IO), i.e. goods and services that are produced in the year and consumed in the same year in another activity on the estate, changes in stock (CS), sales (S) and self-consumption (SC) of both final outputs (derived from the production process) and fixed capital goods, and operating and capital subsidies net of taxes (ST). The costs that are considered for estimating total income figures are the intermediate consumption (IC) of raw materials (RM) and services (SS), and the gross investment in external fixed capital goods (FCie). This FCie matches the annual external fixed capital consumption

[5] The COAS continues to play a prominent socio-economic role for local household economy in the Iteimia area. In addition, families benefit from the employment outside the area where 25% of inhabitants are working in part-time or full-time jobs (Chebil et al. in press).

(FCC_e) in steady state if we value it at their current reposition cost (see Appendix 1). If net subsidies (ST) are included as a private benefit, total income at factor cost (TI_{fc}) is obtained. By contrast if those are omitted, total income at market prices (TI_{mp}) is assessed. Equations [1] and [2] display the benefits and costs considered in this study to measure cork oak woodlands incomes under the simplified AAS application (see Appendix 1):

$$TI_{mp} = IO + CS + S + SC - OC - FCie, \quad [1]$$

$$TI_{fc} = TI_{mp} + ST \quad [2]$$

If the agroforestry system activities were far from an unstable situation, equations [1] and [2] do not allow total income figures estimation. In that case, a more comprehensive complete AAS, as the one proposed by Campos et al. (2001) and Campos et al. (2008), is needed to embrace all outputs and costs derived from the agroforestry production process (see Appendix 1). It is worth mentioning that in the steady state applying the simplified AAS there is no need to consider the annual natural growth of work-in-progress since it physically equals the quantity of its extraction or consumption.[6]

In Jerez, red and roe deer herd populations are stable in numbers. However, they are not still stable in terms of the age class distribution (M. Girón, 2005, personal communication). Woodland is not in a stable situation too, since there are 62 ha recently planted growing young cork oak, carob and pines trees, which entails a yearly increase on Jerez woodland market value (Campos et al. 2001).

Considering that both hunting and forestry activities are not certainly in steady state, a residual value (called ‘changes in stocks’) is added to the Jerez benefits. This item captures the value differences on work-in-progress at the beginning and at the end of the accounting period.

On the other hand, we also are interested in the estimation and analysis of total income distribution among production factors. Thus, we focus on the income generation process and on the income distribution amongst woodland owners, households (in Iteimia) and employees.

Capital income (CI) indicates the income attributed to capital services as a production factor, when the owner of affected capital demands a potential benefit from capital investment. This CI indicator is significant for a private owner that uses the employee work force and puts low emphasis on household self-employment.

[6] Cork and wood growth and extraction are similar only in physical terms, but not in economic terms, since both are ongoing works that require more time than one accounting period (one year) to reach a state where they can be sold. Thus, their economic valuation is being affected by discounting issues (Campos et al. 2001). However, these omissions in steady state do not entail different results either if a complete or a simplified agroforestry accounting frameworks were to be applied.

Private capital income at factor cost (CI_{fc}) can be measured by subtracting the value of total labour costs (LC) from the private total income at factor cost (TI_{fc}):

$$CI_{fc} = TI_{fc} - LC \qquad [3]$$

Total labour costs are compound by the employees' labour compensations (ELC) and the residual value estimated for household self-employed labour cost (SLC), the assessment criteria of which are detailed in the next sub-section.

Self-Employed Labour Costs Residual Value

It is controversial to assume a monetary marginal value to rural households' self-employed labour. The use of local employees wage rates for self-employed labour pricing (e.g. Mahapatra and Tewari 2005; Delang 2006) can frequently lead to a negative capital income result, which could denote – in presence of other employment opportunities – an irrational household economic behaviour. Local wage rates may not be an accurate proxy value of self-employed labour in a context where local market employment demands are extremely scarce.

Moreover, some authors suggest that farmers' subsistence economies are guided by their own rational rules for allocating their own productive factors, which are different from a capitalist firm's aim at profit maximisation (Schejtman 1980). Rural households may have diverse starting positions, opportunities and constraints as well as different objectives, ranging from meeting mere subsistence needs to accumulating wealth (Berzborn 2007).

Considering the limitations in using local marginal wage-rate as the opportunity cost of self-employed labour in a household subsistence farming rationality context, in this study we propose an alternative approach for estimating the self-employed labour costs. In the context of Iteimia, it is assumed that rural households intend to optimise the distribution of their own labour endowment among the diverse uses of their own land related activities in order to maximise their family total income. This objective implies that families seek to satisfy their own basic needs and to obtain resources for the reposition of production means consumed by the production process.

In this study, self-employed labour cost (SLC) is estimated as a residual value, which accounts for rural households' labour rewards, by using the following accounting identity (referring the H subscript to 'household agroforestry activities'):

$$SLC = IO_H + S_H + SC_H - EIC_H - OIC_H - FCie_H - ELC_H - T_G - GRR \qquad [4]$$

EIC_H: households' intermediate consumption on external raw materials and services, OIC_H: the market value of intermediate consumption of own raw materials and services (except grazing resources) that are consumed in the same year by other agroforestry activities, ELC_H: employees' compensation paid by households and T_G: government taxes on products.

The grazing resource rent (GRR) reflects the estimated annual capital income value linked to the owners' right for using grazing resources for feeding controlled animals (livestock and game, the latter only in Jerez).

Valuation Criteria Applied to Jerez and Iteimia Good and Services

In Jerez, the stripped cork leaves the estate after industrial preparation (Campos et al. 2005b), being in Jerez an intermediate output. In Iteimia the cork is sold after it is stripped, and in this case is a final output.

Livestock activity in Jerez focuses on the breeding of selected herds of the pure cattle races, mainly the autochthonous red cow. Horses are also used for livestock management proposes. The grazing resource in Jerez is considered both as monte (this concept embrases the area covered by cork oak forest, shrubland and dry pastureland) and cropland intermediate outputs, attributed in proportion to the quantity of forage units that livestock and game graze at each land type. The mix pulse-cereal annual crops grown at Jerez are principally used in the form of supplementary feed (hay, straw and grains). In addition, there is a rent associated with big game, that comprises the sale of a few licences for red deer hunting (as a population control measure), venison sales and the rights for stand hunting of stags (adult male red deer) and bucks (adult male roe deer), mainly for hunting trophies (Table 13.1).

Households in Iteimia chiefly subsist on livestock rearing and the number of livestock species reared is more diverse than in Jerez, i.e. goats, cattle, sheep and

Table 13.1 Selected cork oak agroforestry commercial benefits for Jerez and Iteimia

		Jerez			*Iteimia*		
Class	Units	Quantity (ha^{-1})	Price (€ unit^{-1})	Benefits value (€ ha^{-1} year^{-1})	Quantity (ha^{-1})	Price (€ unit^{-1})	Benefits value (€ ha^{-1} year^{-1})
Cork stripping		108.1	1.0	107.6	164.9	0.4	65.2
Summer stripped cork	kg	*93.1*	*1.1*	*105.6*	*90.3*	*0.6*	*59.1*
Winter stripped cork	kg	*15.0*	*0.1*	*2.0*	*74.6*	*0.1*	*6.1*
Cork preparation		77.5	1.6	121.6			
Boiled cork	kg	*54.9*	*2.1*	*113.9*			
Raw cork	kg	*22.7*	*0.3*	*7.7*			
Firewood		41.0	0.1	2.3	688.3	0.01	7.1
From cork oak trees	kg	*31.0*	*0.1*	*1.6*	*315.0*	*0.01*	*4.3*
From shrubs	kg				*373.2*	*0.01*	*2.8*
Other firewood	kg	*9.9*	*0.1*	*0.7*			
Other forestry goods				5.2			16.3
Timber	m^3	*0.2*	*31.4*	*5.0*			
Heather bunches	Units	*0.2*	*1.2*	*0.2*			

(continued)

Table 13.1 (Continued)

		Jerez			*Iteimia*		
Class	Units	Quantity (ha^{-1})	Price (€ unit^{-1})	Benefits value (€ ha^{-1} year^{-1})	Quantity (ha^{-1})	Price (€ unit^{-1})	Benefits value (€ ha^{-1} year^{-1})
Charcoal	kg				*39.2*	*0.3*	*10.2*
Acorns collection	kg				*16.2*	*0.1*	*1.0*
Myrtle	T				*0.1*	*27.5*	*2.7*
Mushrooms	kg				*1.1*	*2.1*	*2.3*
Cattle				23.1			92.4
Calves sales	Units	*	*330.0*	*13.5*	*0.1*	*334.9*	*21.3*
Breeders sales and self-consumption	Units	*	*612.4*	*9.6*	*0.1*	*205.6*	*16.4*
Milk sales	l				*151.2*	*0.3*	*42.9*
Milk self-consumption	l				*36.5*	*0.3*	*10.4*
Others							*1.5*
Goats							45.3
Young goats sales	Units				*0.4*	*49.6*	*21.3*
Breeders self-consumption and sales	Units				*0.1*	*97.5*	*9.7*
Young goats self-consumption	Units				*	*49.3*	*0.4*
Milk self-consumption	l				*32.6*	*0.4*	*12.2*
Sheep							22.3
Lamb sales	Units				*0.2*	*69.6*	*12.4*
Breeders self-consumption and sales	Units				*	*113.2*	*5.4*
Milk self-consumption	l				*12.0*	*0.4*	*4.5*
Others							*0.3*
Game				2.9			0.2
Big game hunting rent	Licenses	*	*3,340.5*	*0.5*	*	*97.6*	*0.2*
Small game hunting rent	Licenses				*	*2.0*	*
Red deer meat	kg	*1.4*	*1.3*	*1.7*			
Red deer hunting	Stags	*	*775.9*	*0.1*			
Roe deer hunting	Bucks	*	*699.1*	*0.5*			
Crops				1.3			26.2
Cereals and pulse	kg	*0.3*	*1.0*	*0.3*			*12.8*
Cereal (forage)	kg				*29.4*	*0.2*	*6.2*
Hay and straw	kg	*0.16*	*6.0*	*1.0*	*112.0*	*0.1*	*7.3*

*Less or equal as 0.05

horses. The main dry crops grown in Iteimia are cereals (wheat, barley) and pulses (broad beans) for human consumption, forages and cultivated fruit tress. Cereal and pulse fallow is used as grazing fodder for livestock, forage crops are cut and stored as hay, and fruit tress are mainly olive and fruit trees for household use. It is worth noting that the list of forest commodities produced from Iteimia is larger than that accrued from COAS management in Jerez. This is the case for brush species such as myrtle or mastic tree grown at both forest areas, but only commercially extracted in Iteimia (Table 13.1).

Goods and services have been valued at 2002 average market or estimated prices[7] (without subsidies or taxes on products) that are considered to be constant. Microeconomic data on prices and quantities were collected through interviews or structured surveys applied to forest managers and local inhabitants in the case of Iteimia (Chebil et al. in press) and using primary microeconomic data from a nine-year accounting period in Jerez (Campos et al. 2005b).

Commodities such as cork, firewood, hunting licences and livestock and crop products (regardless if they are sold or self-consumed) are valued on the basis of estate gate market exchange values (price time quantities). In Jerez, grazing resources are for their own livestock and game use, and the grazing resource rent of the monte is estimated on the basis with interviews to local livestock keepers. In the case of Iteimia, the open-access right for grazing resource implies that local households have the right to use this resource without paying the imputed grazing resource rent.

In this study we propose a conditioned market simulation approach to estimate joint open-grazing resource rent and household self-employed livestock rearing labour cost in Iteimia and landowner capital income in Jerez. This approach starts with an objective measurement of livestock activity total commercial income (TI_{Lf}) that comes from assuming a zero grazing rent (GRR = 0). Thus, TI_{Lf} is estimated using the following steady-state identity (referring subscript L to livestock activity):

$$TI_{Lf} = IO_L + S_L + SC_L - EIC_L - OIC_{Lf} - FCie_L - ELC_L - T_{GL} \quad [5]$$

Note that equation [5] is similar to equation [1]. The former refers to a single activity and the latter attains to measure the COAS total income, irrespective of its distribution amongst economic agents. Equation [4] is used for estimating the self-employed total income that Iteimia households obtain from all agroforestry uses.

To estimate a positive grazing rent for Iteimia (GRR > 0) we propose to simulate a market, assuming a subjective GRR for the forage unit (FU)[8] times the number of FU extracted by animals graze. If GRR > 0, it would give us a 'conditioned' livestock total commercial income (TI_L) that, in the case of Iteimia, would allow the estimation of household-conditioned self-employed labour cost (SLC):

$$TI_L = TI_{Lf} - GRR = SLC_L \quad [6]$$

The SLC (equation [4]) equals the Iteimia households' total income from agroforestry (TI_H), except when GRR > 0. The Iteimia open-access grazing resource rent

[7] €1 = TND1.34 (Tunisian dinars), year 2002 (BCT 2003).

[8] A forage unit (FU) represents the energy contained in a kilogram of barley, at 14.1% moisture content, that is 2,723 kilocalories of metabolic energy (INRA 1978).

is entirely taken by households, therefore the self-employed income that households could obtain from livestock rearing has the upper limit of the TI_{Lf} value, that is, when GRR = 0.

In Jerez, a livestock capital income (CI_L) conditioned value can be derived from the following identity, given that employees labour cost (ELC_L) is known:

$$TI_L = TI_{Lf} - GRR = ELC_L + CI_L \qquad [7]$$

The assumed GRR does not affect the total income (TI_{Lf}) that Iteimia households obtain from livestock rearing, as well it, does not affect the capital income that a Jerez owner obtains from COAS as a whole. However, in both cases a GRR > 0 affects the total income from single livestock activity (TI_L).

Results

Animal Activity

Animal activity integrates both benefits and costs accrued from livestock and game management. The importance of livestock management operations, especially at Iteimia and, additionally of deer herds in Jerez, justifies the choice of including animal fodder consumption and costs of the supply feeding resource into the set of physical and economic indicators that best reflect the distinctive technical ways in which both COASs are run.

Grazing Resources and Supplementary Feed Consumptions

The COAS in Iteimia maintains an average livestock *instantaneous stocking rate* (ISR), measured by the number of standard livestock units (SLU)[9] per hectare of utilised agricultural land, which is three times that supported by the Jerez COAS. This implies an average of 0.33 SLU ha^{-1} in Iteimia and 0.11 SLU ha^{-1} in Jerez.[10] It is estimated that the annual total energy requirements of domestic livestock amount to 626.8

[9] Only adult females and males are considered. In case of cattle and horses, we have considered animals older than 24 months, and in case of sheep, goats, and roe and red deer older than 12 months. All standard livestock units (SLU) are presented in adult cow equivalents (Martin et al. 1987). An SLU is defined as a healthy cow with a live weight of 450 kg. An SLU is equivalent to 8.2 sheep, seven goats or 1.5 mares.

[10] Iteimia instantaneous stocking rate (ISR) is the sum of 0.14 cattle, 0.11 goats, 0.05 sheep and 0.03 equines. Jerez ISR is the sum of 0.07 cattle, 0.01 equines and 0.03 red and roe deer.

Table 13.2 Grazing resource and supplementary feed consumption for Jerez and Iteimia (FU ha^{-1})

	Jerez				*Iteimia*				
Class	Cattle	Big game	Equines	Total	Goats	Cattle	Sheep	Equines	Total
Grazing	248.2	50.7		298.9	218.1	150.0	89.7	69.9	527.8
Monte[a]	*218.7*	*50.7*		*269.4*	*218.1*	*140.5*	*89.7*	*66.8*	*515.1*
Cropland	*29.6*			*29.6*		*9.5*		*3.1*	*12.7*
Supplementary feed	55.6	8.8	11.4	75.7	5.3	80.1	7.7	6.0	99.1
Own raw materials	*26.6*	*5.0*	*2.7*	*34.2*	*5.1*	*62.5*	*6.9*	*6.0*	*80.6*
External raw materials	*29.0*	*3.8*	*8.7*	*41.6*	*0.1*	*17.5*	*0.8*		*18.5*
Total	303.8	59.5	11.4	374.7	223.4	230.1	97.4	75.9	626.8

[a] Monte includes pure and mixed cork oak forest, shrubland and grassland

forage units per hectare (FU ha^{-1}) in Iteimia. In Jerez cattle and deer herds total an annual total energy requirement of 374.7 FU ha^{-1} (Table 13.2).

One of the features that characterises the ways controlled animals are fed in both case studies is the large dependence on grazing resources extracted from the monte and cropland. Eighty percent and 84% of total controlled animals' energy requirements in Jerez and Iteimia, respectively, are met with fodder contributed by grazing resources. Under the current Jerez animal management system, cattle, horses and big game get supplementary fodder, from either their own crops or bought-in raw material (mainly mixed feed). In this way, most (89%) of total animal energy requirements are met from the farm's own feeding resources from Jerez crops and monte. In Iteimia, 97% of total energy requirements are met by their own grazing and supplementary feeding resources.

Grazing Resource and Supplementary Forage Unit Costs

The grazing resource rent (GRR) becomes a subjective value given that it is an internal intermediate output (and therefore, an intermediate consumption also). We may have overvalued it in this study. In Iteimia, a subjective GRR of €0.07 FU^{-1} is assumed. This assumption simultaneously implies a livestock keeper's self-employed residual wage-rate of €0.22 $hour^{-1}$, which is 60% of an Iteimia forestry employee's wage rate (Chebil et al. in press).

This trade-off between attributed GRR and livestock activity total conditioned income (TI_L), implies that the upper limit of GRR from Iteimia is €0.26 (Fig. 13.2). Higher GRR values would follow, according to equation [6] negative self-employed labour costs, which is rationally an unfeasible steady state result.

The same trade-off between livestock TI_L and GRR has been performed for Jerez, considering only direct livestock management costs (i.e. before imputing general management cost to livestock activity). In this case, a local market GRR of €0.09 FU^{-1} has been estimated. The interpretation of a grazing resource rent is quite different, since there is no self-employment in Jerez. It must be stressed that an imputed GRR higher than €0.11 FU^{-1} would negate the direct conditioned livestock total income (TI_L) in Jerez (Fig. 13.2).

Animal grazing and supplementary feeding have a forage unit cost that is made up of raw materials (GRR and supplementary fodder) and labour costs associated with the supply of feeding resources (Table 13.3).

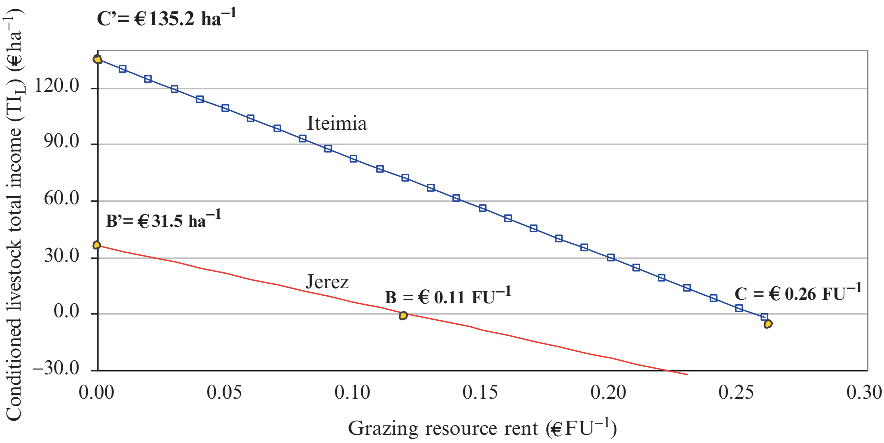

Fig. 13.2 Trade off between grazing resource rent and conditioned livestock total income for Jerez and Iteimia

Table 13.3 Forage unit cost comparison for Jerez and Iteimia (€[a]–2FU-1, year 2002)

	Jerez			*Iteimia*		
Class[b]	RM	LC[c]	Total	RM	LC	Total
Grazing	0.09	0.04	0.12	0.07	0.14	0.21
Monte	*0.09*	*0.04*	*0.12*	*0.07*	*0.14*	*0.21*
Cropland	*0.09*	*0.04*	*0.12*	*0.07*	*0.14*	*0.21*
Supplementary feed	0.15	0.03	0.18	0.21	0.03	0.24
Own raw materials	*0.11*	*0.03*	*0.14*	*0.18*	*0.03*	*0.21*
External raw materials	*0.19*	*0.03*	*0.22*	*0.35*	*0.03*	*0.38*
Total	0.10	0.04	0.13	0.09	0.13	0.22

[a] €1 = TND 1.34, year 2002 (BCT 2003)

[b] FU: Forage unit; RM: Own or external raw materials; LC: Labour cost

[c] Labour costs represent in case of *Jerez* cork oak woodland 95% of total direct cost related to each FU obtained by grazing and 87% of total direct costs in case FU is obtained by supplementary feeding. Additional direct costs refer to machinery and infrastructure use for cattle management and surveillance

[11] It is worth noting that an adult animal, if not fattened or grown, does not generate value added but is income for the year (Campos et al. 2005c). Under the complete agroforestry accounting system framework, breeder sales would be considered for estimating livestock fixed capital revaluations over the accounting period.

In addition to the attributed GRR, grazing operations involve labour costs of €0.04 FU^{-1} and €0.14 FU^{-1} in Jerez and Iteimia, respectively. The average cost of supplying one FU, regardless of its origin, is 0.13 €FU^{-1} in Jerez and 0.22 €FU^{-1} in Iteimia (Table 13.3).

Livestock and Big Game Total Commercial Income

Outputs derived from cattle, goats and sheep rearing that are sold or self-consumed are the main benefits in Iteimia, with a joint value of €160.0 ha^{-1} (Table 13.1). These outputs only reach a value of €23.1 ha^{-1} in Jerez (Table 13.1). Final output sales and self-consumption of breeding cattle add up to 18% and 34% of the livestock benefits in Iteimia and Jerez, respectively (Table 13.4). On the other hand, game sales generate relatively small benefits in Jerez €2.9 ha^{-1} (Table 13.1). Hunting licences generate only a negligible income of €0.2 ha^{-1} in Iteimia, which is included in the forestry activity.

Total livestock activity in Iteimia makes a positive total commercial income at factor cost (TI_{fc}) of €98.8 ha^{-1}.This is almost totally made up of self-employed labour income. In Jerez, livestock and game differ in total income figures. Livestock management generates a positive TI_{fc} of €5.2 ha^{-1} while game generates a net income loss of €€ −13.4 ha^{-1} (Table 13.4).

Labour costs related to animal activity in Iteimia are exclusively due to livestock rearing in Iteimia and account for 74% of total self-employed labour costs. In Jerez livestock and big game management have a joint labour cost of €67.3 ha^{-1}, shared out almost equally between the two animal uses (Table 13.4).

In Jerez, the aggregated livestock and game uses produce a capital loss (CI_{fc}) that is estimated to be € −75.5 ha^{-1}. Nearly two-third parts of the former capital losses are due to game activity (Table 13.4). In this context, it is worth noting that during the past two decades the Jerez owner incurred large expenditure in reducing the red deer population to benefit of both increasing roe deer population and improving natural tree regeneration. Current subsidies to livestock are €16.2 ha^{-1}, which prevents the public owner of Jerez having a higher livestock capital income loss.

Forestry Activity

Forestry Outputs

The physical amount of summer stripped cork is similar at both sites, while winter cork from silviculture improvements (dead wood, thinning, etc.) is almost five times higher in Iteimia than in Jerez. This latter winter stripped cork represents 45% and 14% of the total cork in Iteimia and Jerez, respectively (Table 13.1).

Table 13.4 Total commercial incomes, labour costs and commercial capital incomes for Jerez and Iteimia (€ ha^{-1} year 2002)

	Jerez							*Iteimia*			
		Animals									
Class	Forestry	Livestock	Big game	Crops	Cork preparation	Services	Total	Forestry	Livestock	Crops	Total
1. Benefits	140.7	28.1	7.0	10.3	193.0	9.0	388.2	123.3	179.2	34.3	336.8
1.1 Intermediate outputs	129.3	4.2		8.5			142.1	35.6	7.9	15.9	59.4
1.2 Changes in stocks	0.5		1.0		70.4		71.8				
1.3 Sales	9.6	15.9	3.6		121.6		150.7	81.5	120.3		201.8
Final output	*9.6*	*13.5*	*2.9*		*121.6*		*147.6*	*81.5*	*100.9*		*182.5*
Fixed capital		*2.3*	*0.8*				*3.1*		*19.4*		*19.4*
1.4 Self-consumption	1.3	8.0	2.4	1.8	1.1	9.0	23.7	6.2	51.0	18.4	75.6
Final output	*1.3*	*0.8*	*2.4*	*1.8*	*1.1*	*9.0*	*16.4*	*6.2*	*36.3*	*18.4*	*60.9*
Fixed capital		*7.2*					*7.2*		*14.7*		*14.7*
2. Subsidies net of taxes	33.7	16.2		–0.8	–0.2		48.9	–2.0	–2.5	–0.6	–5.2
3. Raw materials and services	12.5	38.4	19.1	5.7	185.3	1.7	262.6	8.1	76.2	9.6	93.8
3.1 Raw materials	4.6	31.7	13.3	4.0	179.2	0.6	233.4	1.2	61.9	2.4	65.6
3.2 Services	7.9	6.7	5.8	1.8	6.1	1.0	29.3	6.8	14.3	7.1	28.2
4. Gross investment on external fixed capital	2.6	0.8	1.3	1.1	1.6	0.1	7.5	0.4	1.6	2.3	4.3
5. Total commercial income (1 + 2 – 3 – 4)	159.3	5.2	–13.4	2.7	6.0	7.3	167.0	112.8	98.8	21.9	233.5
6. Labour costs	70.1	30.9	36.4	9.4	57.0	7.3	211.0	32.8	98.8	21.0	152.7
6.1 Employees compensations	70.1	30.9	36.4	9.4	57.0	7.3	211.0	19.6			19.6
6.2 Self-employed residual value								13.2	98.8	21.0	133.1
7. Commercial capital income (5–6)	89.2	–25.7	–49.8	–6.7	–51.0	0.0	–44.0	80.0	0.0	0.9	80.8

Before preparation, total stripped cork (summer and winter) has an output value at the estate gate of €107.6 ha^{-1} in Jerez and €65.2 ha^{-1} in Iteimia, respectively (Table 13.1). The stripped cork (before industrial preparation) average price at the estate gate in Iteimia is €0.40 kg^{-1} and for Jerez it has been ascribed a subjective price for fresh stripped cork at the estate gate of €1 kg^{-1} (Campos et al. 2005b). In Jerez summer stripped cork includes, before sale, the industrial preparation of stripped cork results.

Firewood in Iteimia is a major source of energy for cooking and heating for the local population. It is estimated that local households harvested 688.3 kg ha^{-1} year^{-1}. Brush species provide 54% of the former annual firewood of Iteimia consumption and the remaining share comes from cork oaks felled because they were unhealthy (Table 13.1).

The Iteimia and Jerez firewood output values represent 5% and 2% of their respective forestry activity benefits (Tables 13.1 and 13.4). Other forestry final outputs such as timber, mushrooms, acorns and aromatic plants represent 12% and 4% of the respective Iteimia and Jerez forestry benefits (Tables 13.1 and 13.4).

Forestry Total Commercial Income

In Iteimia and Jerez forestry activity reaches a total income at factor costs (TI_{fc}) of €112.8 ha^{-1} and €159.3 ha^{-1}, respectively (Table 13.4). This activity is the primary source of labour income in Jerez and the secondary in Iteimia. In Jerez, forestry labour accounts for 44% of the forestry total income (TI_{fc}). By contrast, in Iteimia it represents 17% of forestry TI_{fc} and 100% of employees' labour cost (Table 13.4).

Forestry subsidies and taxes are relevant in Jerez and negligible in Iteimia. In Jerez, government subsidies net of taxes on goods and services to forestry activity reach €33.7 ha^{-1}, accounting for 21% of total benefits that the public owner receives from this activity. Capital income (CI_{fc}) from forestry activity raises €89.2 ha^{-1} in Jerez and €80.0 ha^{-1} in Iteimia (Table 13.4). Forestry capital income is all retained by the Jerez owner, while in Iteimia it is shared by the State (56%) and by household livestock keepers (44%) as the owners of the cork oak woodland and the holders of grazing resources use rights, respectively (Campos et al. 2008).

Crops, Cork Preparation and Services

Crops make a significant contribution to household self-consumption and animal supplementary feeding in Iteimia. This activity generates a total commercial income of €21.9 ha^{-1} and a capital income of €0.9 ha^{-1}, corresponding to cropland GRR (Table 13.4). In Jerez crop activity is a less important source of animal feed with a total commercial income of €2.7 ha^{-1} and generates a negative capital income to its owner of €−6.7 ha^{-1} (Table 13.4).

Cork stripping is presumed to be in a stable situation in both case studies. This means that cork extraction matches cork annual growth. The changes in stock figure of €70.4 ha^{-1} in Jerez reflects cork preparation activity and refers to the value of cork that has been stripped at the time of accounting but will be prepared for sale in the next year. Cork preparation produces raw material which includes both raw cork that was stripped the year before and cork from the current stripping period (Table 13.4).

In Jerez, 72% of the stripped cork weight is the residue, after boiling the bark and other minor tasks, sold to the stopper industry for an average price of €1.6 kg^{-1} (Table 13.1). Sales of prepared cork bark totals €121.6 ha^{-1}, accounting for nearly one-third of the total private benefits in Jerez. However, cork preparation in Jerez costs more than in Itiemia (Campos et al. 2005b, for a detailed analysis), and this results in a capital income loss of € −51.0 ha^{-1} (Table 13.4).

'Service activity' is the cost to the Jerez owner cost for housing the tourist visitors of this estate. Output is valued at the cost of providing these services, so no capital income is derived from this activity, but there is a labour income of €7.3 ha^{-1} (Table 13.4).

Total Commercial Cork Oak Agroforestry Income

Jerez and Iteimia COAS generates a total private commercial income (TI_{fc}) of € 167.0 $ha^{-1}$and € 233.5 ha^{-1}, respectively. Agroforestry-based activities in Jerez produce a labour income of € 211.0 ha^{-1} and at the same time generate a capital loss (CI_{fc}) of € −44.0 ha^{-1} (Table 13.4). In Iteimia, labour income amounts to €152.7 ha^{-1} and is responsible for 65% of TI_{fc}. Self-employed residual labour cost and grazing resource rent that make up the Iteimia households' total income (TI_H), account for 73% of Iteimia agroforestry TI_{fc}. The Tunisian State as landowner estimates a capital income of roughly €44.4 ha^{-1}, which makes up 55% of the Iteimia capital income (CI_{fc}) and 19% of its total income (TI_{fc}). The employees labour compensation accounts for the remaining 8% of total income in Iteimia.

Capital income loss in Jerez seems to be related to nature conservation and social guidance management criteria of its public owner. This results in roe deer and autochthonous red cow race conservation and local employment generation. In Jerez, subsidies seek to partially compensate for the market capital loss of the owner set against public benefits derived from wildlife forest resources conservation. In Iteimia, however, the public owner assumes low investment on natural capital regeneration and families work to maximize self-employed labour income without expecting subsidies from the government. Thus, local households assume the risk of maintaining most of the traditional cork oak agroforestry activities.

Iteimia COAS agroforestry use generates a relevant labour income (Table 13.4), which in purchasing power parity (PPP) terms[12] is 69% higher than the labour income from Jerez on a per hectare basis.

The special issue for Iteimia households is the wage-rate (in euro per hour) obtained from COAS. In Itiemia, given both the annual working hours[13] spent by local households in agroforestry-based activities and the self-employed labour income (SLC) they obtain from those, the self-employment hourly pay, in Spanish purchasing power parity terms, is almost €0.6 hour^{-1}. This latter would be the families' hypothetical hourly pay if local families were asked to pay €0.07 FU^{-1} to the State owner for livestock grazing. Considering that the imputed value of grazing resource rent (GRR) corresponds to livestock keepers in Iteimia, the household' real livestock total commercial income ($TI_{Lf} = SLC_L + GRR$) gives an hourly pay of €0.7 hour^{-1} in purchasing parity terms, when GRR = 0. This latter hourly wage-rate amounts to 82% of forestry employees' hourly pay in Iteimia which, in 2002, came to €0.9 hour^{-1} in PPP terms (Chebil et al. in press). The average employees' wage-rate in Jerez is almost €11 hour^{-1}, 15 times higher in terms of PPP than the household's wage-rate in Iteimia and 13 times more than the employees' one.

Considering that Iteimia COAS uses about 615 ha of useful agricultural land (Campos et al. 2008) and affects 110 households (Chebil et al. in press), then the average total annual income (TI_H) from agroforestry activities is close to €948 household^{-1}. Most of the forestry workers in Iteimia are hired from the same households, which would imply that Iteimia household's TI_H from their own (self-employed) and paid (employees) work averages €1,050 household^{-1}. This latter income figure cannot be directly compared with the official average Tunisian rural household income,[14] as our measurement accounts only for just local cork oak agroforestry income.

Discussion and Conclusions

Cork oak agroforestry total commercial income in Jerez and Iteimia has been measured based on a low number of easily-collected microeconomic market data. However, this simplification restricts total income estimation to the special

[12] Given the 2002 official exchange rate of €1 = TND1.34 (BCT 2003), we have transformed Tunisian dinars (TND) into euros (€) and converted the Iteimia economic values into euros exchange values. In our case, the Jerez versus Iteimia purchasing power parity (PPP) rate shows the number of euros that in Spain have the equivalent good and services consumption power than one Tunisian euro exchange value. In 2002, the PPP rate for one Tunisian euro exchange value is 2.33 (estimated using The World Bank (2004) data). That is, we can buy the same goods with €1.00 in Iteimia or with €2.33 in Jerez. Then, to compare labour incomes in Jerez and Iteimia we calculate their values in terms of the same consumption power capacity.

[13] These estimates are performed ignoring adult working hour equivalences, given that some tasks are carried out by children.

[14] Rural income per capita in Tunisian was estimated in 2000 to be TND 864 (INS 2000). Considering the inflation rate, the euro and TND exchange rate and the average rural household size (4.67 person's family^{-1}) the average rural household income in Tunisia was near to €3,194 in 2002.

conditions of steady state case (Rodríguez et al. 2004 and Appendix 1), which is believed to be an unrealistic assumption for both case studies. From the standpoint of soil fertility and natural regeneration of woody vegetation, current managements in Jerez and Iteimia seem to be far from stable. So, our pilot exercises generate useful data on current management in COAS and should be seen as starting point for future potential real sustainable income measurement.

At both Mediterranean basin sites, cork oak stands are ageing at an uncertain rate due to the lack of recent assessment of forest seedling resource and regeneration. However, this aging of cork oaks might imply a future decline in cork growth in wooded areas in Jerez and Iteimia. For simplicity in this study it has been assumed that the cork growth will be stable, hence, the assessed total commercial incomes are presumably overvalued.[15]

Livestock and red deer restrain natural regeneration of cork oak in Iteimia and Jerez, respectively. In Jerez, red deer appears to be the main cause of damage to natural tree regeneration. Even if it seems that in Jerez there is no current widespread overgrazing, there might be localised overgrazing of seedlings and regeneration trees because of their higher palatability. In Iteimia, as in other Tunisian COASs, there are no restrictions on livestock grazing and unsuitable goat management is likely to be the main cause of the lack of natural tree regeneration (Ben-Mansoura et al. 2001).

On the other hand, the steepness of land in Iteimia and the lack of vegetation cover in some zones increase the risk of water erosion, and this is especially seen near to the villages. Neither loss of brushwood in Iteimia through overgrazing or soil erosion is considered in the estimate of total income (Chebil et al. in press).

In this study, it is clear that two similar environments can generate very different commercial results. Results from Jerez show that nature conservation and social oriented management decrease commercial capital income and increases labour income. But the apparent paradox is that a subsistence economy, as in the Iteimia case, generates both high self-employed labour and capital incomes per hectare basis. This will likely have a negative long-term impact on agroforestry system resources conservation due to overgrazing and crop erosion.

We also highlight the higher land use diversification in the Iteimia case study, in terms of extracted forest products, the livestock species and crop varieties. These may be a major strategy to minimize hazards and warranting the families' subsistence on the land. Iteimia generates more total income per hectare on a purchasing parity basis than Jerez. This greater total income figure in Iteimia is boosted by an intensive use of labour input per hectare and a higher resource extraction (e.g. grazing and shrub cutting), which shows the potential of Mediterranean cork oak agroforestry systems to support a diversified economy based on multiple animal and crop outputs from forestry. However, there is still concern over long-term sustainability of natural capital use.

[15] In the case of cork oak, silviculture takes into account the regeneration of the cork tree. Then, if other factors remain equal, livestock income would likely decrease in respect to what it has been estimated in the Jerez and Iteimia case studies.

In Jerez, many nature conservation activities attract a subsidy on the basis of the public environmental and employment services that it is believed the estate gives to society. In Iteimia, nature conservationist measures, which might restrict current grazing pressure, would likely decrease current household livestock commercial income (see Chebil et al. in press). Thus, local families should receive compensation for social equity and nature conservation policies. This compensation scheme should also include the value of cork oak forest conservation services provided by the livestock kept by local households. These reduce the risk of potentially catastrophic woodland fires by clearing and removing dead wood. In Jerez most fire prevention and control services are provided and paid for at an increasing rate by the government (Campos et al. 2005b).

In this work, we just focus on commercial goods and services that are controlled by different types of cork oak woodland owners (legal or actual). However, total commercial income gives an underestimate of the widespread benefits of COAS. Mediterranean *Quercus* woodlands sequester carbon, retain historically important landscapes, supply watershed services and provide refuge to high levels of biodiversity. Moreover, most migratory birds (from Central and Northern Europe to Central Africa) roost in Mediterranean cork oak woodland, and this might be endangered by current deforestation trends, especially in Northern Africa. In this context, forest services to biodiversity conservation, amongst others, could justify the creation of a specific program on cork oak agroforestry system conservation on both sides of the Mediterranean basin. Special attention will need to be paid to mitigating income loss that families might incur because of the specific land use restrictions such as temporary grazing exclusion and other measures prescribed for a sustainable cork oak agroforestry management programme.

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Appendix 1 Linking Complete and Simplified Agroforestry Accounting Systems

Total income at market prices (TI_{mp}) using the complete agroforestry accounting system (AAS) (e.g. Campos et al. 2001, 2008) is estimated according to the following equation:

$$TI_{mp} = TO - IC + CG_{mp} \quad [A.1]$$

Where TO is the total output, IC the intermediate consumption and CG_{mp} the capital gains at market prices. TO and IC come from the production account, which records the outputs and the production costs of the agroforestry system during the accounting period (year); while the CG_{mp} comes from the capital balance account that records changes on asset values during the accounting period.

Total output (TO) is estimated as the sum of intermediate (IO) and final (FO) outputs:

$$TO = IO + FO \quad [A.2]$$

The final output comprises the gross internal investment (GII), the final sales (SFO), the final stock (FSO) and other final output (OFO), which accounts for the imputed value of self-consumed final goods and services:

$$FO = GII + SFO + FSO + OFO \quad [A.3]$$

Gross internal investment (GII) under steady state assumptions[1] equals to own fixed capital withdrawals net of fixed capital goods destructions (see equation [A.12]) and the fixed capital consumption of own capital goods (FCC_i). The final stock (FSO) embraces the gross natural growth (GNG) value of multi-period products (i.e. cork and firewood)[2] and the final stock value of annual products – i.e. animal and crops – (FSOo):

$$FSO = GNG + FSOo \quad [A.4]$$

On the other hand, intermediate consumption (IC) is estimated as the sum of raw materials (RM), services (SS) and the work-in-progress used (WPu) during the accounting period:

$$IC = RM + SS + WPu \quad [A.5]$$

The fixed capital consumption accounts for both internal (own) fixed capital consumption (FCC_i) and external fixed capital consumption (FCC_e):

$$FCC = FCC_i + FCC_e \quad [A.6]$$

The steady state situation implies that the cork and crop yields, as well as herds, are in a stable situation. In that case, the WPu equals to the sum of the revaluation of multi-period products' work-in-progress (WPr), the gross natural growth of multi-period products and the value of annual products used during the accounting period, which under steady state conditions (constant prices) match the final stock value of annual products (FSOo):

$$WPu = WPr + GNG + FSOo \quad [A.7]$$

The capital gains at market prices (CG_{mp}) are estimated as the sum of work-in-progress (WPr) and fixed capital (FCr) revaluations, minus the fixed capital destruction (FCd), and plus the FCC[3]:

$$CG_{mp} = WPr + FCr - FCd + FCC \quad [A.8]$$

Both the WPr and the FCr come from the capital balance account, which is broken into two accounts: the work-in-progress (WP) balance and the fixed capital (FC) balance. The WPr under steady state assumptions is estimated according to equation [A.7]. While FCr is estimated as the difference between the final (FCf) and initial (FCi) capital values and the withdrawals (FCw) and entrances (FCe) of capital:

$$WPr = GNG + FSOo - WPu \quad [A.9]$$

$$FCr = FCf + FCw - FCi - FCe \quad [A.10]$$

Fixed capital entrances are broken down into the gross investment on fixed capital goods (FCgi), that can embrace both internal (FCii) – own-produced capital goods (i.e. breeders, infrastructure) – and external (FCie) capital goods (i.e. tractors, machinery). While the fixed capital withdrawals are made of fixed capital sales (FCs), self-consumption of fixed capital (FCo) and fixed capital goods destructions (FCd). In a steady state, the initial fixed capital and final fixed capital values match, thus the FCr is estimated as:

$$FCr = FCs + FCo + FCd - FCii - FCie \quad [A.11]$$

In steady state, the gross internal investment (FCii) should offset self fixed capital withdrawals net of fixed capital destruction ($FCw_i - FCd_i$) and the internal fixed capital consumption (FCC_i):

$$GII = FCii = FCC_i + FCs_i + FCo_i \qquad [A.12]$$

Therefore, the fixed capital consumption related to own capital goods is:

$$FCC_i = FCii - FCs_i - FCo_i \qquad [A.13]$$

It is assumed that there are no sales, self-consumption or extraordinary fixed capital goods destruction of external fixed capital goods in the cases of Jerez and Itemia:

$$FCs_e = FCo_e = FCd_e = 0 \qquad [A.14]$$

Hence, the gross external investment (FCie) at reposition costs[4] is equivalent to the fixed capital consumption of external capital goods (FCC_e):

$$FCC_e = FCie \qquad [A.15]$$

By substituting equations [A.12] to [A.15] into equation [A.11], the FCr is equal to:

$$FCr = FCs_i + FCo_i + FCd_i - FCC_i - FCs_i - FCo_i - FCie \qquad [A.16]$$

$$FCr = FCd_i - FCC_i - FCie \qquad [A.17]$$

Considering the former TO, IC and CG_{mp} partial identities, the total income at market prices (TI_{mp}) is then estimated as:

$$TI_{mp} = \begin{bmatrix} (IO + FCC_i + FCs + FCo + SFO + GNG + FSOo + OFO) \\ -(RM + SS + WP_r + GNG + FSOo + FCC_i + FCC_e) \\ +WP_r + (-FCie - FCC_i + FCd) - FCd + FCC_i + FCC_e \end{bmatrix} \qquad [A.18]$$

$$TI_{mp} = [(IO + FCs + FCo + SFO + OFO) - (RM + SS + FCie)] \qquad [A.19]$$

Considering that sales (S) and self-consumption (SC) concepts in the simplified accounting structure include both final outputs (derived from the production process) and fixed capital goods, and that the intermediate consumption (IC) includes raw materials and services:

$$S = FCs + SFO \qquad [A.20]$$

$$SC = FCo + OFO \qquad [A.21]$$

$$IC = RM + SS \qquad [A.22]$$

Then, the TI_{mp} identity corresponds to equation [1] of this study:

$$TI_{mp} = IO + S + SC - IC - FCie \quad [A.23]$$

The accounting structure we present in this work includes an additional benefit, called "changes in stock" (CS), that captures the differences on work-in-progress at the beginning and at the end of the accounting period of big game and forestry that in the Jerez case study are not under steady state conditions. Therefore, in Jerez, the TI_{mp} is measured as:

$$TI_{mp} = IO + CS + S + SC - IC - FCie \quad [A.22]$$

Appendix Notes

[1] The steady state assumptions are: (i) Stable yields and constant prices, (ii) no extraordinary loss of capital goods; and, finally, (iii) fixed capital is perfectly divisible, so annual gross investment in amortizable fixed assets may be equalled to fixed capital consumption.

[2] Multi-period products refer to those that need more than the accounting period (a year) to reach the final form when they are sold or self-consumed.

[3] The FCC is added to the CG_{mp}, in order to correct its double counting, firstly to estimate the total cost (TC = IC + LC + FCC) and secondly to estimate the final fixed capital (FCf) value.

[4] The reposition cost of used production goods is the depreciation value of the same goods if they were bought as new production goods in the accounting year.

Chapter 14
European Black Truffle: Its Potential Role in Agroforestry Development in the Marginal Lands of Mediterranean Calcareous Mountains

S. Reyna-Domenech* and S. García-Barreda

Abstract The European black truffle is the highly valued fruiting body of the ectomycorrhizal fungus *Tuber melanosporum* Vitt. Despite the technical advances achieved during the 19th and the 20th centuries, truffle production has suffered a pronounced decline. At present, the ecological requirements of this fungus are relatively well-known and cultural practices have been developed to meet these requirements; nevertheless, plantation yields remain highly unpredictable. Black truffles are naturally found in many Mediterranean calcareous mountains with limited agricultural and forestry potential. An agroforestry approach, integrating management of truffle-producing forests and cultivation of the fungus in marginal agricultural land could contribute to sustainable rural development of these less favoured areas, thanks to the socio-economic and environmental implications of the black truffle cultivation.

Keywords Non-timber forest products,sustainable development, truffle cultivation, *Tuber melanosporum* Vitt., truffle silviculture

Introduction

The European black truffle (*Tuber melanosporum* Vitt. or *T. nigrum* Bull.) is an ectomycorrhizal fungus from the class Ascomycetes. Its fruiting body (sporocarp) is found underground and is highly valued in international *haute cuisine*, because of its refined and pervasive flavor. Current black truffle production comes almost exclusively from France, Spain and Italy. These countries comprise most of the worldwide black-truffle natural distribution area (Fig. 14.1).

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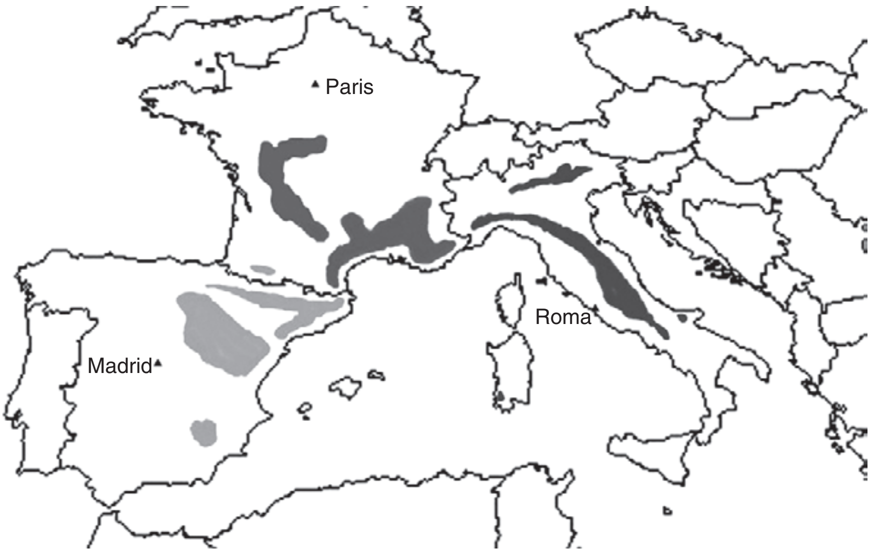


Fig. 14.1 Main natural distribution areas for *Tuber melanosporum* (French area is taken from Delmas 1983, Italian from Gregori 2007 and Spanish is modified from Reyna 2000)

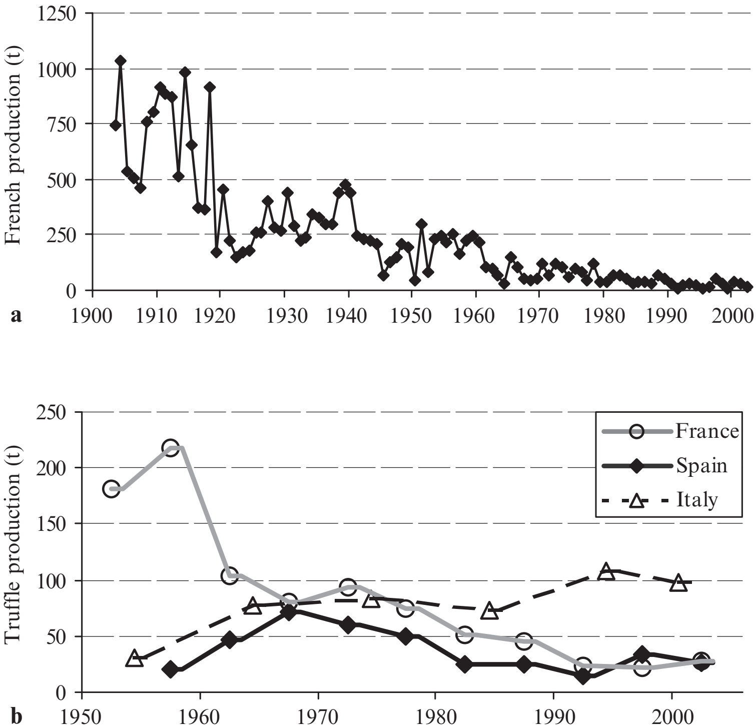
Historical Evolution of Truffle Production

The definitive rise in truffle use in French and Italian cooking began in the 16th century and was driven by kings, princes and other aristocrats. Increased culinary use led to technical advances in the management of naturally occurring *truffières* (non-planted truffle-producing stands) and expanded truffle harvesting in France and Italy during the 19th century, which is known as the golden age of black truffle production. In 1868, French production was estimated to be around 1,588 t (Chatin 1869).

At the beginning of the 19th century, a French farmer named Joseph Talon made an important finding on the relation between truffles and oaks, which he summed up in the sentence "If you want truffles, sow acorns". Thousands of hectares of oak trees were planted thanks to this simple idea.

The dread plague *Phylloxera* also played a role in this golden age, since truffle cultivation was used as an alternative to vineyards (Olivier et al. 1996). The French reforestation laws of 1860 and 1882 contributed to the expansion of truffle-producing trees, like the evergreen holm oak (*Quercus ilex* L.), in calcareous mountains such as the Luberon and Mont Ventoux (Diette and Lauriac 2005). In Italy, the reforestation activities driven by Mattirolo and Francolini were outstanding (Granetti 2005a).

In the 20th century, however, French truffle production declined spectacularly, and the current annual production in this country is between 10–50 t (Fig. 14.2). It is commonly accepted that this decline was a consequence of rural depopulation



a

b

Fig. 14.2 Evolution of black truffle production in France during the 20th century **(a)** and comparison of production trends in France, Spain and Italy from 1950 to 2005 **(b)**. In Italy, all harvested species are considered (French production is taken from Diette and Lauriac 2005, Spanish from Reyna 2000 and Italian from Pettenella et al. 2004)

caused by two World Wars and by the rural to urban drift. This rural abandonment resulted in the practical disappearance of firewood cutting, charcoal production, lands dedicated to marginal agricultural activities and forest grazing by the once-vast flocks of sheep. As a consequence, forest stand density increased greatly. In addition, much of the farmers' empirical knowledge on truffle management was lost (Blondel and Aronson 1995; Olivier et al. 1996; Bye and Chazoule 1998; Sourzat 2001).

In Italy, the decline in production was smaller and limited to the first half of the century (Manna 1990). The main reasons for this decline were deforestation during the war periods 1914–1918 and 1939–1945 (truffle trees were cut for firewood) and the traditional problems of poaching and over-harvesting, which are related to Italian property laws. Despite this, Italian truffle production seems to have increased since the 1950s (Pettenella et al. 2004) (Fig. 14.2).

In contrast to France and Italy, Spain has only recently incorporated truffles into its popular gastronomy. And although Chatin (1892) had already mentioned a small Spanish truffle production (the first harvesters in Spain were probably Frenchmen searching for truffles in the Catalan Pyrenees), it was not until the 1950s that the systematic collection of naturally occurring Spanish truffles began. By the 1970s, most of the naturally occurring Spanish *truffières* had been found and exploited. The oldest known truffle plantation in Spain dates from 1968 and is located in Castelló (eastern Spain). It followed methods similar to those used in traditional French and Italian plantations.

An alarming reduction in Spanish truffle production was observed in the 1970s (Fig. 14.2). This can be explained by the increasing rural depopulation, the collapse of many traditional forest uses and the intensive harvesting practices that prevented the natural reinoculation of short roots by means of spores. Additional reasons for the decline could be that reforestation activities using conifers were carried out in truffle-producing stands, and that, according to wild fauna data, there was a spectacular increase in the number of wild boars. Although truffle spores are dispersed when eaten by wild boars, this species has the potential to damage the roots and the soil of the *truffières* through its extensive and deep rooting activity (Reyna 2000).

In the 1970s, another relevant discovery was made in France and Italy. Mycorrhizal seedling production was developed by researchers from the INRA (French National Institute for Agricultural Research) and the IPLA (Piedmont Institute for Trees and the Environment), on the basis of the experiments by Mannozzi-Torini (Chevalier 2001b). The introduction of mycorrhizal-infected seedlings on the market greatly increased plantation activity in France and Italy, in an attempt to mitigate the worldwide scarcity of truffles.

Moreover, truffle growers in France began to form associations at the end of the 1960s, and the French government established subsidies for truffle plantations on agricultural lands in the 1970s. Public technical assistance and training activities for agriculturalists were also developed (Bye and Chazoule 1998).

It is estimated that French truffle agriculturalists planted 1,000 ha year^{-1} between 1990 and 2005 (Sourzat 2005). At present, it is estimated that there are about 8,000 ha of young mycorrhizal-infected plantations (less than 10 years old) and about 10,000 ha with ages ranging from 10 to 30 years (Escafre and Roussel 2006). The main tree species used in these plantations are downy oak (*Quercus humilis* Mill. or *Q. pubescens* Willd.), evergreen holm oak and hazel (*Corylus avellana* L.). The most active regions (with the highest production levels and plantation rates) are located in the southeast (Vaucluse, Drôme and Gard) and the southwest (Lot and Dordogne).

The most active regions in Italy at present are located in the centre of the country (Marche, Umbria and Abruzzo). Detailed data on the area occupied by truffle plantations are not available, but considering all the plantations of the different truffle species (including *Tuber magnatum* Pico, *T. aestivum* Vitt., *T. borchii* Vitt., *T. brumale* Vitt., etc., which are a minority in comparison with *T. melanosporum*), it is estimated that there are about 5,000 ha (Gregori 2007). In *T. melanosporum* plantations, the most commonly used host tree is downy oak, but hazel, European hop-hornbeam (*Ostrya carpinifolia* Scop.) and evergreen holm oak are also common.

In 1971, the world's largest truffle plantation belonging to a single landowner was planted in Soria (northern Spain). It consists of 600 ha mainly planted with evergreen holm oak, 250 ha of which are irrigated (Reyna et al. 2007). Despite the presence of this huge plantation, Spanish truffle plantations did not spread until the end of the 1980s, when mycorrhizal-infected plants were first made available on Spanish markets (Rodríguez-Barreal et al. 1989). At present, it is estimated that there are more than 4,000 ha of truffle plantations in Spain. The current annual rate of planting is estimated between 250 and 500 ha $year^{-1}$. The most active regions are located in the east (Teruel, Castelló) and the northeast (Soria, Huesca). The most planted tree species is evergreen holm oak, although hazel, downy oak and Portuguese oak (*Quercus faginea* Lam.) are also common (Reyna et al. 2005).

These privately initiated plantations have succeeded in stopping the decline in truffle production in France and Spain, but a real recovery in national productions has not yet been observed (Sourzat 2005; Reyna et al. 2005). As a result, the current production of black truffles in Europe has two clearly differentiated provenances: naturally occurring *truffières* or truffle plantations. There are no official data on this, but opinion surveys among dealers and experts suggest that fewer than 10% of French black truffles and about 70% of Spanish ones come from natural *truffières*. In Italy, considering all truffle species together, about 50% come from natural *truffières* (Gregori 2007; Sourzat 2007).

Truffle research has been promoted in France and Italy by the five International Congresses on Truffles held since 1968. In Spain, it was not until the 1990s that research activity increased. Most current research groups in the three countries are limited by modest staff, poor financial resources and little collaboration with the private sector. The experience of the experimental stations in Le Montat (Lot) and Sant' Angelo (Marche), in which there is close collaboration between researchers and truffle growers is especially interesting.

Ecology

Life Cycle

Since it is a symbiotic fungus, the black truffle depends mainly on living host trees as a carbohydrate source. Its symbiotic phase is formed by ectomycorrhizae (ECM) and their attached mycelium. Nevertheless, *T. melanosporum* mycelium conserves some pathogenic and saprophytic capabilities: it can infect the roots of some weeds and grasses producing necrosis in the root cortices and it forms stromata on the roots of host trees (Plattner and Hall 1995; Pargney et al. 2001a). These capabilities and/or the toxic substances produced by the fungus (Bonfante et al. 1971; Pacioni 1991; Papa et al. 1992) seem to be responsible for the formation of the *brûlé* (burn). The *brûlé* is the area where most of the sporocarps appear; it is characterised by its scarce vegetation. Other interesting vegetative structures are the latent hyphae found in old, non-active ECM by Pargney et al. (2001b).

In relation to the sexual stage, the environmental and biological determinants of the fruiting process have not yet been discovered. A strictly self-fertilizing reproductive system was proposed by Bertault et al. (1998), but recent research on *T. magnatum* suggests that this truffle outcrosses (Paolocci et al. 2006). The morphology of the fertilization process also remains unknown (Poma et al. 2006). Callot et al. (1999) described *T. melanosporum* ascogonium, but the antheridia of this species have not been identified.

A great number of truffle primordia can be found in the soil of productive *brûlés* in June (Olivier et al. 1996; Callot et al. 1999; Di Massimo et al. 2006). Most of them die without achieving maturity. The sporocarp is supposed to grow autonomously, without any attachment to the host tree, from the initial stages of development (Barry et al. 1994; Callot et al. 1999). From December to March, the mature sporocarps produce their particular smell and attract various mammals and insects, which disperse their spores.

Symbiont Plants

T. melanosporum has a relatively wide range of host species (Ceruti et al. 2003). The most widespread truffle-producing plants are evergreen holm oak, downy oak and hazel. Locally, other species can also sustain good truffle production, depending on the climate and the soil: English oak (*Quercus robur* L.), kermes oak (*Q. coccifera* L.), Portuguese oak, European hop-hornbeam, European hornbeam (*Carpinus betulus* L.), Oriental hornbeam (*C. orientalis* Mill.), etc.

The root system of each plant species develops in a different way and this affects *T. melanosporum* ECM numbers. In 3-year-old plantations, Olivera (2005) found that hazel seedlings had a more extensive root system and a higher percentage of ectomycorrhzial short roots colonized by *T. melanosporum* than evergreen holm oak and Portuguese oak. In an older plantation (7 years), however, Etayo (2001) found a higher number of soil-resident fungi colonizing short roots of hazel than those of evergreen holm oak, suggesting that hazel short roots are more readily colonized by *T. melanosporum*, but also by soil-resident fungi.

Climate

Most truffle-producing regions are located in transition zones between Mediterranean-type climates and temperate ones. They usually experience a summer arid period (the mean temperature in degree celsius being more than twice the amount of rainfall in millimeter), but this is not as marked as in the typical Mediterranean-type climate (with an arid period of 3 or more months). The mean annual temperature in the truffle-producing regions is 8.6–14.8°C, the mean temperature of the warmest month is 16.5–23°C, the mean temperature of the coldest month is 1–8°C and the mean annual rainfall is 450–900 mm, although areas with up to 1,500 mm have been cited in France (Pacioni 1987; Reyna 2000; Ricard et al. 2003).

Summer rainfall (July and August) is a highly unpredictable climatic factor in most of the *T. melanosporum* distribution area, and it is the climatic factor with the greatest influence on sporocarp yield in productive *brûlés* (Callot et al. 1999; Ricard et al. 2003). In this period the sporocarp is likely to grow autonomously, and it seems to be sensitive to low soil moisture.

Since there is considerable variability between regions, analyses of climatic data do not show any clear summer rainfall threshold for yield reduction, but Ricard et al. (2003) point out that August rainfall in years of maximum production ranges from three to four times the mean temperature. The number of summer days without rain which the sporocarps can withstand depends on soil characteristics and maximum temperatures, but the experience of truffle growers and climatic analyses suggest that it is around 30–35 days (Roux 2001).

Soil

Black truffle typically inhabits calcareous soils, with pH 7.5–8.5 and some content of calcium carbonate in soil gravels, fine mineral particles or clay-humus complex. These soils are never saline (conductivity lower than 0.35 mmhos cm^{-1}, measured in solution 1:5). Their organic matter is usually 1–8%, the C/N ratio is usually 5–15 and they lack leaf litter (Bencivenga et al. 1990; Sourzat 1997; Reyna 2000). Sand-size organic matter and microbial activity are lower than in surrounding soil (Callot et al. 1999; Ricard et al. 2003). They are well-aerated and well-drained soils, with a well-developed structure and no soil crust and are never hydromorph soils (Lulli et al. 1999; Callot et al. 1999). Truffle-producing soils are usually found on low south-facing slopes (5–30%).

Soil biology (especially microflora and macrofauna) might also be important, but present knowledge is limited (Mamoun and Olivier 1992; Callot et al. 1999; Mello et al. 2006).

Stand Vegetation

Truffle-producing stands show a convergent vegetation physiognomy. Most of the best naturally occurring *truffières* locate in areas with open vegetation (canopy cover lower than 30%, Hart-Becking index higher than 1.5, scarce shrub cover) and receive direct sunlight on their soil surface (Fig. 14.3). Most of the new *truffières* appear in such a situation (Olivier et al. 1996; Reyna et al. 2004; Sourzat 2004; Granetti 2005b).

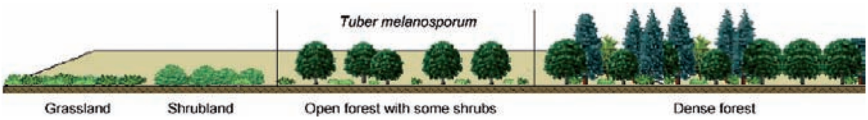


Fig. 14.3 Plant succession in abandoned agricultural land, showing the stage at which *T. melanosporum* is usually found

The Hart-Becking index is calculated as the ratio between the average spacing of trees and their dominant height. It is a practical index for assessing the stand density of the forest (i.e. tree cover on an area).

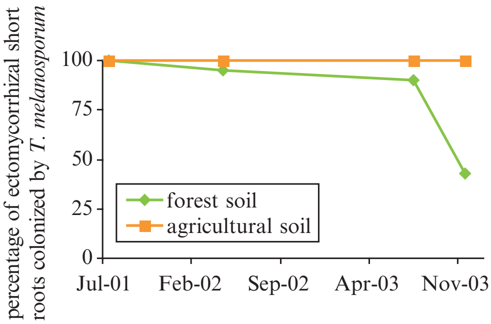
Competitor Ectomycorrhizal Fungi

The soil contains propagules from a high diversity of ectomycorrhizal fungi. The soil inoculum potential accounts for all the propagules that can effectively colonize fine roots. It depends on land use: soils that have not supported ectomycorrhizal plants (oaks, pines, etc.) for a long time show a lower ectomycorrhizal inoculum potential. Therefore, if seedlings inoculated with *T. melanosporum* are planted on these soils, their roots are less likely to be contaminated with soil-resident fungi (Fig. 14.4, Frochot et al. 1990). *T. melanosporum* competes poorly with many soil-resident fungi, and this seems to be related to the low level of genetic diversity of the black truffle and its narrow tolerance to environmental variation (Bertault et al. 1998).

The use of mycorrhizal-infected seedlings reduces root colonization by soil-resident ectomycorrhizal fungi when compared to non-mycorrhized control seedlings (Frochot et al. 1990; Reyna et al. 2006). The quality of seedling mycorrhization (number and percentage of colonized roots) is consequently an important component in black truffle cultivation. Bourrières et al. (2005) found that the percentage of short roots colonized by *T. melanosporum* in the nursery and 4 years later in the field were correlated.

The most important competitor in many truffle orchards is *T. brumale*, especially in France. This truffle shows similar ecological requirements to *T. melanosporum*, but has wider ecological amplitude (Mamoun and Olivier 1993; Callot et al. 1999; Raglione et al. 2001). It is commonly accepted that the main problems appear in plantations where the cultural practices have not taken into account the ecological requirements of *T. melanosporum* (low pH, lack of soil aeration, excessive irrigation, shade, fertilization or organic matter). Linear mechanised tilling helps to expand the propagules of this species (Sourzat 2004).

Fig. 14.4 Land use affects persistence of *T. melanosporum* mycorrhizae on roots of commercially inoculated evergreen holm oak seedlings. Roots grown in forest soil show more colonization from soil-resident fungi. Differences between land uses were significant for the three measurements (From Reyna et al. 2006)



Harvesting and Improvement of Naturally Occurring *Truffières*

Truffle Silviculture

In many black truffle-producing forests and old truffle orchards in France, Italy and Spain, the stand density is higher than advisable (canopy cover higher than 30%, Hart-Becking index lower than 1.5). Truffle silviculture models have been designed and experimentally applied in Spain (Hernández et al. 2001; Reyna et al. 2004) and Italy (Gregori et al. 2001; Tagliaferro 2001) to combat this situation. They consist of opening the vegetation and eliminating the non-productive, competitor trees and their associated ECM. Trees and shrubs from species that do not produce black truffles are clearcut, whereas trees from black truffle-producing species are pruned, until a canopy cover lower than 30% is achieved around the *brûlés*. Other cultural practices can also be applied when necessary: weeding, soil tillage, liming, slash burning, etc.

With clearcutting, pruning and weeding, Gregori et al. (2001) immediately regenerated truffle production (around 5 kg ha^{-1}) in an old truffle orchard in Marche. Previously, the orchard hardly produced black truffles, and after the treatment no black truffles were found in the corresponding unmanaged control plot.

In natural *truffières* in Castelló, Reyna and Garcia (2005b) monitored the evolution of ECM and sporocarp yields after truffle silviculture (clearcutting pines, pruning of *Quercus* and removing shrubs) was applied in 2000–2001 (Fig. 14.5). A slight but non-significant increase in the percentage of ectomycorrhizal short roots colonized by *T. melanosporum* was observed (Fig. 14.6). In relation to sporocarp yield, given that no unmanaged control plots existed, the evolution of the production was assessed through comparison to yield data previous to the treatment. Given that sporocarp yield is highly variable from year to year, mainly for climatic reasons, an index for the meteorological suitability of the year was incorporated (i.e. black truffle production in Spain). In this way, it seems that the *truffières* responded positively to the silvicultural treatments (Fig. 14.6), but only after 3 years (in 2003–2004, when the ratio between sporocarp yield and the suitability index was for the first time higher than in 1997–1998, before the management treatment was imposed).

Fig. 14.5 Application of truffle silviculture in a mixed pine-oak forest with a low density of *brûlés* (Reyna et al. 2004). Clearcutting of pines and pruning of oaks are carried out only around currently producing *brûlés* (*brûlés* in white)

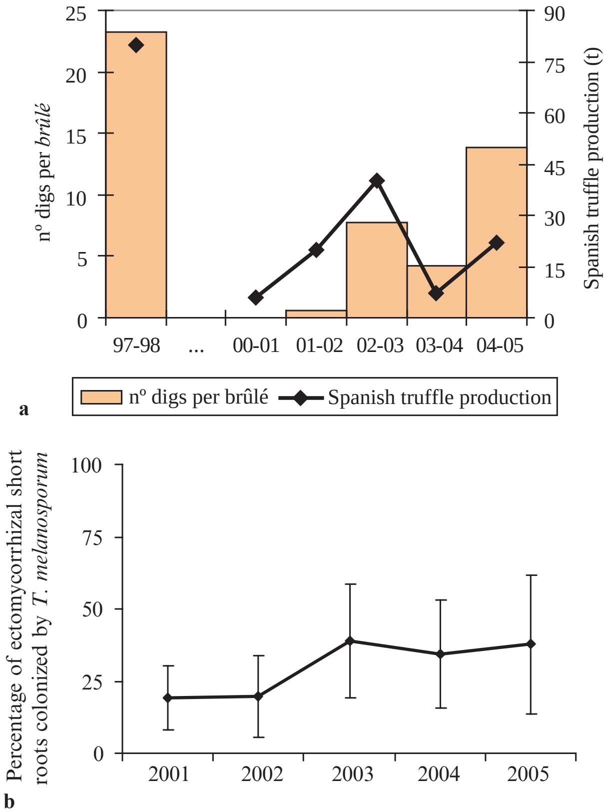


Fig. 14.6 Response of *T. melanosporum* to truffle silviculture: **(a)** sporocarp production in the managed *truffières* (estimated on the basis of the number of digs), with respect to the suitability of meteorological conditions in the region (estimated on the basis of truffle production in Spain), **(b)** percentage of ectomycorrhizal short roots colonized by *T. melanosporum*. The silvicultural treatments were carried out in 2000–2001. Digs are the holes made for harvesting truffles (Figures taken from Reyna and Garcia 2005b)

Property Conflicts and Harvesting Regulation

In Spain and France, truffles belong to the landowner by right of accession (Omaggio 2001; Trull 2007). In Italy, however, truffles are considered "*res nullius*" or ownerless property (i.e. they are not the object of rights of any specific subject and therefore they belong to the first taker) if the soil is not cultivated (De Angelis 2005).

Due to the high market price of *T. melanosporum,* over-harvesting is common. Because the spores of the truffle are completely encased in the sporocarps, systematic and intensive harvesting prevents reinoculation of the exploited *truffières* and colonization of new ones.

Over-harvesting and the use of destructive harvesting techniques are more likely to occur when the legal property rights of mycological resources are not properly defined or when a private exploitation system does not exist (common property resources). Sustainability should be guaranteed through reinoculation of the *truffières* and/or harvesting regulation (Gil et al. 2001).

Cultivation of the Black Truffle

Cultural Practices

Truffle cultivation consists of three clearly differentiated stages: the plantation and colonization period (the first 4–7 years, in which the plant adapts to field conditions and the fungus spreads), the consolidation period (until the 10th–15th year: the *brûlé* is developed and the first truffles appear) and the exploitative period (i.e. the productive stage, from the moment the orchard attains full production).

As the requirements of the cultivated fungus are slightly different at each stage, the cultural practices must also be specifically applied. Cultural practices also differ depending on local climate, soil conditions and previous experience of the agriculturalist. Thus, a variety of trufficulture models exist (e.g. in France: Pallier and Tanguy methods) (Olivier et al. 1996; Callot et al. 1999).

Most available experimental data on truffle cultivation focus on its effect on *T. melanosporum* ECM, which is mainly useful for the pre-productive period, not the exploitative period. Unfortunately, experiments on cultivation technique effects on sporocarp yield are scarce, lack scientific design and are highly influenced by interannual meteorological variability. Despite this, some remarks are provided below regarding present experiments on this subject, because of their practical interest to managers and researchers.

First of all, the establishment of the trees is critical, since plants with quicker growth are the first to form the *brûlé* and to produce sporocarps (Shaw et al. 1996; Granetti and Baciarelli 1997; Lulli et al. 1999; Letizi et al. 2001). Widespread fertilization is recommended by some authors (Chevalier and Poitou 1989). Bonet et al. (2006) found no detrimental effect from low-level foliar fertilization (fertilizer: 12% w w^{-1} nitrogen, 7% w w^{-1} phosphoric anhydride and 7% w w^{-1} potassium oxide, diluted in water to 1.2%) on *T. melanosporum* ECM in the short term (18 months); however, a meta-analysis of mycorrhizal response to phosphorus and nitrogen showed some potential detrimental effects of fertilization on mycorrhizal abundance (Treseder 2004).

Quality of the seedlings (morphology and physiological status of plants) and previous preparation of the ground also play a role in successful establishment. Tree shelters can be helpful as well: Olivera (2005) found that they increased shoot growth in *Q. ilex* L. seedlings without any effect either on root biomass or on *T. melanosporum* ECM.

Soil management of the plantation influences soil moisture, evolution of soil organic matter and soil biology. A choice must be made between chemical control of weeds, mechanical soil tilling and grassing (i.e. maintaining a spontaneous or seeded grass cover between the rows of trees).

Pesticides are not generally recommended because their long-term effects on *T. melanosporum*, soil fauna and soil microflora are unknown; only glyphosate and ammonium gluphosinate (herbicides) have been scientifically tested, and they seem harmless in the short term (Garvey and Cooper 2001; Bonet et al. 2006). Presence of the grass *Festuca ovina* L. (which is common in productive *brûlés* in France) has a detrimental effect both on 1-year-old hazel survival and on *T. melanosporum* ECM (Mamoun and Olivier 1997); thus, the close proximity of grasses to young seedlings should be avoided. Bonet et al. (2006) also found that chemical weed control increased seedling survival during the 1st year, as compared to mechanical tilling and unmanaged control.

Mechanical soil tilling is also used during the exploitative period to increase sporocarp production. No conclusive data exist on its effectiveness, but Ricard et al. (2003) suggest that it increases sporocarp size and depth and yields more rounded sporocarps.

In relation to soil moisture management, excessive irrigation should be avoided. Bonet et al. (2006) found that high levels of summer irrigation (totally compensating for the water deficit) during the establishment period reduced the number of *Q. ilex* short roots and *T. melanosporum* ECM when compared to moderate irrigation (compensating for half the water deficit) and unmanaged control. Mamoun and Olivier (1990) found that a high level of irrigation (soil moisture 31%) increased root growth in hazel, reduced the number of *T. melanosporum* ECM and increased root colonization by other ectomycorrhizal fungi, when compared to more reduced irrigation levels (soil moisture 12% and 21%).

During the exploitative period, summer irrigation is commonly used to increase sporocarp production, especially in dry summers. No conclusive data exist on its long-term effects, the optimum dose or the frequency required, but the available results (Ricard et al. 2003; Hernández et al. 2005) suggest that it increases the total weight of the truffles produced, but not their mean size. Hernández et al. (2005) performed two waterings of 5–15 mm per summer (water interval: 15–25 days), and Ricard et al. (2003) carried out four waterings of 20 mm (water interval: 20 days) per summer.

Mulching usually consists of calcareous stones, shrub branches or cereal straw. It aims to prevent soil water evaporation (Horton et al. 1996), but it can also have side effects on ECM. In a young plantation, Etayo (2001) found that permanent mulching with cereal straw reduced short root colonization by *T. melanosporum* and increased the number of other ectomycorrhizal species colonizing the short roots. Zambonelli et al. (2005) found the same effect in a *T. uncinatum* plantation. In productive *truffières*, no conclusive data are available, but Hernández et al. (2005) found that mulching with calcareous stones increased weight yield of sporocarps. In a productive truffle orchard in southeastern France, soil stoniness appeared as the main ecological factor accounting for spatial variability in sporocarp production (Oliach et al. 2005).

Finally, tree management (pruning, choice of planting distance) is mainly related to stand density and becomes important when the plantation ages. The trees are usually pruned from the 3rd–5th year (when the trees reach an approximate height of 1 m) and an inverted cone-shaped crown is sought. The most common planting distances range from 4 × 5 to 8 × 8 m for oaks, hazel and hop-hornbeam.

Sporocarp Yield and Economic Evaluation

In contrast to saprobic species, which can be easily grown, ectomycorrhizal fungi are far more difficult to cultivate. Some black truffle plantations produce more than 20 kg ha^{-1} $year^{-1}$ at the age of 15 while others, at the same age, have not started to produce (Olivier et al. 1996; Bye and Chazoule 1998; Callot et al. 1999; Bencivenga and Di Massimo 2000; Reyna et al. 2007). Technical assessment would be necessary to find out if the reasons that account for these differences are environmental (soil, climate), biological, or due to management practices (Sourzat et al. 2001). The economic yield of a plantation will depend on the age it attains full production and the percentage of trees producing sporocarps. Duration of the exploitative period is unknown, but it seems to be at least 25–30 years, since plantations of this age range are currently in production and show no signs of depletion.

In spite of these uncertain factors, economic evaluations have been attempted in France, Italy and Spain. Bonet and Colinas (2001) reviewed some of them and found that the internal rate of return- IRR (the discount rate that makes the net present value of cash flow of a project equal to zero, that is, the interest yield expected from the investment) was always above 9%, although the investment return time was longer than 10 years.

As an example, an economic evaluation is presented which attempts to deal with two of the most uncertain factors in the truffle plantation project: sporocarp yield and truffle price. The price of European black truffles varies greatly from year to year and its future level is likely to depend on the evolution of global black truffle production. The estimated IRR for the chosen assumptions is shown to vary from

Table 14.1 Estimated internal rate of return for a truffle plantation when considering different assumptions related to sporocarp yield, irrigation and truffle price. Establishment and exploitation costs have been calculated for eastern Spain [a]. It is assumed that the plantation starts producing at the age of 8 and reaches full production at the age of 15. Lifetime of the project: 25 years

	Black truffle price (euros kg^{-1})		
Sporocarp yield at full production, irrigation	200	400	800
5 kg ha^{-1} – unirrigated	4	8	12
10 kg ha^{-1} – unirrigated	5	10	15
15 kg ha^{-1} – unirrigated	10	15	21
20 kg ha^{-1} – irrigated	10	15	21
30 kg ha^{-1} – irrigated	13	19	25
60 kg ha^{-1} – irrigated	18	25	33

[a]Cropland price: 4,500 euros per hectare, 250 seedlings per hectare are planted at a price of 6 euros each, establishment and exploitation cost: 25,000 euros for non-irrigated plantations and 52,000 euros for irrigated plantations

4–12% in the lower yield scenarios to 18–33% in the higher yield ones (Table 14.1). Public subsidies, which are common in many regions, are not included in these calculations.

Socio-economic and Environmental Impact of Black Truffle

Economic Importance: Estimated Production and Prices

Making a correct evaluation of the total truffle production is difficult because of the level of secrecy that generally surrounds the sector. In recent years, however, information has become more transparent and accessible, especially since plantations are beginning to predominate. According to the GET (European Tuber Group), from 1990 to 2002 the mean annual European production of *T. melanosporum* was 59 t (approximately 40% France, 40% Spain and 20% Italy). Annual variability in truffle production remains high because it is strongly correlated with summer rainfall (annual production varied between 10–50 t in France, 5–80 t in Spain and 2–30 t in Italy). An undetermined amount of truffles are sold unofficially and are not quantified in the statistics, e.g., Gregori (2007) suggests that current Italian production is about 50–80 t). The GET estimates that international markets could absorb a truffle supply ten times higher.

Prices are also highly variable. From 1991 to 2005, the mean black truffle price paid by wholesalers to truffle growers in France varied between 200–650 euros kg^{-1} (Sourzat 2007), whereas in Spain it varied between 150–520 euros kg^{-1} from 1995 to 2006 (prices measured in constant 2005 euros). The prices paid by wholesale dealers to truffle growers depend on the annual production (law of supply and demand); the quality, size and degree of impurities of the truffles (truffles from plantations are usually higher valued) and the country where they are sold (yearly

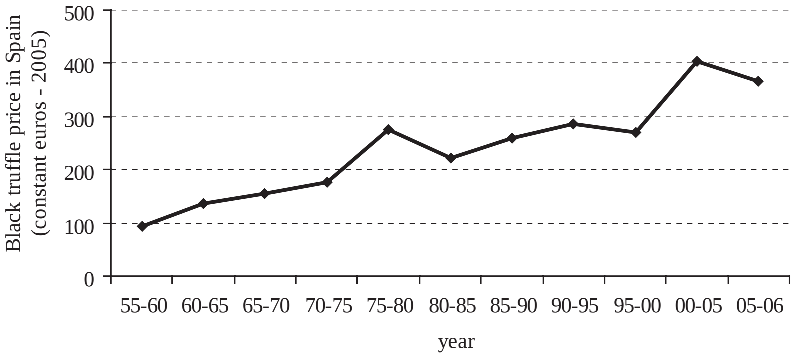


Fig. 14.7 Evolution of mean black truffle prices in Spain (paid by wholesalers to truffle harvesters), measured as constant euros of 2005 (Reyna et al. 2005)

prices paid to French truffle growers are about 40% higher than those received by their Spanish counterparts). Apart from these variations, the price of the black truffle in Spain is estimated to have increased 4% each year over the last 50 years (Fig. 14.7). In France, a similar tendency emerges from the 1991-to-2005 data, and, in addition, truffle growers are increasingly using retail e-commerce to sell their truffles (Sourzat 2007).

Consumer prices can be much higher (e.g. the price of fresh black truffles in Paris reached 2500 euros kg^{-1} in 2005).

The average annual value of black truffle production in France (revenues for truffle growers) is estimated to be 20 million euros, while the total economic impact of trufficulture is estimated to be 70 million euros (Escafre and Roussel 2006). In Italy, the value of the production of all species of truffles was estimated to be 18 million euros for the year 1999 (Pettenella et al. 2004). In Spain, an annual value of 2.4–9.7 million euros is estimated for black truffle production (years 2000–2005) on the basis of the estimated production and the mean price paid to truffle growers at the Vic market (northeastern Spain) (Reyna et al. 2005).

Social Implications: Rural Development

In many regions of the *T. melanosporum* distribution area, but especially in the southernmost ones, ecological conditions limit the agricultural potential and yields of traditional Mediterranean crops. For instance, in the Iberian Mountain Range (northeastern Spain) agricultural activity is usually centred on the cultivation of cereals; however, barley production levels rarely exceed 2,000 kg ha^{-1}, which is at the very limit of positive economic returns. Other unirrigated crops such as almond, carob and olive trees are not feasible because of inadequate temperature conditions, and vineyards are almost always outside the areas protected by official guarantees of origin and quality. Moreover, due to poor accessibility, these areas also show little industrial development and, as a result, they have suffered significant depopulation and ageing.

At present, trufficulture offers a viable development alternative and is helping to stop rural depopulation in these regions. Black truffle is also having indirect implications on agricultural land prices. According to Samils et al. (2003), land prices in Sarrión (a town in Teruel where truffle orchards are quickly spreading over former cropland and wasteland) increased 300% from 1995 to 1999, while unirrigated cropland prices increased 75% and 14% in the neighbouring provinces of Teruel and Zaragoza, respectively.

For most farmers in France, Italy and Spain, truffles are not the main source of income, but they provide economic diversification and extra incomes. In France it is estimated that there are 15,000 truffle growers, while in Italy it is estimated that there are about 200,000 truffle harvesters, although only 5% are professional harvesters or growers (Pettenella et al. 2004; Escafre and Roussel 2006).

Apart from agricultural activities and direct retail of fresh truffles, the fungus is also responsible for a variety of new activities such as mycorrhizal plant nurseries, preparation of canned truffles, retail of manufactured food products, organization of truffle fairs, development of local mycological gastronomy and agrotourism (guided visits to truffle orchards, visits to traditional truffle markets, ecomuseums in Sorges, Dordogne, and Metauten, northern Spain, etc.). In Italy, the National Association *Città del Tartufo* (Towns of Truffles) was founded for the promotion of truffles and the organization of shows.

Environmental Value: Sustainability and Multifunctionality

By providing many renewable resources, Mediterranean forests have historically played an essential role in the livelihood of Mediterranean peoples. However, on the northern shore the objectives of forest management have shifted in the last decades from production of material products (firewood, charcoal, livestock, etc.) to production of non-material goods and services (leisure, landscape, erosion and water-cycle control, biodiversity, etc.), due to social changes and low timber yields. As a result, the link between rural populations and their environment has in part been lost.

In this situation, revenues from the black truffle (or other non-timber forest products like game management) maintain this link and contribute to the conservation of natural formations of Mediterranean oaks. They also contribute to oak extension through new plantations.

Many truffle orchards can easily be considered as organic crops as they are grown without pesticides and synthetic fertilizers, produce quality and healthy food products and safeguard infiltrated water quality (IFOAM 2006). In addition, trufficulture keeps many small and marginal field plots cultivated and thus limits soil erosion risk and increases water infiltration rates.

Fig. 14.8 Truffle plantations could potentially be used in fuelbreaks as a means of controlling the spread of spontaneous vegetation and enhancing the sustainability of wildfire hazard reduction structures

In summary, in Mediterranean mountainous counties, truffle harvesting has an added value in that it falls fully within the concept of sustainable development, due to the ecological conditions in which it is produced and the socio-economic environment benefiting from its production.

In relation to other possible forest products and services, forest management for truffle production is largely compatible with wildlife and game (except for excessive populations of wild boar), extensive livestock production and wildfire hazard reduction.

Fuelbreaks are the basis of wildfire hazard reduction. Their target vegetation structure is very similar to that of truffle silviculture; thus, the biocidal effects of truffles can be used in fuelbreaks as a means of reducing maintenance work and promoting a multifunctional and more sustainable management (Fig. 14.8). In fact, productive truffle orchards constitute excellent fuelbreaks, due both to *brûlés* and tillage (Reyna and Garcia 2005a).

Future Prospects

Black truffle is naturally found in many Mediterranean calcareous mountains with limited agricultural and forestry potential. An agroforestry approach that integrates the management of truffle-producing forests with truffle cultivation in marginal agricultural lands could contribute to the sustainable rural development of these less favoured areas, thanks to the socio-economic and environmental implications of the black truffle. However, some legal, institutional, cultural, ecological and technical issues must be taken into account.

Future prospects for naturally growing *truffières* are poor unless adequate silvicultural measures are applied. If this does not take place, these *truffières* will continue to thicken, thus preventing the permanence of the truffle and, more importantly, the appearance of new *truffières*. The present decline has also been caused by abusive practices that are gradually disappearing, though, unfortunately, they are still being applied in certain areas. There are only two ways to eliminate these unprofessional practices: by developing legal regulations that address the reality of the situation and, especially, by developing agrarian extension activities for the people who are directly implicated.

In contrast, from the point of view of plantation trufficulture, the potential is high, due to the extension of both calcareous soils and climatically appropriate areas. One serious problem is the risk of accidentally introducing Asiatic truffles in

European plantations; these include *Tuber himalayense* Zhang et Minter, *T. indicum* Cook et Massee, *T. pseudohimalyense* Moreno, Manjón, Diez et García-Montero and *T. pseudoexcavatum* Wang, Moreno, Riousset et Manjón, all of which lack commercial value and can be found in European truffle batches. The confusion or deceit that Spanish, French and Italian nurserymen may be subjected to by those who sell low-value truffle species for inoculation purposes constitutes a grave threat for the sector, not only because of the economic repercussions involved for the agriculturalist, but also because of the serious ecological problems derived from the uncontrolled introduction of very invasive exotic species.

In the last years, specific protocols for rapid molecular identification of *Tuber* spp. ECM are being developed (Paolocci et al. 1999; Douet et al. 2004). Molecular methods could assure a more accurate monitoring of nursery-inoculated seedlings, but they can also be used to prevent the fraudulent use of sporocarps of species other than *T. melanosporum*, as well as for ecological studies, e.g., studies on intraspecific genetic variability, reconstruction of the past history of truffles, characterization of the ectomycorrhizal community, detection of *T. melanosporum* mycelia in soil, etc. (Mabru et al. 2004; Richard et al. 2005; Mello et al. 2006; Suz et al. 2006).

Currently, there are no official directives regulating either the production in nurseries of seedlings inoculated with European black truffle or the certification of their quality and purity. A European-scale truffle certification protocol is needed to serve as a reference for European truffle controllers.

At present, truffle plantations in some regions receive subsidies from the Common Agricultural Policy (CAP) for the afforestation of agricultural land. These subsidies have two key aspects that should be emphasized. First of all, the plantations that receive subsidies from the CAP are granted the legal consideration of forest areas, and this could make their management difficult in the medium term if unaccompanied by complementary legislative measures, because legal limitations on cultural practices obviously differ between agricultural and forest land.

Secondly, if the cost of the land is excluded, CAP subsidies mean no cost for the farmer. In similar situations, subsidies higher than 80% have shown little effectiveness, because in many cases the aim shifts from producing the product to simply accessing the subsidy, which becomes a business in itself. Obviously, this is not the case in regions with a tradition of trufficulture, where these subsidies are likely to work; however, in some other regions plantations established thanks to subsidies will be bad examples of truffle cultivation.

An interesting opportunity arises from the new European Union Regulation on Rural Development (EAFRD 2005); its measure “First establishment of agroforestry systems on agricultural land” could be exploited by Member States for truffle plantations, e.g., Hungary intends to include mycorrhizal plantations aimed at producing *T. aestivum*, *T. magnatum*, *T. macrosporum Vitt*. and *Mattirolomyces terfezioides* (Mattir.) E. Fisher (FVM 2007). The French government and the French Federation of Truffle Growers are also looking for a way that truffle plantations can receive single farm payments (SPF), by deriving from the European definition of permanent woodland a French-specific definition that excludes truffle plantations (MAP 2007).

Professional associations of truffle harvesters and growers are well-developed in France and Italy, while they are more recent in Spain. The national federations have recently formed the GET. Thus, the various public administrations now have valid interlocutors to help them to both organise the markets and establish co-financing mechanisms for the producing sector. A result of this association is the joint trufficulture project being developed by France, Italy and Spain with the aim of producing quality truffles, in large amounts, and with long production periods (GET 2004).

The general ecological requirements of the black truffle are relatively well-known, but research is still needed regarding its sexual reproduction, environmental determinants of fruiting and influence of soil microorganisms. Yields from truffle plantations remain highly unpredictable; thus, research effort must also be addressed at improving trufficulture models that are suitable for local situations. Some researchers are also studying whether the genetics of the tree plays a role in its production of truffles (Callot et al. 1999; Chevalier 2001a).

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Chapter 15
Assessment of the Extent of Agroforestry Systems in Europe and Their Role Within Transhumance Systems

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Abstract Agroforestry systems are unevenly distributed across Europe and are often linked to transhumance, the seasonal movement of stock which is widely in decline. Whilst the high biodiversity associated with traditional agroforestry is widely recognised, the ecology of modern systems is less well understood. The inherent nature of the agroforestry systems means that it is necessary to know the characteristics of both the tree canopy and of the crop or ground cover beneath. Field visits are therefore essential, not only to determine the presence of agroforestry systems, but also to obtain measurements of their extent and detailed characteristics. A worked example is given for Atlantic Europe of a procedure that could be extended to the whole of Europe, demonstrating how eventually local figures could be used to produce a Europe-wide ecological resource assessment. Such European estimates are a primary requirement for determining an appropriate EU policy for their maintenance. The Driving forces, Pressures, State, Impact, Response (DPSIR) framework has then been applied to the *identification and characterisation* of habitats threatened by the decline in transhumance. These include agroforestry systems, the most widespread of which are the *dehesas* and *montados* (Spain and Portugal respectively), which contain functioning networks of mature silvoarable habitats with well established high levels of biodiversity in both flora and fauna. Transhumance has declined substantially over the last two centuries and there are now relatively small areas of silvopastoral systems which still depend on the practice; in the Iberian Peninsula, the south of France, Italy and Greece. Extensive areas of these systems remain, but they are only used for grazing by local communities.

Keywords Atlantic Europe, *dehesas,* DPSIR framework, environmental strata, *montados*, silvopastoral

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Introduction

The inherent nature of agroforestry systems implies that it is necessary to know not only the characteristics of the tree cover, but also those of the crop or ground cover beneath or between the trees. The general use of the term agroforestry therefore incorporates a combination of land cover and land use. It is known that remotely sensed images can only give an indication of the existence on the ground of such systems, although local knowledge can assist in interpretation. Thus the "agroforestry areas" (class 2.4.4 of the CORINE land cover map) can be used to indicate where *dehesas* or *montados* are but cannot give information as to whether grassland, fallow or crops are present beneath or between the trees. Aerial photographic interpretation can give more detail; e.g., on the density of the trees; but again cannot determine what is growing on the ground and how it is used. Field visits are therefore essential, not only to determine the presence of agroforestry systems, but also to obtain measurements of their extent and detailed characteristics.

Expert local knowledge can be used to describe the principal characteristics and provide a summation of the systems' extent at a regional level. However, whilst this approach defines local conditions, it cannot provide European estimates because the relationship of local areas to the whole domain is not known. The present paper therefore describes a procedure which could be applied to the whole of Europe, together with a worked example of its application in estimating the occurrence of veteran trees and the area of agroforestry systems in the Atlantic zone of Europe, as defined by Metzger et al. (2005). The Driving forces, Pressure, State, Impact and Response (DPSIR) framework is then applied to identify habitats, including agroforestry systems, that are linked to transhumance and are now threatened by its decline.

A European Stratification System for Ecological Resource Assessment

The frequent policy requirement for strategic estimates, in addition to the need for detailed field survey, have long been recognised in landscape ecology and more widely by scientists involved in studies assessing biodiversity. The apparently opposing needs of extensive coverage and local recording make it essential to use samples from a defined population, comparable to the procedures used in socio-economic surveys. Such an approach for strategic ecological survey was initiated at a regional level in the mid 1970s by Bunce and Smith (1975), and followed up in the 1990s by Bunce et al.(1996 a, b, and c). Sheail and Bunce (2003) described its eventual development at a European scale. The approach is based on the regression principle that environmental variables, e.g., climate and altitude, are related to ecological parameters, e.g., land cover and species composition. The methodology formalises these relationships so that environmental strata determined by multivariate analysis can be sampled, in order to derive ecological estimates. At a regional and

European scale, using modern statistical methods, altitude and climate data can be recorded and classified into relatively homogenous classes, which can then be used as strata for sampling. Such strata are comparable to traditional biogeographic divisions of Europe but differ in that the criteria which determine them are explicit and reproducible. The methodology has been utilised in Great Britain (GB) to assess ecological resources since 1978 (Haines-Young et al. 2000) and at a national level in Spain for habitat change, using aerial photographs (Regato et al. 1999). The first statistical environmental classification of Europe was produced by Jones and Bunce (1985). More robust European environmental strata have now been produced, as described by Mücher et al. (2003) and Metzger et al. (2005), and have been used in the worked example for Atlantic Europe described in the next section.

A 1 km^2 sampling unit was used in GB as a scale suitable for field sampling, but which also enabled all the squares to be classified at a national level. Consequently, dispersed random samples of 1 km^2 were drawn from the environmental strata and surveyed in the field for land cover, habitats, vegetation and soil. National estimates of the extent of ecological parameters, such as habitat types and hedgerow length, were then made using standard statistical procedures (Haines-Young et al. 2000).

A Worked Example of the Application of European Environmental Strata in the Atlantic Zone of Europe

The veteran tree and silvopastoral survey of Atlantic Europe, described by Smith and Bunce (2004), provides a good example of how the extent of agroforestry systems could be assessed in accordance with policy stakeholders' requirements. This project involved field survey from a defined population and was initiated because of controversy concerning the extent of veteran trees[1] in GB, as compared with elsewhere in Atlantic Europe. The customer, English Nature, needed such figures to establish an appropriate policy for maintaining the resource. For practical reasons, the extent of the survey was restricted to the Atlantic Zone in GB, the Netherlands, Germany and France, as described by Metzger et al. (2005) in the European Environmental Classification. Other environmental zones such as Alpine South and Mediterranean North were not sampled, although they could be subsequently included using the same procedure. Thirty sites and 90 1 km^2 samples were taken at random from the strata, and records made of a standard list of habitats derived from the GB Countryside Survey (Haines-Young et al. 2000). An assessment was also made of wood pastures, which are silvopastoral systems (i.e. with grazed grass beneath or between the trees) and their current state was recorded (e.g. whether they were still in use or abandoned). No silvoarable systems (i.e. with crops or fallow beneath or between the trees) were recorded in the samples.

[1] Veteran trees are defined as those older than 150 years old, associated with a Diameter Breast Height (D.B.H.) over 2 m.

The estimate of wood pastures was 329,063 ha, which is surprisingly high, but within the confidence intervals previously produced for GB.

Details of the veteran trees were also recorded in the sample squares as described by Smith and Bunce (2004). The estimate of the total number of trees was between 17 and 29 × 10^6, with estimates of the number of trees with Diameter Breast Height (DBH) over 2 m being between 1.3 and 2.8 × 10^6. The results showed that the majority of veteran trees were outside GB – which was the opposite of the information available to the customer before the survey.

This project therefore demonstrates the advantages of applying stratification to estimate a complex land use resource. No estimates are available for the extent of such resources throughout Europe, nor of their current status, but this example shows the feasibility of obtaining such figures, which are a primary requirement for determining an appropriate policy for their maintenance.

Ecological Considerations of European Agroforestry Systems

The ecological and biodiversity benefits of silvopastoral systems are described by Gómez-Sal (2001) and recently extensively reviewed (Mosquera-Losada et al. 2005), and vary from maintaining autochthonous breeds of cattle to the conservation of rare birds and animals, with further details being provided in the present volume. Many silvopastoral systems have been maintained for centuries, but are now widely threatened. Intensively managed silvoarable systems (equivalent to a crop monoculture with additional trees) are locally common – e.g. in central France – but only limited information is available on their ecology. However, Palma et al. (2007) constructed models to show the benefits of trees in reducing erosion and nitrogen run off. In less intensively managed silvoarable systems there are often residual patches of annual and perennial ruderal species, which contribute to biodiversity in terms of both fauna and flora; especially if rare arable weeds are present. In all such agroforestry systems biodiversity of plant and animal species is enhanced by the heterogeneity created by trees, which may also provide natural corridors linking forest patches.

The current composition of the landscape is also important in terms of the variety of patches present, which will determine the potential contribution of newly planted trees to biodiversity. Thus, there are likely to be differences between adding new poplar plantations within an existing matrix of forest patches, as opposed to planting new trees in otherwise monotonous cereal landscapes. Such new tree patches may act as stepping stones and later provide refuge for animals, especially birds and insects.

The situation is very different in *dehesas* and *montados* in Spain and Portugal, respectively because there still exists a functioning network of mature silvoarable systems with well established high levels of biodiversity in both flora and fauna. These ecological benefits are recognised by the establishment of agri-environment schemes to maintain such systems in Extremadura (western Spain). These agroforestry systems cover large areas of the Iberian Peninsula but their use by transhumance systems is in decline (Pérez-Soba et al. 2007). However, they are still widely grazed by local animals. Expert local knowledge, detailing information on structure and current use by animals, is therefore needed now in order to complement the existing information and to provide a basis for future planning and management of resources.

Application of the DPSIR Framework to Agroforestry Systems Threatened by the Decline in Transhumance

Extensive animal husbandry involving seasonal relocation of livestock is called transhumance, and often involves silvopastoral systems. The ecological rationale is based on the exploitation of distant but complementary resources to overcome seasonal shortage of pasture or forage. Throughout the European mountains comparable systems developed, with their detailed character being defined by local environmental characteristics and national priorities. They represent an exemplary method of sustainable land use because they have been developed over centuries, but changes in agricultural practice and society suggest that they will degenerate in the future.

The present paper firstly assesses the role of transhumance in maintaining agroforestry systems in Europe and then identifies the habitats that are linked to them in practice. Many transhumance systems formerly involved silvopastoral land with animals moving through them on their way to the open grazing land in the mountains. Such systems were found throughout the mountain areas of Europe, from Norway to Switzerland, Italy and Spain, and their current state (summarised by Bunce et al. 2004) varies widely according to local conditions. The TRANSHUMOUNT project described by Bunce et al. (2004) was set up to review the status of transhumance in Europe and potential policy options for its maintenance, as described by Herzog et al. (2005). At the start of the project it was planned to use the DPSIR framework described by Petit et al. (2001) as a convenient way to summarise the available expertise in the consortium. This approach summarised expert judgement with tables of various pressures on habitats across Europe. However, the existing method was not adequate to express the complexity of the ecological significance of transhumance and its associated threats. Accordingly the DPSIR framework was expanded with the following objectives:

1. Extending the range of habitats from those defined strictly as “mountain” to all those used by transhumant animals
2. Considering only pressures related to transhumance
3. Broadening the information on habitats by including comments on the extent of transhumance and its beneficial or detrimental influence on them

These assessments were made according to the expert opinions of the project consortium and could be subsequently be quantified.

Consequently, the following approach was developed:

Step 1. The pressures on the habitats were divided into three groups:

a. Pressures from driving forces not related to agriculture, which have no direct link with transhumance but which can lead to changes in habitats and biodiversity. Examples: exotic afforestation (widespread in Portugal and Spain), urbanisation and climate change.
b. Pressures from driving forces related to agriculture, which have no direct link with transhumance. Examples: ageing population and rural migration to urban areas.
c. Pressures which are directly linked to land used by transhumant animals. Examples: changes in the species of grazing animals (specifying the influence of a shift from one species to the other), lack of shepherding and cessation of hay cutting.

From these three groups, only the last one was considered because it was directly related to transhumance.

Step 2. European habitats were divided into six classes according to their relevance to transhumance and only the sixth class was fully assessed, in order to concentrate on the most important habitats associated with transhumance. The full impact assessment is given in Bunce et al. (2004) and policy options for their maintenance are described by Herzog et al. (2005).

The *first four habitat classes* consist of those habitats (a) not present in transhumant regions (e.g. marine habitats); (b) present in transhumant regions but not affected by transhumance (e.g. sparsely vegetated habitats); (c) of limited extent (e.g. inland saline grasslands); and (d) minimally affected (e.g. bogs).

The *fifth category* consists of forest (woody vegetation cover > 30% and height > 5 m), tall (height 2–5 m), mid (height 0.6–2 m) and low (height 0.1–0.6 m) scrub. In many Mediterranean regions the structure and composition of these habitats is determined by the intensity of their use by stock. The pressures on these habitats are primarily related to the status of transhumance and can change quite rapidly on cessation of grazing, which also controls the structure of the vegetation. Within this category there are variable degrees of local reversibility and it is not therefore possible to generalise the impacts.

The *sixth category* consists of the following habitats, which are considered to be widely controlled by transhumant activities, although only two are agroforestry practices:

1. *Low woody scrub between 0.6 m and 2 m, with associated bare ground, herbs or grasses*. This category is widespread throughout the Mediterranean and its composition and height is largely controlled by grazing. This category has high biodiversity and its composition is often governed by a combination of fire and cattle, sheep and goat grazing. The state is stable or declining, depending on local conditions, and the impact of transhumance is high, because it maintains the biodiversity. The policy response should be to maintain traditional management.
2. *Annual vegetation is present where disturbance is so great that perennial species do not survive*. This habitat is only present extensively in the Mediterranean and

is maintained by high pressure of sheep, cattle, pigs and goats combined with ploughing and fire. It may be present between trees, in which case it forms part of a silvoarable system. The state of this habitat is susceptible to any change of management, which enables succession to take place. The impact of such changes leads firstly to a rapid conversion into grassland and then into various scrub categories. The policy response is to support extensive grazing systems, the use of fire and to prevent afforestation, although in Portugal new *montados* are being planted with low tree densities.

3. *Intensively managed mesic, usually quite eutrophic grasslands with over 70% grass cover*. These habitats are used by transhumant stock, especially in winter, in countries such as Romania, Spain and Italy. Although they have low biodiversity, they are important in that they support spatially separated non-intensive grasslands with high biodiversity. They are maintained by modern industrial agriculture techniques and are usually stable, with impacts being buffered by the high nutrient status. No response is therefore needed for this category.
4. *Mesic and wet acid pure grassland with grass cover over 70%*. It is especially widespread in Britain, in the mountains of the west. It is a degraded system and, although used by local transhumance, is of low biodiversity. Technically it is maintained in its current state by overgrazing, especially of sheep, and would undoubtedly change to low scrub if these animals were removed. Therefore, although stable at present, it could change. It is doubtful that any policy response might be required.
5. *Dry, very dry and xeric grasslands with grass cover over 70%*. These are present through the Mediterranean mountains and on south facing slopes in the Southern Alps. They are frequently in various states of abandonment due to the decline of extensive grazing and the lack of shepherding. The impact is that the original mixture of grassland and herbs has turned into pure grassland, which can eventually be colonised by trees and shrubs. This decline can only be halted by maintaining traditional systems of extensive grazing.
6. *Mesic, acid, neutral and basic mixed grassland*. Such grasslands are relatively frequent in the Alps and Pyrenees and more rarely in northern mountains. This category is one of the most important in conservation terms and often depends on transhumance. It includes many Alpine hay meadows and herb rich pastures that are highly valued both scientifically and aesthetically. They have high biodiversity and are maintained by sheep and cattle grazing, without the use of artificial fertilisers. Although generally stable, such grasslands can change state very quickly if the balance of the pressures changes. The impact of transhumance is therefore high and, if not maintained, these grasslands will lose biodiversity.
7. *Dehesas* (Spain) and *montados* (Portugal). Many of these areas are integral to transhumance systems and consist of open forest or scattered trees, mainly of *Quercus ilex* and *Quercus suber*. They occur principally in western and central Spain and central Portugal, and less frequently throughout Mediterranean Europe. These habitats are not always easy to identify from land cover maps. In particular the CORINE Land Cover Agroforestry category (class 2.4.4) is considered as the main dehesa and *montado* class. However, the classes of

Broad-leaved forest (3.1.1), Sclerophyllous vegetation (3.2.3) and Transitional woodland-shrub (3.2.4) might also cover some types of *montado* systems (Van Doorn and Pinto-Correia 2007). The major ecosystem types in the *dehesas* are: evergreen sclerophyllous forests, woodlands or scrub. These habitats are considered to be one of the most important for biodiversity in Europe (Gómez-Sal 2001) and contain many bird and animal species from the Bird and Species Directives. The pressures are from all types of grazing animals, as well as direct management, e.g. crop cultivation. The state of these systems is that they are inherently unstable, because they depend on heavy grazing. Associated arable systems are also declining, as is the use of traditional breeds of sheep and cattle. The impact is that the structure is directly dependent on traditional management, especially transhumance. Abandonment of these practices therefore leads to scrub invasion and the loss of open habitats. Consequently, policy support is required for mixed grazing and the promotion of traditional agricultural practices (Pérez-Soba et al. 2007).

Conclusions

Agroforestry systems are complex and it is necessary to record their composition and state in situ. Currently such information is not available in a consistent form throughout Europe, which hinders the development of a long term policy regarding their maintenance and identification of links with agricultural systems and biodiversity.

Formerly, many agroforestry systems were an integral part of transhumance practices, but these are now largely in decline. A recent review of *dehesa* landscapes concluded that the disappearance of traditional transhumance has important negative impacts on the sustainability of the *dehesas* (Pérez-Soba et al. 2007). New ways must be found to maintain agroforestry systems in modern society; including novel EU funded agri-environmental and rural development measures. Finally, it is necessary to provide scientific knowledge for a greater recognition of the environmental services provided by these systems, and also their significance for sustainable development.

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Chapter 16
Agroforestry in the Netherlands

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Abstract Early farming activity migrated originally from forests. A high rate of cultivation led to almost complete degradation of Dutch forests. To conserve them it was necessary to prohibit grazing of forests. Since a few decades, grazing has been used as a measure to improve the natural values of forests. An agroforestry system, which existed for a long period in the Netherlands, was high-growing fruit trees (*boguards*) with an underlayer of grass, which was mowed or grazed by cows and sheep. Recently there has been an increased interest in combining trees as multipurpose natural elements with agricultural activities. Research and demonstration projects have been established in different parts of the Netherlands. Walnut (*Juglans regia* L.) is the most widely planted tree species. Density varies between 25 and 100 trees per hectare. Understorey vegetation is mostly grass, which is grazed by sheep, cows or horses/ponies or is mowed and ensiled. Other combinations of tree species with understorey are explored. Some research has been carried out regarding the attitude of modern farmers. Farmers from different regions had different attitudes. The needs of an urbanising countryside seem to favour chances for agroforestry.

Keywords Fruit trees, history

Agroforestry in Ancient History and More Recent Times

Nowadays, agroforestry activities in the Netherlands are limited. Since the 1950s, high labour costs and land prices have forced farmers since the 1950s to expand their farms for large-scale agricultural production. This has been realised with a rational, intensive use of fertilisers and chemicals to increase growth and to control weeds and

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diseases. Agricultural enterprises specialise in monocultures, rather than mixing crops or mixing crops with trees. But due to the negative effects of intensive agriculture with monocultures, interest in agroforestry has been growing since the early 1990s. In this paper we describe the development of agricultural and other land use activities in the Netherlands up to the present day.

Growing agricultural crops and husbandry activities in the forest are the first agroforestry activities recorded in the Netherlands. By about 2500 BC farmers started individually farming in the forest, which mainly consisted of deciduous species such as birch, alder, oak, ash and elm, but also Scots pine. They cut and burnt the forests, starting with the open, easily reached dryer parts on sandy soils, grew grain on small cultivated fields and domestic stock (sheep, pigs, cows) on the perimeter of the forests. Since bronze tools could be made (ca. 1500 BC), forests could be felled easier. This led to an open landscape with heath-fields on sandy soils (eastern part of the Netherlands). In the period after 500 BC, when tools made of iron were introduced, agricultural methods became more intensive and low situated areas in the west and north of the country were settled. During this period meadows had already been established in the coastal zone, using sheep and cows for grazing. Also ship-building activities, especially after the arrival of Romans in 50 BC, which needed a great amount of timber, contributed to a decrease in forest cover. By now, the increasing population needed a growing volume of firewood including charcoal.

After the retreat of the Romans (AD 270) and the invasion of the Celts and Germans, many forests disappeared due to reclamation for permanent farming. During that period the first settlements appeared. They used a system of inner and outerfields, with cropfields (inner fields) around the village and heaths (outer fields) behind the cropfields. During the day sheep grazed on the heath fields and at night they were kept indoors where they left their manure. This manure was used to fertilise the fields.

After AD 800 the feudal lords, bishops and monks took on the duty of reclaiming land and this accelerated forest loss. With expanding commercial activities and development of cities an increasing amount of timber for buildings and ships was needed. All these processes led to a gradual reduction in the Dutch forest area. In the 17th century almost all forest (except some protected areas) had disappeared. Since the beginning of the 19th century new forests have been planted, originally on inland drift sands, to protect the villages against wind-blown sand. In the 19th century and the first ten years of the 20th century new forest areas were established, especially on the former heath fields. Most of these forests were conifers, such as Scots pine (*Pinus sylvestris* L.), spruce (*Picea abies* L. Karst.), larch (*Larix kaempferi* Lamb.) and Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco). In the second half of the 20th century new forests also appeared on the new, reclaimed land in the polders. These forests consisted of broadleaved tree species such as poplar, willow, oak, ash, elm, lime and maple. Nowadays, forests in the Netherlands cover 360,000 ha (7% of the total area), with *Pinus sylvestris* as most important species (33%) and oak (mainly *Quercus robur* L.) (18%) as the most important broadleaved species. However, since the forest law was introduced (1938) forest grazing, as in many places in Europe, was prohibited in the

Netherlands. The main functions of the forests were protection against soil erosion, timber production and for hunting.

Since the 1970s grazing has been used as a specific measure to improve the natural values of forests, including biodiversity. In more recent times different types of combinations of agriculture with trees have been developed and these will be discussed here.

Agroforestry Today

Nowadays agroforestry is practised on some farms in the Netherlands. Several experiments have been carried out to demonstrate the possible advantages of the implementation of agroforestry systems. The types of agroforestry practices that can be found in the Netherlands are presented below.

Farm Agroforestry Systems Practices

One of the most common types of agroforestry is the combination of fruit trees with husbandry. In the 20th century, a large area (5,000 ha in 1984) of fruit orchards were situated on clay soils between the rivers Rhine and Meuse. These had mature fruit trees like apple, pear or cherry and were spaced at 50 to 150 trees per hectare. The grassy vegetation in the shade under the trees was largely "*boguard*" species, like *Dactylis glomerata* L., *Holcus mollis* L. and *H. lanatus* L., which were usually mowed or grazed by cows and sheep (sometimes even pigs, for example under plum trees as a secondary use of the system). It was a system which developed using different products, without subsidies. Since the 1970s most of the high stem fruit-tree orchards have been replaced by intensively managed low stem trees of new cultivars, with high stem numbers per hectare. In the most intensively used orchards, however, the combination with livestock farming did not work particularly well due to insolvable problems such as the need to protect the trees, and soil compaction by livestock. The only combination that sometimes worked out well was when poultry was the animal component (Bloksma et al. 2002).

The second type of agroforestry system which has been used for a long time is a combination of growing poplar with husbandry. In the province of Noord-Brabant in the southern part of the country, farmers have been growing poplar for industrial purposes (veneer for matchsticks) over a large area (ca. 3,000 ha). The grass cover has been used for hay-making or for cattle grazing. In this system, in which poplars were established at 100–200 trees per hectare, some research has been carried out on grass production under competition for light, moisture and nutrients.

A third example, which can be considered as a type of agroforestry system, is farming between rows of alder (*Alnus glutinosa* L. Vill). At the borders of the wetlands of the northern part of the country, the landscape has developed into a dense network of alder rows, between which the farmers kept their cows or harvested grass. During summer cows grazed the meadows between the alder rows. In winter time the alders were pruned vertically (branches were used as firewood) or felled (for firewood or construction timber) in a 25 year rotation. Presumably grass growth was increased by the biological nitrogen fixation by the alders (De Boer and Oosterbaan 2005).

As stated earlier, grazing is being used nowadays as a specific measure to improve the natural state of forests. Since the 1980s grazing of forests by domestic ungulates has become a more common practice in the Netherlands (Kuiters 1998). Natural processes, such as grazing by wild and domestic grazers, were given more priority in forest management. Subsidies for tree planting were stopped by the government and since then spontaneous regeneration is considered as a key process to guarantee sustainable timber output. Grazing can improve conditions for tree regeneration by reducing the accumulated litter layer, thereby creating better conditions for germination and establishment of tree saplings. For successful further growth the applied grazing pressure must be extensive at densities of no more than 1–3 animals per 100 ha on nutrient-poor sandy soils (Jorritsma et al. 1999). In the Atlantic area of Spain it was found that grazing can enhance tree regeneration (McEvoy et al. 2005).

Grazing by domestic ungulates can be applied as a management tool to create semi-open park-forests with species-rich transition zones between closed forest and open grassland or heathland (Kuiters 1998).

The total cover of Dutch forest landscapes grazed by domestic stock was estimated around 31,000 ha (9% of the total forest area) in 2003 (Table 16.1). Most sites are composed of a mosaic of forest, heath- and/or grassland which are integrally grazed. Cattle are mostly used, often in combination with one or more other domestic grazers such as horses or sheep. Either year-round or seasonal grazing is practical. The average size of

Table 16.1 Overview of forest grazing in the Netherlands in 2003 (seasonal grazing is either summer-grazing (period April–October) or winter-grazing (November–March). Mean-stocking rate amounts to ca. 20–30 livestock units per 100 ha, in year-round grazed areas ca. 3–10 livestock units per 100 ha, depending on grassland cover)

	Year-round grazing	Seasonal grazing	Total
GRAZED SITES			
Cattle grazing	40	64	104
Horse grazing	7	2	9
Sheep grazing	26	36	62
Goat grazing	2	4	6
Combined grazers	37	37	74
Total number of sites	112	143	255
COVER			
Total area (ha)	16,831	14,129	30,960
Minimum size (ha) per site	5	5	5
Maximum size (ha) per site	3,900	1,733	3,900
Median size (ha) per site	57	45	50

the grazed sites is rather small, approximately 50 ha. The largest grazed forest areas cover several thousands of hectares with free-roaming, extensively managed grazer populations, often combined with wild ungulate populations. Sometimes nature management organisations have their own livestock, but mostly animals of farmers are used. Grazing of forested sites can be economically very profitable through the production of certified 'green' meat. This is produced without recourse to any fertilizers, pesticides or antibiotics and is of a very special quality (Kuiters 2005).

Experiments and Experiences of Agroforestry Systems

Since the negative effects of agricultural practices with intensive use of chemicals in large-scale monocultures are known, the search for alternative ways of producing crops and food has been intensified. This led to the establishment of experimental plots and individual efforts of farmers throughout the country (Table 16.2).

Between 1989 and 1994 an experiment was carried out mixing *Populus robusta* Schneid. (202 and 404 trees per hectare) with sugar beet, maize and grass (*Lolium perenne* L.) grown each year with three levels of fertiliser. After six years, the growth of grass under 202 trees hectare (tree height was about 10 m) was 30% lower than grass without trees, at a fertilisation level of 300 kg N ha^{-1}. For grass under 404 trees hectare, the reduction in yield was 60%. The growth of sugar beet and maize under 202 trees per hectare was, respectively, 45 and 55% lower than without a tree cover. These figures include loss of area for the rows of trees (Oosterbaan et al. 1997).

The growth of crops between the trees is economically feasible for at least six years, even without direct subsidies to stop agricultural production. This form of mixed cropping is an interesting way of establishing a tree plantation. When the number of trees is reduced, mixed cropping should be possible on a permanent basis (Oosterbaan et al. 1997). Although it has not yet been investigated, the use of small crowned poplar clones at 50–100 trees per hectare would allow a rotation period of 30 years with a permanent crop mixture.

An intergovernmental program "Sustainable Technological Development" is aimed at developing new sustainable means for issues such as food production. This led for example to the establishment of several experimental multipurpose plantations in the eastern part of the Netherlands. In cooperation with eight farmers and estate owners 10 ha of walnut (*Juglans regia* L.) (cultivars 'Broadview', 'Buccaneer'), cherry (*Prunus* sp.) and sweet chestnut (*Castanea sativa* Mill.) were planted at different spacings of 10–20 m. For these plantations, multipurpose tree species were chosen, e.g. those that produce fruits and valuable timber (Peeters et al. 1996; Oosterbaan and Van den Berg 1997; Oosterbaan 2000). The established plots had trees with grass as the agricultural crop. The grass was either mowed and made into silage or grazed by cows, sheep or ponies. An overview of these silvopastoral experiments is presented in Table 16.3. Investigations carried out from 1999 to 2003 focussed on: grass production and composition; tree development and growth; fruit production; ways of harvesting the nuts and the routes for selling them;

Table 16.2 Agroforestry experiments and experiences in the Netherlands

Type of agroforestry	Tree species	Crop	Location	Area (ha)
Poplar/grass, beet, maize	Populus	Grass, sugarbeet, maize	Estate De Eese (province Overijssel)	4
Walnuts/grass	*Juglans regia* and hybrids, *Castanea sativa*, *Prunus avium*	Grass (+cows, sheep, horses)	Winterswijk (province Gelderland)	10
	Juglans	Grass	Hengelo (province Gelderland)	2
	Idem	Grass(+cattle)	Kallenkote (province Overijssel)	9
	Idem	Grass	Piershil (province Zuid-Holland)	2
	Idem	None	Idem	1
	Idem	Grass	Elst (province Gelderland)	2
	Idem	Horticultural species	Breedenbroek (province Gelderland)	4
	Idem	Hazelnuts	Ommen (province Overijssel)	2
	Idem	Hazelnuts and Hippophae	Luttelgeest (province Flevoland)	1
	Idem	Grass (recreation)	Province Noord-Brabant	5
Poplar, *Sambucus*, bulbs	*Populus spec.*, *Sambucus nigra L.*	Hyacinths	Boelenslaan (province Friesland)	1
	Pinus sp.		Donkerbroek (province Friesland)	2
	Cedrus sp.		Province Friesland	1
	Gleditsia sp.		Province Friesland	1
Robinia/ potatoes	*Robinia pseudoacacia L.*	potatoes	Province Gelderland	1
Alnus/ horticulture	Alnus cordata(Lois) Duby.	Horticultural species	Province Drente	

Table 16.3 Area allocated to different spacing plantations with walnut, sweet chestnut and cherry

	Narrow spacing (10 × 10 m)		Wide spacing (20 × 20 m)	
Tree species	Grazing (ha)	Mowing (ha)	Grazing (ha)	Mowing (ha)
Walnut	1	1	3	3
Sweet chestnut and cherry	½	½	½	½

biodiversity; the prospects for income from tourism. In 2003 the plantations were surveyed for the presence of butterflies, grasshoppers and crickets.

To predict the development of trees and grass production, data on young plantations were combined with data from older plantations on similar soil types in the eastern part of the Netherlands.

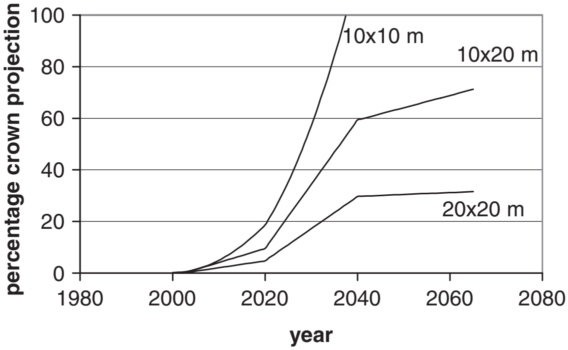

Fig. 16.1 Predicted crown development of walnut plantations with different tree distances

Grass production varied from 3 to 9 t dry matter per hectare per year. In the four years of investigation there was no visible evidence that the trees had negatively affected composition or production of the grass crop. Based on predicted crown development (Fig. 16.1), reasonable levels of grass production will be possible for a long period. So far, the nut production from the young plantations has not been profitable. This is similar to results found in Great Britain (Newman and Adams 1997; Oosterbaan et al. 2005). Compared with flower-rich grasslands, the multipurpose plantations harboured more grasshoppers.

The initial investment required to protect the trees, namely poles and wire netting to protect against animals, resulted in a low net income for the first five years. Later, the income from the combination of walnuts and quality timber with grass is reasonable and may exceed the income from subsidised, extensively managed grass (see also Fig. 16.3).

Walnuts, better adapted to cooler weather conditions, were selected from green areas in the north and evaluated for their characteristics. This resulted in at least two cultivars ('*Dionym*' and '*Amphyon*') with excellent yield potentials together with a good form and timber quality. Both cultivars have a low susceptibility to diseases and are particularly suitable for organic cultivation. '*Dionym*' and '*Amphyon*' are planted in private gardens, but also in a commercial organic orchard of 1.5 ha, in which 200 walnut trees were grown together (mixed cropping) with cultivars of hazelnuts (*Corylus avellana* L.) and Sea Buckthorn (*Hippophae rhamnoïdes* L.) (Oosterbaan and Schepers 2005). The rest of the experiments with different combinations of trees species and crops (Table 16.2) are private initiatives and are spread throughout the country.

Social Aspects of Agroforestry Systems Implementation in the Netherlands

Most agricultural activity in the Netherlands takes place on large farms. Since they have specialized production systems, mixing crops with trees is a novel idea to many modern farmers. Depending on the landscape type, different systems have been established in different places.

Attitude

As a contribution to the SAFE (Silvoarable Agroforestry for Europe) project, farmers' attitudes towards agroforestry in the Netherlands has been investigated. A group of farmers from the small-scale land use landscape on sandy soils in the east of the country was compared with a group of farmers in the open, large-scale landscape on clay soils in the northern part of the country. The first group was more optimistic towards the introduction of agroforestry than the second group (Postma 2005). The most likely explanation was that the 'small-scale farmers' were already used to working with trees around their fields. They were also used to small fields and did not have the feeling that working with trees was something 'new'.

Agroforestry in an Urbanised Society

In urbanised societies it is very important to maintain a green living environment. With "multipurpose plantations" agroforestry can contribute to sustainable cities and urban environments which are more pleasant to live in.

"Multipurpose plantations" consist of multipurpose trees and crops, preferably interacting in a positive way. Multipurpose trees deliver different tangible products like fruits, leaves, bark, twigs, timber, roots and extracts for medicines or other use (Fig. 16.2). Besides these products, trees provide protection against climatic influences (wind, snow, rain, sun, fine dust), enhance biodiversity, C-fixation, dust fixation and protect against erosion (De Boer and Oosterbaan 2005; Oosterbaan et al. 2006a). Crops such as mixed-species grass vegetation deliver fodder, higher biodiversity (compared with monocultures of *Lolium perenne*) and contribute to an attractive landscape (Oosterbaan 2004).

Trees can be spatially orientated in different ways, for example in geometrically organised plantations or in a more natural random pattern. Generally people tend to prefer and appreciate semi-open landscapes which are easy to move through, have clear lines and open water (Van den Berg 2003). A well-defined structure and spatial variation are attractive characteristics to people and encourage visitors to explore (Van den Berg 2003). Multipurpose plantations, managed in a natural way, meet these demands. The most suitable situation to establish multipurpose plantations is the transition zone between the open landscape and the dense forest area. It is preferable that trees and crops influence each other positively. For example, the crop species used should be adapted to the shade of the trees. Animals could also benefit from the shade, for example, cows kept cool produce more milk under better animal welfare conditions. The crop may have a positive effect on the trees, for example by weed control or by contributing biological, microbial nitrogen.

Calculations for a walnut/recreation system showed that such a system can deliver a positive financial output. In a comparison (Fig. 16.3) of a multipurpose

Products:
- Attractive landscape
- Biodiversity
- Fruits
- Timber
- Bark, twigs and others
- Crop
- Other products (e.g. honey)
- Recreation

Fig. 16.2 Overview of the products which could be obtained from a multipurpose plantation

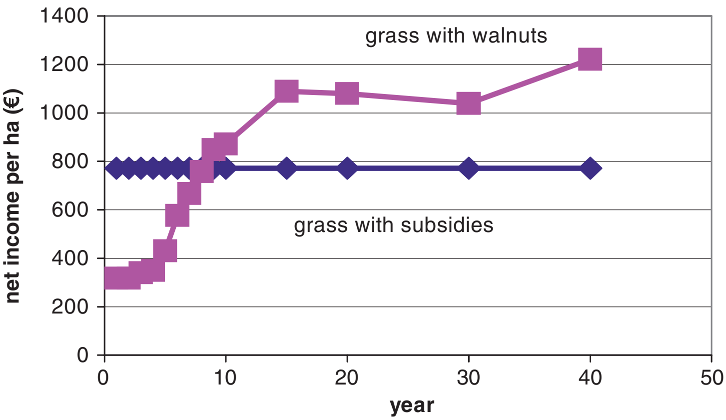

Fig. 16.3 Comparison of net yield per hectare between grass (with subsidies (◆)) and grass with walnuts (■)

plantation consisting of walnuts and grass (mowed or grazed) with subsidised grass farming for extensive management, the plantation option was the most profitable (Oosterbaan 2004, 2006b).

Agroforestry in a European Context

At an agroforestry meeting in Wageningen (2005), one of the most important outcomes was the growing interest shown by practioners and scientists in building a knowledge network in the Netherlands (Mayus and Oosterbaan 2005; Boomplan 2007).

The Netherlands was one of the partners in the European SAFE-project where a biophysical agroforestry model (Yield-SAFE) was developed. This model enables prediction of yields and the analysis of economic scenarios of modern agroforestry systems (Boomplan 2007). Some important conclusions of the SAFE-project are:

- Modern agroforestry systems are compatible with present day agricultural techniques. Specific tree management schemes are necessary (such as tree alignment and stem formative pruning). In modern agroforestry systems, low tree densities (30–100 trees hectare) allow crop production to be maintained until tree harvest.
- Average productivity of silvoarable systems is higher than the productivity of separated trees and crops. Productivity increases of up to 30% in biomass and 60% in final products were evidenced (exclusive result). Tree-crop systems are able to capture more resources from the environment than pure crop or pure tree systems: in facilitation, a process that explains why mixed plots are significantly more productive than pure plots.
- With the developed models, optimum management schemes can be provided for tree stand densities, tree spacing, tree row orientation, tree species choice, intercrop rotation choice, and specific tree and crop management techniques, such as tree root pruning.
- Economic calculations show that agroforestry plots are always as profitable as agricultural plots in a no-grant scenario, and that they are often more profitable with high value timber trees (such as walnut or *Sorbus* species). Annual crops maintain the annual income for the farmer, while managed low density tree stands will provide a capital for the future. Optimal densities of tree stands are between 30 and 100 stems hectare, depending on tree species and site fertility (SAFE 2007).

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Chapter 17
The Potential for Silvopastoralism to Enhance Biodiversity on Grassland Farms in Ireland

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Abstract In the western British Isles, pastoral agriculture with sheep and cattle is the dominant land use. Current changes in EU policy, specifically the implementation of farm decoupling through the Single Farm Payment, enforcing the Nitrates Directive, environmental cross-compliance measures and other initiatives within the Rural Development Plan have driven the need to find alternative land use systems which can enhance biodiversity on grassland farms. Ireland has a moist, temperate climate which suits intensive livestock production systems, and these have negatively impacted on the region's biodiversity. This represents a microcosm of the general problems facing such systems in the British Isles and north western Europe. The integration of farm woodlands and trees onto farmland can address these issues. Silvopastoral systems, where wide spaced trees are planted into grassland have been shown to be compatible with conventional grassland systems, increase biodiversity and enhance the farmed landscape. Research in Ireland with sheep on upland vegetation and sheep and cattle on lowland pastures has shown that such systems can reduce nutrient leakage, increase some invertebrates, birds and flora and create spatial heterogeneity in the canopy and soil. This delivers much more sustainable agroecosystems while still allowing the combination of farming and rural economic development. Such systems should be targeted to and adapted for farmers who wish to develop conservation, amenity, recreation and environmental 'goods' on their farms, be compatible with current agri-environment measures, the organic farming sector and rural community group objectives. These objectives are common to the British Isles and the example of their applicability in Ireland should encourage others to apply them more widely in the region.

Keywords Rural development, silvopastoral systems, agri-environment policy, forestry

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Introduction

In north-western areas of Europe and the west of the British Isles, a moist, wet climate has best suited pastoral agriculture with sheep and cattle. The island of Ireland exemplifies this scenario and represents a microcosm of the region where the enhancement of biodiversity on grassland is a prime agri-environment objective (McAdam 2005).

Over the past 50 years, livestock production from grassland in Ireland has been intensified substantially (Moss 1997; Connolly et al. 2002; Feehan 2003) creating serious environmental problems such as reduced biodiversity and nutrient leakage into water courses. Nowadays, EU policy aims to reduce the levels of output from grassland systems through implementation of fertiliser restrictions under, e.g. the Nitrates Directive and to promote sustainable farming practices which attempt to address some of the damage caused by previous intensive agricultural practices (Finn 2003). Such a policy is to be implemented through decreasing levels of livestock output, tightening nutrient management on farms, enhancing biodiversity through a more sustainable and lower input agriculture, increasing tree cover to contribute to habitat heterogeneity and increased stabilisation of rural communities as is happening in other EU countries.

Tree cover in Northern Ireland (6%) is the lowest in Europe (mean 31%) (Cooper and McCann 2002) and in Ireland is approximately 10% (Bulfin 1999; Short et al. 2005).

Agri-environment Policy

It is widely accepted that agriculture has a multifunctional role, delivering not just food but other public goods such as the protection of habitats and biodiversity and enhancement of the countryside (DARD 2003). The increasing need to integrate food production with responsible countryside management is reflected in the changing emphasis of agricultural policy. The need was originally addressed through EU regulation 797/85 which stated that member states could introduce agri-environment measures in order to ameliorate some of the long-term environmental damage caused by intensive agriculture. Subsequently, as part of the reform of the Common Agricultural Policy, regulation 2078/92 stated that member states should introduce agri-environment measures (Finn 2003). Agri-environment measures became compulsory in 1999 in the EU (under regulation 1275/99) and are now an integral element of Rural Development Plans. The underlying concept behind these measures is the encouragement of producers to farm in an environmentally friendly way through active management of the countryside and reduced inputs, especially of pesticides and fertilisers.

The aim of establishing these schemes is to help safeguard areas of the countryside where the landscape, wildlife or historic interest is of particular importance and where that interest would benefit through farmers continuing with, or engaging in, environmentally sensitive farming practices. These programmes, with their direct and tangible commitment to such farming practices, marked a significant departure from agricultural policy. Farmers are effectively being paid by Governments to 'produce' countryside (Baldock et al. 1990). The additional financial support received by farmers also contributes towards rural development and ensuring the stability of rural populations.

Where agroforestry aligns with EU policy is much less well defined. Silvopastoral systems can contribute to reduction of livestock grazing pressure, better nutrient management and amelioration of animal living conditions if introduced to intensive or semi-intensive farming systems. Animal welfare is now a key element of cross-compliance measures for the Single Farm Payment. Silvopastoralism aligns closely with current EU policy for intensively managed pasturelands which will be decoupled from subsidies based on headage payments for production to a system of payment based on stewardship of land with strict environmental and other cross-compliance measures attached.

In a more global context, silvopastoralism can be a mechanism to create land use systems with levels of carbon sequestration which are higher than those from pastureland and which can buffer the more adverse effects of climate change (Mosquera-Losada et al. 2005).

Agricultural officials in Northern Ireland are regarding silvopastoral systems as eligible forage area for Single Farm Payment (SFP) as long as agriculture remains the primary land use. Within the current Rural Development Regulation support is provided for agroforestry (EC, 2004).

It is proposed that silvopastoral systems, where wide spaced, protected trees are planted into grassland and managed as a multi-functional system to realise significant ecological, social and economic benefits, represents one option to introduce trees to the farmed landscape. This paper will analyse the background to the evolution of practice and thinking and the current research on silvopastoral systems in Ireland will be reviewed to demonstrate the validity of this proposal. The opportunity for Ireland and Northern Ireland offered under increased modulation proposals within the Rural Development Plan will contribute to this proposal.

Climate, Soils and Land Use in Ireland

The island of Ireland consists of a large central lowland of limestone with a relief of hills and several coastal mountain ranges and is situated in the extreme north west of Europe between 51.5 and 55.5 degrees north latitude and 5.5 and 10.5 degrees west longitude. The Irish Sea to the east, which separates Ireland from Britain, is 17.6–192 km wide. The total land area is 84,421 km^2 (70,282 km^2 in the Republic of Ireland and 14,139 km^2 in Northern Ireland).

Topography is varied, a high proportion of the land is undulating, hilly or mountainous. Approximately 30% of the region is above 150 m altitude. Soil cover is very varied, alluvial sands, clay and heavily gleyed soils, reflecting a diverse parent geology several periods of glaciation and relatively high rainfall. There are extensive areas of peat bogs and underlying drainage is a key determinant of soil fertility and land use (Wilcock 1997).

The cool maritime climate is ameliorated by the Gulf Stream and temperatures are fairly uniform over the country. The coldest months are January and February which have mean daily air temperatures between 4°C and 7°C while July and August are the warmest months (14–16°C). Extremes of temperature below −10°C or above 30°C are very rare. May and June average 5–7 hours of sunshine per day. In low-lying areas mean annual rainfall is 800–1,200 mm and in upland areas can exceed 2,000 mm. Rainfall is well distributed throughout the year but about 60% of the total falls between August and January. Cloud cover is high, mean total hours of sunshine per year is 1,300 (Betts 1997).

Agriculture and Land Use

In Northern Ireland 78% of the area is in agriculture (1.1×10^6 ha) and 70% of the farmed use is classified as Less Favoured Area (LFA). Agriculture is based on livestock production from grassland and approximately 2.3×10^6 sheep and 1.7×10^6 cattle graze 78% of the land area (MLC 2003). Of this area, 54% is grassland which has been improved by cultivation reseeding (usually with *Lolium* spp.) fertilising and more intensive management; 36% is unimproved and semi-natural grassland (i.e. native grassland or degraded previously improved grassland or grassland, which has been man-modified at some stage in the past but is now unmanaged) and 5.5% is in arable production (Cooper and McCann 2002). There are approximately 30,000 farms, mean farm size is 35.5 ha and 92% of farms are either owned or owned and rented (DARD 2003). In the Republic of Ireland, there are 144,000 farms in a total farmed area of 4.4×10^6 ha (63% of the area), mean farm size is 29.3 ha, most farms are cattle or sheep based (MLC 2003) and the proportion of LFA is 67%. Tree cover over the whole island is 9.3% and approximately 80% of this area is with exotic conifer species (mainly *Picea sitchensis* Bong. Carr and *Pinus contorta*) planted on wetter, heavier or more acidic soils.

Biodiversity

Ireland has typically only about 50% of the British Isles total biodiversity, a very low level of endemism and a small proportion of the world total for most species groups (Anon 2000). This is largely because: Ireland was glaciated until only 12,000 years ago; recolonisation since the ice age has been slow due to rising sea levels and the resulting sea barriers; isolation from continental Europe; habitats are restricted by size; northerly latitudes have fewer species. However, the naturally impoverished fauna and flora is significant because: Ireland contains several important subspecies and variants as a result of post glacial isolation; there is less interspecific completion; the warm, wet, oceanic climate benefits some groups such as cryophytes and pteridophytes; valuable overwintering habitat for wetland birds (Anon 2000). The main issues affecting biodiversity in Ireland include policy and activities in the fields of: agricultural systems and support, forestry and woodland management, coastal and marine management, water use and management, construction and development, tourism and recreation, peatland management, introduced species, protecting special areas for biodiversity, protecting priority species and habitats and conserving genetic biodiversity. For the purposes of this paper, only agricultural systems and support will be considered.

The effects of post-war agricultural intensification in Europe and the resultant reduction in semi-natural habitats have been well documented (McCracken 1993).

In Ireland, state-funded programmes of drainage, land reclamation and the change from hay production to conserving grass as silage has led to major increases in intensively managed grassland with low species diversity at the expense of more natural habitats such as wetlands, boglands and species-rich grassland. Concomitant with an increase in areas of intensively managed grassland was a substantial increase in stocking rate and its associated problems of high volume slurry production. Agricultural-related pollution incidents from slurry and silage effluent increased to a maximum in the mid 1990s and then declined. This trend was fuelled by the Common Agricultural Policy which encouraged increased food production up until the early 1990s.

Trees and Biodiversity on Farms

Woodlands and Biodiversity

Semi-natural Woodlands

Northern Ireland is the least wooded region of Europe, with an approximate total tree cover of 6%. Only 1% consists of mixed species broadleaf semi-natural woodland (i.e. woodland which had some form of human modification in the past) and the remaining 5% of total land area is introduced, exotic conifers.

Remaining areas of semi-natural woodland occur on steep slopes or other areas inaccessible to forestry practices (Mitchell and Kirby 1990; Cooper and McCann 2000). These remaining fragments of semi-natural woodland usually survive adjacent to grazing land and include many woods which have been grazed by deer and domestic stock for many hundreds of years (McCracken 1971; Mitchell and Kirby 1990; Kirby et al. 1994). Such woodlands make an important contribution to upland agriculture by providing shelter and grazing for domestic stock (Blyth et al. 1987; Mitchell and Kirby 1990), in addition to their importance as conservation and landscape features (Kirby et al. 1994).

Despite this long history of grazing in woods, the practice has been considered one of the main threats to present-day ancient woodland (Rackham 1990).

Concerns over lack of tree regeneration in many woodlands in Northern Ireland have resulted in all grazing activity being excluded from many woodlands under agri-environment agreement (McEvoy and McAdam 2005).

However, a number of changes to the woodland ground flora have been observed under a regime of grazing that may increase botanical diversity:

(1) A reduction or total elimination of palatable species, thus reducing diversity, driving the community towards a species-poor assemblage of a few hardy and resistant species (Putman 1996; Tubbs 1997).
(2) An expansion in numbers of species resistant to grazing pressure, by virtue of prostrate growth form, or through possession of physical or chemical defences against herbivory (Putman 1996).
(3) A reduction in dominant species, such as *Rubus fruticosus* agg. (bramble), *Pteridium aquilinum* L. Kuhn (bracken) and rank grasses may enhance diversity by providing a release from competition for the lower growing, less vigorous forbs, thus increasing diversity (McEvoy and McAdam 2002).
(4) Grazing may facilitate the co-existence of potential competitors by preventing dominance of the more vigorous species.
(5) Herbivores may introduce new species to the woodland on their bodies, in hair, wool, between propagules of hooves, etc., or by dunging. These processes are known as epi- and endozoochory (Gill and Beardall 2001). Plants with small hard seeds are most likely to survive digestion. Most of the species known to be dispersed in this way are grasses and small herbs.

To evaluate the impact of livestock on the vegetation of semi-natural woodlands in Northern Ireland, a programme of surveying was undertaken between April 2002 and June 2003 (McEvoy et al. 2006a). One hundred and five areas of broadleaf woodland areas were sampled.

Significantly more species of higher plant ($p < 0.01$) were found in grazed woods than ungrazed woods. Additional species found in grazed woods tended to be ruderals such as *Cardamine flexuosa* With. and *Cerastium fontanum* Baumg. Ungrazed woods were found to have significantly more leaf litter and deadwood than grazed woods ($p < 0.01$) with approximately twice the ground cover of leaf-litter.

No significant difference ($p > 0.1$) was observed in percentage cover of bryophytes.

Grazed woods were found to have significantly more grass cover (approximately twice as much) than ungrazed woods ($p < 0.01$).

Ungrazed woods were found to have significantly more bramble (*Rubus fruticosus* agg.) cover than grazed woods ($p < 0.05$). Bluebell (*Hyacinthoides non-scripta* L. Chouard ex Rothm.), a typical woodland indicator species, had significantly less ($p < 0.05$) cover in grazed woods compared to ungrazed woods.

Grazing has also been shown to have positive association with tree regeneration. An investigation on seedling and sapling density of oak *Quercus robur* in a range of habitats in a grazed wood in Galicia, NW Spain found significantly more seedlings and saplings inhabiting open, grazed areas, compared to areas of taller ungrazed vegetation and scrub (McEvoy et al. 2006b). Stocking rate is an important factor. The absence of grazing allows tall shrubs grow up, which avoid significantly tree regeneration due to the lack of light input to the soil (McEvoy et al. (2006a).

Plantation Woodlands

Current trends in tree planting favour slow-growing broadleaves which require fertile conditions. The introduction of grants and premia by the Government to the private sector in Britain, i.e. the Woodland Grant Scheme (WGS) has vitalised interest in forestry among farmers and the choice of land available for tree planting has widened significantly. There is a considerable interest now in planting broadleaves on good quality lowland that was previously used for intensive pastoral agriculture. Any future increases in the area covered by trees is likely to come from such areas of farmland which are released from pastoral grazing by farmers wishing to destock or reduce their stock under the single farm payment (SFP).

Forests established on intensively managed, species-poor grassland habitats can often create greater opportunity for wildlife as the variety of habitats increase. Forests in such areas also contribute to reductions in fertiliser and pesticide applications, as unlike modern agriculture, sustainable forests do not require large quantities of these chemicals on a continual basis.

However herbicide applications are still required as ex-agricultural and improved grassland sites are normally much more fertile than the unimproved grassland sites that have been the subject of forestry planting in the past and competition is a major establishment issue.

Competition by grasses and herbaceous weeds in young plantations can seriously reduce the survival and early growth of the trees and lead to an extended establishment period. Grasses especially can compete vigorously for light, nutrients and water (Williamson and Lane 1989). Culleton and Bulfin (1992) found considerable amounts of apical bud death and dieback in young plantations with no weed control.

One way of fulfilling all of the above requirements may be the use of livestock to graze the unwanted herbage as a form of biological control. Forest grazing has had a revival, following an initial interest in the 1970s (Adams 1975). This has most likely arisen from the research carried out on agroforestry systems since the early 1990s (Sibbald et al. 2001) in the UK. In silvopastoral systems created by planting trees into pasture, some form of tree protection maybe necessary for up to 5 years for sheep (depending on tree species) and 12 years for cattle. This usually involves plastic tree guards or netting.

Many silviculturalists are reluctant to support prescribed livestock grazing because of fears of browsing damage to young trees (Sharrow et al. 1992).

However, this method of weed control in forest plantations has been successfully carried out in a number of countries including; Greece (Papanastis et al. 1995), New Zealand (Breach 1986; Brown 1986; Dale and Todd 1986; Hansen 1986), the United States (Sharrow et al. 1992), Spain (Silva-Pando and González-Hernández 1992; Silva-Pando et al. 1998; Rigueiro-Rodríguez et al. 1997), Japan (Shibata 1970; Ide 2001) and the Netherlands (Kuiters et al. 1996; Kuiters 1998). These systems differ from conventional agroforestry systems, which incorporate trees into a livestock/pasture system, where the livestock forms the basis of the system. In the forest grazing systems mentioned above, the livestock is used purely as a silvicultural tool, with the trees the principal component of the system.

An experiment was carried out where sheep were grazed in temporary fenced paddocks at a stocking rate of 178 Livestock Units LSU ha^{-1} in a 5-year old broadleaf plantation of oak *Quercus* spp. and ash *Fraxinus excelsior* L. (1.5 m spacings) on fertile ex-lowland pasture in Northern Ireland (McEvoy 2004). The grazing regime was rotational and intensive, with two grazing periods of 5 days in February and October 2001.

Results showed that a significant proportion of the rank herbage height was removed in the first 24 hours of livestock introduction. Herbage biomass was reduced by approximately half after 5 days. Sward height in grazed plots remained significantly lower than control plots for over 6 months after cessation of grazing, whilst biomass remained significantly lower for over 4 months after cessation of grazing.

No significant tree damage to either oak or ash was measured during the February grazing period, however significant damage to the lateral branches of both oak and ash was observed in the October grazing period. Ash was more commonly browsed than oak. Terminal leader damage did not occur on trees greater than 152 cm. Annual height increment of both tree species was unaffected by grazing, but annual stem diameter increment was significantly reduced in both oak and ash in February grazed plots and not in October grazed plots. The reduction in rank herbage by grazing and trampling may also encourage colonization of typical shade and woodland species form the dense network of species-rich hedgerows and banks which occur on the site. Further research is required to assess the potential of such a resource to colonise broadleaf plantations to create a species-rich woodland understorey.

From a series of six co-ordinated trials (the UK National Network Silvopastoral Experiment, Sibbald et al. 2001) across pastoral areas in the UK, protected trees – Sycamore *Acer pseudoplatanus* L. (at all sites) and Ash, *Fraxinus exelsior* L. Hybrid Larch Larix decidua, Red Alder *Alnus rubra* and Scots pine, *Pinus sylvestris* L. were planted at woodland (2,500 per ha) and two silvopastoral spacings (5 × 5 m – 400 trees per hectare; 10 × 10 m – 100 trees per hectare) unto pasture grazed by sheep to a predetermined sward height profile and compared with a pasture-only system.

Silvopasture and Biodiversity

A review of the effects of silvopasture on biodiversity is presented by McAdam (2000). Broadly, it was concluded that invertebrates (especially spiders) were encouraged to grassland sites by the presence of trees. Most of the work reported was on the effects of silvopasture on some invertebrate groups, birds and grasses and broadleaved plants typically invading sown, *Lolium*-based grassland (e.g. Cuthbertson and McAdam 1996). This, in turn will provide more food for birds (McAdam 2000). Dennis et al. (1996) and McAdam et al. (2007) found that spiders and staphylinid beetles appeared to respond more rapidly to the introduction of silvopastoral systems than carabid beetles. Silvopastoral systems appear to encourage birds normally associated with hedgerow and woodland onto grassland, creating a dynamic assemblage of species unique to silvopastoral systems and creating a more diverse farmed landscape where birds can have access to cover and food in a series of wildlife corridors (McAdam et al. 2007). From the silvopastoral National Network Experiment in the UK (Sibbald et al. 2001) it was found that the presence of trees tended to speed up the natural process of succession from a diverse soil seed bank and create pasture with greater floral richness (McAdam 2000).

Silvopasture in Ireland

Research on silvopastoral systems to date has been concentrated on quantifying production (eg Mcadam et al. 1999b) and fewer resources have been directed towards the investigations of ecological interactions (Crowe and McAdam 1999; McAdam 2000; McAdam et al. 2006). In 12 year old silvopastoral systems (at the Agri-Food and Biosciences Institute (AFBI)) lowland grassland field station at Loughgall, output was only marginally reduced 11 years after planting ash at 400 stem per hectare as part of the National Network Experiment (Sibbald et al. 2001). The impact of the system on aspects of biodiversity (carabid beetles, spiders, birds and flora) was investigated when trees had been established for up to 8 years. More spiders were collected from silvopasture than either pasture or woodland treatments and within the agroforestry, at the higher density of planting (400 stems per hectare vs. 100 stems hectare) (Johnston 1996). Carabid beetles were more numerous and from a wider range of species in the silvopasture than open pasture (Cuthbertson and McAdam 1996; Whiteside et al. 1998). Toal and McAdam (1995) found that, generally significantly more birds were recorded on lowland and upland silvopasture in summer and winter than either open pasture or woodland. In establishing silvopasture at Loughgall, plant diversity was slightly greater (but not significantly so) near trees than in open pasture (McAdam 1996; McAdam and Hoppé 1996) but in a mature, 35 year old poplar stand at 8 × 8 m spacings, Crowe and McAdam (1992) found that plant diversity was significantly greater than in the open sward. This work showed that over the life history of silvopastoral systems in Ireland, changes in biodiversity will occur and this will likely result in systems which have significantly greater levels of biodiversity than conventional grassland.

In the Republic of Ireland Short et al. (2005) established a silvopastoral experiment at Johnstown Castle in County Wexford (Teagasc Research Station) in 2002 with oak (*Quercus robur*) in an alley design and grazed by cattle. Trees were successfully established and cattle managed in the system. The establishment of an alley silvopastoral system (in this case with electric fencing) into existing pasture increased ground beetle abundance relative to a plantation being introduced. The study also showed that there may be potential for silvopastoral systems to be used as a tool in the prevention of non-point source pollution from overland flow originating from pasture (Short et al. 2005).

Integration of Systems

Under the arrangements set in place following decoupling with SFP, the agricultural industry might develop in two groups of agricultural production: 'competitive pillar' – a relatively intensive agriculture industry competing on world markets in a strictly business-orientated method of raw material/food production; 're-creational pillar' – conservation, amenity, recreation and environment (CARE goods) – state subsidy aimed at producing CARE goods through funding to farmers/landowners. The 'bridge' between these two pillars is rural development policy, which can provide benefits in both areas. The integration of trees onto farms and into livestock systems (silvopasture) at a range of scales and levels offers a strategic policy option to realize some of these goals.

Agriculture has come through a series of crises recently and farm incomes are currently severely depressed. In difficult times farmers generally concentrate on short-term goals and needs, longer term needs being much less attractive. This tends to severely limit the opportunity for innovative long-term planning. The needs which can be justifiably met by planting trees tend to be longer term. However, currently farmers are by necessity concentrating on the short- to medium-term goals. Although this fact has always been recognized as major drawback to farmer investment in woodland-related enterprises, it would appear that this limitation is particularly strong at present. The position of trees in silvopasture becomes even more difficult as it is viewed as an unproven technology in a range of woodland options which are already considered as limited in achieving short- to medium-term goals. Speculating on the potential for agroforestry planting in Northern Ireland, given the current state of the industry, it is likely that silvopasture should not attempt to substitute for current or proposed woodland planting (McAdam and Crowe 2002) but be targeted to those farmers and landowners included in the recreational pillar (of the CAP) category, all farmers interested in agri-environment measures, and increasing levels of biodiversity in grassland; conservation bodies and community groups; farmers with specific nutrient management problems, e.g. riverside and general bioremediation scenarios and the organic sector (McAdam and Crowe 2002, McAdam 2005; McAdam et al. 2006).

Conclusions

The climate, soils and biodiversity on grassland farms and their associated environmental problems and production goals within a ‘decoupled scenario’ found in Ireland represent a microcosm of a much larger area of livestock production from grassland found in north west Europe.

In the light of current policy directions in areas such as part-time farming, broader environmental issues, need to diversity farming systems in sympathy with the environment, decoupling and the review of the CAP and the need for environmental cross-compliance to qualify for the SFP, there is a need to increase the utilisation of trees in the rural landscape.

In Ireland silvopastoral systems have been shown to have potential to enhance biodiversity and still be compatible with livestock farming at a range of scales of intensity.

It is likely that silvopastoral systems will be able to offer added value in terms of sustainability (McAdam et al. 1999a), environmental benefits or CARE goods. Any tree planting strategy should include a range of options which highlight the short- medium-term outputs possible, should highlight the environmental benefits and animal welfare generated, must align with requirements of agri-environment schemes and be attractive to rural community groups and the organic farming sector.

These objectives apply across the whole of north west Europe and the example of their applicability to Ireland should be applied on a wider scale in the region.

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Chapter 18
Wood Pastures in Germany

R. Luick

Abstract Compared to many other European landscapes such as on the Iberian Peninsula, in the Abruzz and Apennine Mountains in Italy and especially in many eastern and southeastern European countries, agroforestry in Germany today is of peripheral significance. There are two systems that can still be found: wood pastures including semi-open pastureland and traditional orchards – the so-called central European savannas – in this context. There are three important points to make about these systems: (1) historical and cultural importance; (2) their ecological significance as outstanding and unique habitats; (3) there is interest in the remaining systems from a conceptual perspective as possible options for low intensity agricultural systems in less favoured areas. In the following article the focus is on wood pastures and semi-open pastureland. The article presents an overview of various subjects of interest. Starting with the history of wood pastures the current status and distribution of wooded pastureland in Germany is presented. Then the legal status of pastoral uses of woodland is covered including viewpoints from forest and conservation legislation perspectives. A crucial issue is the status of wood pastures within the context of the Common Agricultural Policy of the European Union which mainly supports intensive production systems. The economics of wood pastures is then presented. The article concludes with examples highlighting the ecological value of wooded pastureland and ways to integrate them into modern conservation approaches.

Keywords Agroforestry, semi-open pastureland, conservation, agricultural policy, cultural landscapes

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Historical Aspects of Wood Pastures and Semi-open Pastures

It can be assumed that the husbandry of pasturing in woodlands by humans was already practised in Neolithic times and is one of the oldest land use practises in human history (Ellenberg 1954; Bakker and Londo 1998; Vera 2000). Written evidence exists from Roman times and refers to the taxation system of this time that distinguished between "silvae glandiferae" which means fruit-carrying wood pastures and "*silvae vulgaris pascuae*", the normal wood pastures (Grossmann 1927; Plochmann 1979). This can be interpreted in such a way that, in addition to the normal grazing with livestock such as cows, sheep, horses and goats, the pasturing of pigs in oak and beech forest was of special economic importance since pigs were the main source of fat and meat.

It is well documented that pig grazing on a large scale in woodlands – as well as in lowland and in mid-altitude regions – was common practice in central Europe during the entire Middle Ages and up until modern times (Plochmann 1979; Dannenberg 1990; Beinlich et al. 2005). Fruit-carrying trees were considered as "bread trees" and enjoyed special protection. Violations against these practises were prosecuted as mentioned in the common Germanic rights. It can be assumed that the pastoral use of woodlands was sometimes of even higher economic interest than their arboreal value. It has been proved for southern German communities that the income of rural people relied to a great extent on the giving-out of rights for pig grazing in the common woods.

Pig grazing was regulated in detail and was supervised by a "*magister porcariorum*", the swine master of a community. The monetary success of pig fattening in the woods depended on his skills. In the Lusthardswald forest, near the city of Bruchsal in southern Germany, (60 km^2 in area), some 20,000 pigs were fattened up in good tree fruiting years. This realized a rent of 10,000 guilders for the landowner, the bishop of Speyer.

Considering the purchasing power at that time, such a rent amounted to 200,000 to 500,000 euros. In this context it is of interest that studies by Prins (1998) and Vera (2000) support the assumption that the distribution of oak stands, in particular, had been promoted by herded pig flocks as an accompanying effect rather than by intentional planning.

More recent features of pastoral use of woodlands in Germany – and this applies to central Europe in general – are very much related to agricultural systems originating in early medieval times. For more than a thousand years the so-called "three-field-system" was the prevailing concept in many central European regions. The mostly fenced off dwelling sectors with farm houses, gardens and orchards (equating to the so-called first circle of dwellings) was followed by a second circle encompassing arable cultivating in a consecutive system of winter- and summer-grown cereals and fallow sites. In the third circle, up to two thirds or more of the communal surface consisted of common land that included woods, semi-open and open grassland and was used as grazing for the communal livestock. The consequent housing of livestock during wintertime that depended on the harvesting and storing of fodder was a more or less unknown concept until the second half of the 18th century. Most livestock, therefore, were kept almost all year round on the common ground or – during winter months – on harvested and fallow land closer to the village. These were the heydays of pastoralism.

However these historic pastures and, with them, wooded pastures could also have been described as unproductive, with very low carrying capacities, even at a subsistence level, and detrimental in the long run to the environment. This applies especially to livestock-keeping systems which depended on year round grazing which caused serious damage to woods and soils.

These plus various other negative effects such as the enormous demand of wood for charcoal and glass production, mining, utilization for construction wood, fire based slash and burn cultivation, pruning and coppicing of trees for fodder, caused woodlands to disappear entirely in many regions. Even in remote mountainous areas, such as in the mid-altitude German Mountain Range, the percentage of wooded areas declined to less than 20% of the total land surface (Luick 1996, 1997). A historically interesting aspect of this is the development of wood pastures as a side effect of the salt mine economy in the eastern Bavarian alpine region. The need for firewood to supply the salt mines of Berchtesgaden, Reichenhall and Schellenberg was severe and extended over time even to high alpine zones. It is recorded by Rösch (1992) that the salt mine of Reichenhall in southern Bavaria alone consumed up to 200,000 m^3 of wood per year which was mainly spruce (*Picea abies* (L.) H. Karst.). The resulting clear cut areas were then given as pastures to the farmers – at least until the re-growth of the tree layer took place. Wood pasturing was even supported by the foresters at that time, since the selective grazing by the livestock fostered the regeneration of the desired spruce (Picea abies) (Rösch 1992).

The agrarian three-field-system was the subject of major reforms in the second half of the 18th century, since it was no longer capable of supplying the fast growing population. In conjunction with scientific and technical progress, during the epoch of enlightenment, new models of agriculture had been introduced into rural societies – often by force. The new evolving agricultural system included elements such as: the housing of livestock and the production of winter fodder for example hay. In addition new crops such as potatoes or Lucerne were introduced which were then grown on the previous fallows. Major changes in land-use and landscape composition also resulted in the dividing-up of the common lands into private property.

Current Situation of Wood Pastures and Semi-open Pastureland

Today, wood pastures are one of the rarest elements in the central European cultural landscape heritage. In general, remnants of wood pastures can only be found in some lowland reserves and mountain areas where, due to site conditions, the intensification processes in agriculture had natural limitations. Depending on the geographical region and individual structural characteristics, wood pastures and, with them, the generally associated semi-open pastureland, are known under various terms in Germany such as: Allmendweiden, Baumweiden, Harte/Hardte, Hutungen, Krattwälder, Maisalmen, Ötzen, Schachen, Tratten, Weidewälder, Weidfelder and Wytweide.

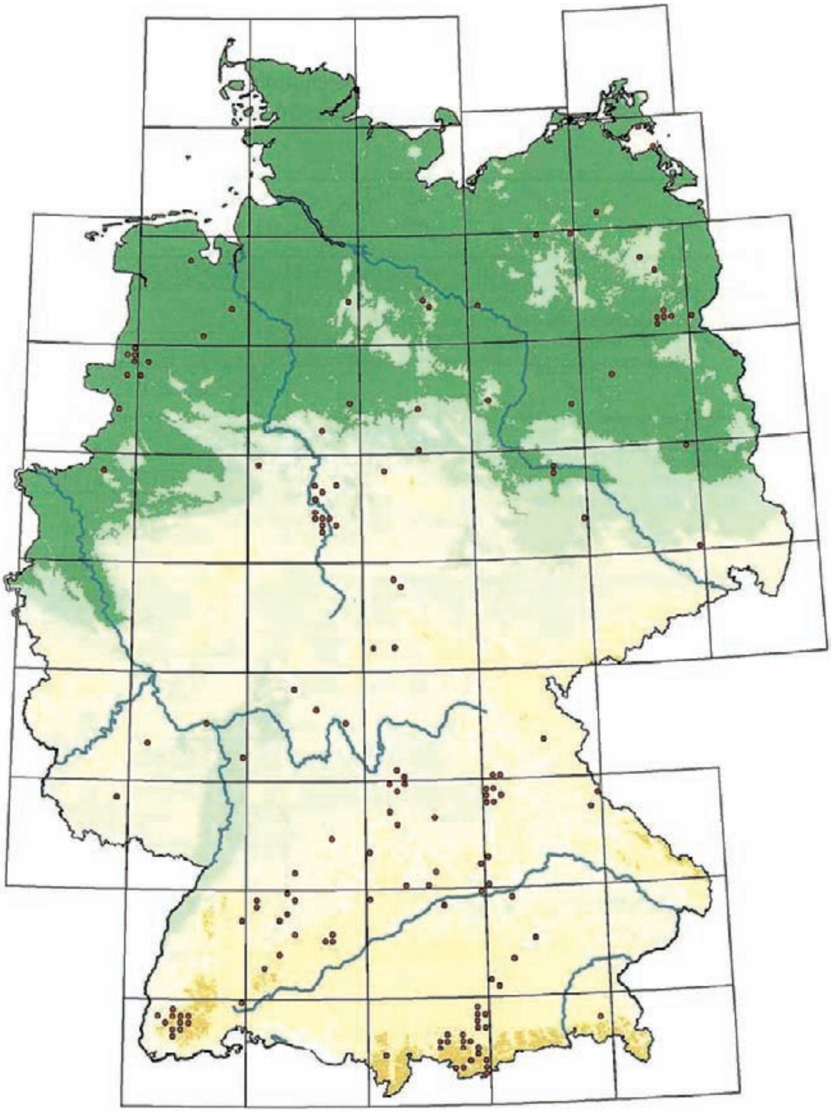

Fig. 18.1 Wood pastures and semi open pastures (Hudewälder) in Germany according to Glaser and Hauke (2004). There are three regions to be addressed where such systems are still in practice on significant scales: in north-western Germany along the river Ems, in the southern part of the Black Forest in the South-West and as the most widespread region in southern Bavaria in the Districts of Bad Tölz-Wolfratshausen and Garmisch-Partenkirchen

A recent mapping by Glaser and Hauke (2004) of active sites shows 218 wood pasture locations of more than 5 ha with a total area of 5,500 ha. Only 62 locations have an area greater than 20 ha (Fig. 18.1). Three regions are central to the current distribution of wood pastures: reserves along the Ems-River in the Northwest, the commons in the southern Black Forest area in the south-west and wood pastures in the central part of the Bavarian alpine region. The scope of areas with semi-open features can only be estimated since no systematic mapping or inventory exists. In general, such locations are to be found within the context of the wood pastures detected by Glaser and Hauke (2004). It is the author's opinion that there still exists between 50,000 and 100,000 ha of pastureland containing significant wooded areas. The maximum estimated figure includes chalk grassland systems with sheep grazing on the Jura Mountains, which often contain shrubby arboreal elements such as *Juniperus communis* L., *Rosa* spp. and *Crataegus* spp. (Luick 2004).

Legal Situation of Wood Pastures

The use of the term wood pasture can have different meanings and distinction must be made between the judicial, agricultural, forestry and ecological definitions. In the judicial sense, wood pasturing carries a legal status whereby privileged users are entitled to use forests within certain borders for pasturing; such rights usually derive from long-term common practices. The great number of different rights can be grouped according to details such as livestock species, grazing period, type of pasture use and more (Table 18.1).

Certain types of woodlands were banned from pasturing as early as medieval times. The reasons for this cannot be explained in terms of sustainability, but are related to hunting interests of the nobility. The consequent legal abolishment of pasturing in woodlands and its persecution did not prevail all over central Europe until the second half of the 18th century, and was stipulated by an emerging awareness of detrimental economic effects of the overuse of woodlands. The growing

Table 18.1 Possible regulations for pasture rights (Based on Grossmann 1927)

Type of regulation	Details
Livestock species and entitled pasture rights	Cattle (dairy cows, young stock) horses, sheep, goats, pigs
Grazing period	Full grazing period, pre-grazing period, late grazing period, escape from snowfall
Type of pasture use	Open pastureland, entire wood pasture, semi-open pastureland, pasture on foreign property (open and wood pastures)
Eligible persons	Individual farmers, co-operatives in various forms like owner- or grazing co-operatives, non-agrarian people
Contract partners	State, federal states, communities, agricultural or and forestry holdings, co-operatives, juridical bodies

demand for timber and firewood on the one hand, and the scarcity of natural resources on the other, led to government reactions, such as the large-scale afforestation of pasturelands with low productivity. Thus, to secure these plantations and to improve the degraded condition of the few remaining forest stands, the banning of wood pastures was necessary.

The legal situation of wood pastures in Germany today can be traced back to the origin of planned forestry in the late 18th and first half of the 19th century. For example, from forest legislation in the Dukedom of Baden in the southwest of Germany from 1833 it can clearly be seen how enforced measures were implemented to stop the pastoral use of woodlands.

Under article 32 of the forest legislation for the Dukedom of Baden it states that:

- In timber forests wood pastures are only permitted if the coppice of deciduous trees is older than 35 years or the coppice of coniferous trees has reached an age of at least 30 years.
- The moving of livestock shall only be allowed in the period from May to October.
- It is prohibited to graze livestock in the forest before sunrise and after sunset.
- The pasturing of sheep and goats in forests is strictly forbidden.
- The coppicing and pollarding of fodder is not allowed.
- The collecting of litter and mosses from deciduous and coniferous trees is only allowed in timber forests older than 40 years for deciduous trees and 30 years for coniferous trees.
- The fattening of pigs with acorns and beechnuts is only allowed if the natural regeneration is guaranteed.

In the second half of the 19th century, the legal regulations concerning wood pasturing were continuously enforced. Today, pasturing in woods is defined in detail according to the individual forestry legislation for the 16 federal states of Germany. The laws range from the general prohibition of grazing to official prosecution even if practised on private property. However in some states there is the theoretical possibility for official grazing permission. In the latter case, the corresponding forestry legislation specifies that wood pasturing – as referring to non-timber forest products – can be granted as long as obligations to maintain good forest health are not endangered.

The initial hurdle when faced with the question of how to implement new forms of wood pastures in some German states is the question of forest conversion whether it would be permanent or temporary.

In this case, the authorities have to ensure that the interests of all parties are taken into account. This means, specifically, the uniting of public interest in the forest with those of ecological functions of woodlands and the requirements of pastoral use of the forests. The forest administration will deny permission if they deem the grazing of woods to be in contrast to the role of the forest in terms of the economic and social benefits that woods and forest offer. Furthermore, in the case of potential areas for wood pastures that extend over more than 10 ha, an environmental impact assessment study is obligatory. In summary, if the authorities establish there is no public interest expressed in the founding of new wood pastures then permission for such will be refused.

A unique role of wood pastures in Germany can be ascribed to the Bavarian Alpine types of wood pastures where, in contrast to the rest of Germany, legal rights for pasturing have never been totally abolished. Existing rights for the pastoral use of woodlands are usually linked to the alpine system, which means a form of transhumance with summer grazing at higher altitudes whilst in the valleys hay is harvested for the returning livestock in wintertime. Table 18.2 shows the scope and distribution of wood pastures in Bavaria for the year 1978, which was the last complete inventory (Engelmaier 1978). It can be seen that about three quarters of the total surface of wood pastures of some 55,000 ha occur in just three districts and all of them include alpine parts with alp systems. However it should be pointed out that these figures only express the potential rights and it has to be assumed – although there is no scientific proof – that, even in the 1970s, the number of areas with wood pastures still in use was much smaller. Therefore, when using official figures, they always have to be interpreted as potential areas for woodland grazing.

Since the system practised in the Alps is essential to Bavarian cultural tradition, all issues concerning the ecology and economy of alpine pastoralism are of crucial public interest. On the other hand, it has also been pointed out that the cessation of wood pasturing in the Bavarian alpine region is of federal importance. From the government's perspective since 1995, several instruments were outlined as alternative methods to enable the legal withdrawal of pasturing rights. These instruments included the following: the fiscal compensation of loss of grazing rights, replacement of pasture with equivalent pasture elsewhere, i.e. not in the alpine zone and the conversion of rights to those of equivalent value in timber. Calculating the costs of either compensation or replacement of pastures is a very complicated and a hotly debated process between the farmers and the authorities. It has to be stated that conversion measures, in general, are not applied by enforced means but are only carried out on a voluntary basis.

Table 18.2 Scope and distribution of wood pastures in Bavaria (Engelmaier 1978)

District	Wood pastures (ha)	Share of total wood pastures in Bavaria in %
Berchtesgadener Land	6,877	12.6
Traunstein	6,847	12.5
Rosenheim	546	1.0
Miesbach	10,132	18.5
Bad Tölz-Wolfratshausen	13,291	24.3
Garmisch-Partenkirchen	16,258	29.7
Weilheim-Schongau	516	0.9
Ostallgäu	148	0.3
Oberallgäu	29	0.1
Lindau	14	0.0
Total	ca. 55,000	99.9

Although the extent of open alpine grazing areas did not change between 1920 and 1985, the area of wood pastures declined by 52% (Hölzel 1995). Remarkably, 21,000 ha of wood pastures and accompanying rights were taken away between the years of 1959–1987 alone. On steep slopes, where the protection functions of forests in respect to landslides and avalanches are prevailing factors, the cessation of grazing was of paramount importance and this aim has now been achieved.

There is also no doubt that grazing on steep slopes, which are subject to erosion, is not sustainable. In addition, the negative impacts, of the heavier "modern" cattle breeds in terms of trampling and erosion on soils and forested areas can be quite considerable in areas of steep sided slopes. However, Rösch (1992) highlighted the fact that the floristic and structural composition of previously grazed Erico-Pinetea woodland communities has changed significantly. This was due to the termination of grazing activities and resulted in massive encroachment of grasses into former pastures which prevent the natural regeneration of woody species and therefore reduced slope stability.

A confusing legal aspect has to be incorporated into the pasturing issue when discussing the subject of biotopes designated under nature conservation laws – which in Germany are federal laws. Historical forest sites with long-term impact of grazing livestock are often characterised by structural and floristic features of high conservation interest. Good examples are pasture sites with trees such as oak, beech and juniper, which have grown into large solitary individuals over time due to the impact of grazing. To guarantee and ensure the ecological processes (such as germination and growth) of pasture trees the impact of grazing is an essential requirement, and yet, as stated earlier, it is often forbidden or difficult to practice. As a result many of these sites which are of heritage value are steadily losing their individuality. A second example is the situation of woody structures such as hedges and scrubby areas, which are very typical for semi-open pastureland. A conflict emerges if a static conservation status has been ascribed to such types and will thus automatically interfere with the dynamic conservation approach of extensive grazing.

A final topic within the context of legal constrains that will shortly be addressed is the situation of semi-open grazed grassland. As a result of undergrazing or because of the interruption of the grazing tradition, semi-open pastures, in particular, are faced with scrub encroachment and virtual development towards complete tree cover. Such areas come under two legal processes, namely regulations concerning agriculture and forest law. Despite long time agricultural uses and historical rights, the forest law can be interpreted in such a way that once the tree layer has reached a certain surface cover, the area will then be declared as woodland. This new legal situation has the consequence that understorey clearing measures and pasturing are no longer permitted. An overeager forest administration keen to increase their area of influence has often followed this line in the past. Farmers then acted to prevent such developments the agricultural bodies sometimes completely removed all trees and successional stages with woody vegetation to form distinct borders between open land and forests. The ecological loss of high value eco-tones and of the particular landscape types has been considerable. Although on a local basis, on both sides, this fundamental viewpoint has steadily been replaced by pragmatic understanding, in official circles the "battle" for clear separation of land use systems is still inherent and practised.

Wood Pastures and Implications of Modern Agriculture and Policies

One of the most impressive examples of large-scale extensive grassland areas are the commons in the southern part of the Black Forest, in the State of Baden-Württemberg. In contrast to many of the Bavarian types of wood pastures, as elements of the alpine transhumance system, the commons in the Black Forest are genuine relicts of the medieval three-field system. This means that the greater part of the communal surface was never divided up into private property during the agrarian reforms of the 19th century. Not only does the open grassland belong to the commons, it also consists of semi-open and wooded areas. In general, the commons have predominantly been used as pastures. Indeed, it is the only region in Germany where commons have survived and are still used. Taken together they cover in total an area of some 10,000 ha and stretch over different communities. The cultural and ecological importance of this area has been highlighted by various studies (Eggers 1957; Schwabe-Braun 1980; Schwabe and Kratochwil 1987; Kersting 1991; Bischoff 2004).

The Black Forest commons are an excellent example of the socio-economic situation that extensive grazing systems have in Germany and this also applies to many more regions all over Europe. Less favoured regions are often faced with a rapid decline of a viable agricultural economy and, especially, of systems based on extensive livestock keeping. Although significant amounts are paid as subsidies, these payments are not enough to maintain high value nature-oriented farming systems. The decline of agriculture and the actual and notable abandonment of many holdings have a complex explanation. One major threat is the situation of small-scale mountain dairy farms. Long-term overproduction in the dairy sector has resulted in steadily dwindling milk prices. On the other hand, production costs are increasing and are not compensated for by a growing level of subsidies. The official advice for remedying this situation was, and still is, to improve competitiveness and to rationalize the production system. As a consequence of this thinking, farms in less-favoured areas have attempted to de-stock low producing areas, e.g. wood pastures and semi-open and extensive grazing, change the system to year round housing of livestock and implement high energy feeding and improvement of the grassland economy (intensive manuring and change to silage production). However these adjustments are usually accompanied by high risks and farms have reached their economic and social limits. The consequences for the countryside are clear; one point being an increasing shortage of livestock to continue the management of wood pastures and semi-open grassland by grazing systems.

Although small in size and confined to the northwest of the state of Lower Saxony, the so-called Hutewald pastures in the Emsland area are important because of the long tradition of grazing and their outstanding landscape character due to impressive solitary oak trees. The environmental context of these reserves is rather unusual since they are situated in surroundings best known for one of the most intensive livestock regimes in Europe including dairy and pig fattening systems. The problem of these extensive pastures is not only the impact of direct and indirect pollution and eutrophication but also the lack of interest and suitable livestock for grazing the nature reserves. Since extensive systems with suckler cows are not typical in this region, some reserves have not been grazed – or not sufficiently grazed – by livestock and the pastures are losing their defining characteristics that are so typical of the features that can be seen in the Hutewald pastures. This is also the case when alternative strategies like mowing are carried out.

The Luxemburg reforms of 2003, which set out the policy frame of the European Union for the common agricultural policy (CAP) until 2013 for the First Pillar, will create more uncertainty over the future viability of extensive farming systems in less favoured areas.

One element of Pillar 1 policy is the so-called decoupling of payments – meaning that from 2005 onwards, financial support provided to farmers will not be dependent on growing a specific area of crops or keeping a certain number of animals.

Instead, farmers will receive a Single Farm Payment that will be based on their historic level of CAP support. Linked to these is also the introduction of "cross-compliance" whereby farmers will qualify for the decoupled payments provided they undertake to comply with a suite of EU directives (including the Birds and the Species and Habitats Directives) and keep their land in good agricultural and environmental condition. In respect to grassland, mulching the sward once a year, or alternatively mowing every second year with the removal of the growth is an easy way to accomplish this cross compliance prerequisite. It is necessary to understand why and how policy measures are a major threat to low productive agricultural systems such as wood pastures or semi-open grassland. It can easily be predicted how livestock farmers operating under severe conditions will adjust to such new rules. They will obtain the same amount of money no matter whether they continue with the difficulties and inconvenience of livestock business or if they simply comply with the cross compliance obligations and just mulch the sward.

In addition, the new Rural Development Regulation of 2005 that specifies the strategic approach for the Second Pillar – including the agri-environment programmes as a main instrument – will also undergo major reforms. Agri-environment schemes have proved to be supporting instruments for extensive livestock systems that may include wood pastures or in low intensity grassland systems in general. At the time of writing, the outlook for cultural landscapes or the high nature-value farming systems that produce and maintain them is not very promising. In particular, the need to cover a wider range of issues within the Second Pillar will mean that less money than at present will be available for the support of agri-environment measures in the less favoured areas where most of the remaining traditional cultural landscapes still occur.

Economic and Ecological Aspects of Wood Pastures and Semi-open Pastures

From an economic point of view, wood pasturing is of little interest any more – at least from a central European perspective. Reports by Spatz and Weiss (1982), Liss (1988) and Spatz (1999) based on investigations in the Bavarian Alps in southern Germany point out that the quantity of fodder per grazing area in forests only accounts for about 20% at most, of the equivalent to open pastureland. Furthermore, the energy content of grazed vegetation in wood pastures is much lower than open pastureland and often does not satisfy the physiological demands of a proper diet; because of poor and scarce resources, the energy needed by the livestock to find fodder increases over time and results in declining milk production or/and lowered weight gain. This assessment was different in the past when the expectations for growth and productivity of livestock were much lower than today. Recent experiments in sub-alpine wood pastures in Switzerland stress, however, that the selection of high-quality feeding plants ensures a sufficient and balanced diet (Mayer et al. 2001). One positive effect that the pasturing of ground vegetation in forests can have is the medicinal value of the diet because of the great floristic variety of the species and the range of beneficial compounds they contain (Mayer et al. 2001).

Studies were conducted in the past (Schwab 1982) on test sites to prove the negative impacts of extensive wood pasturing. This was also to discredit the possible sustainability of extensive wood pasturing and the low impact, in terms of damage to trees and natural regeneration, if proper management was carried out. Within a wood pasture grazed by cattle heavy damage was recorded as forest vegetation was heavily damaged by grazing livestock (Table 18.3). Closer scrutiny of the design of the experimental areas (Schwab 1982), showed that livestock densities over the period of monitoring on the area were far beyond any practical reality and that the size of the test site areas were too small, preventing roaming and selecting of fodder resources by the livestock. The test site was 17 ha of which two thirds consisted of woodland and was grazed as follows: within a period of four weeks in June and July 94 livestock (63 young heifers and 31 calves) and additional for another period of four weeks in October and November with 99 dairy cattle and 94 young stock.

What is often neglected in the discussions about the impact of livestock on woodland is the role of game. Table 18.4 shows results from a study of how game (mainly roe deer) had affected the natural regeneration of tree species in high altitude woodland in Bavaria (Schauer 1982). The experiment compared fenced enclosures and adjacent areas open to wildlife. It was found that:

Table 18.3 Impact of livestock (cattle) on forest vegetation according to Schwab (1982): This was counted ignoring the age of the species and measuring all visible damage within a layer reachable to livestock (approximately 2 m in height)

	Grazing impact of livestock on trees (%)	
Species	Leaves	Seedlings, buds, branches
Acer pseudoplatanus L.	90	60
Fraxinus excelsior L.	90	60
Salix spp.	90	40
Sorbus aucuparia L.	90	30
Abies alba Mill.	–	70
Fagus sylvatica L.	50	50
Picea abies L.	–	30

Table 18.4 Impact of game on forest vegetation in a comparative study according to Schauer (1982): a = fenced areas, b = non-fenced areas. It was counted in a way that all specimen of a species (on the fenced and non-fenced test sides) were set as 100%

	No impact (%)		Medium impact (%)		Severe to high impact (%)	
Species	a	b	a	b	a	b
Acer pseudoplatanus L.	30.9	42.7	2.3	11.7	66.8	45.6
Picea abies L.	50.3	88.9	18.5	8.4	31.2	2.7
Abies alba Mill.	90.3	54.9	3.3	19.6	6.4	25.5
Fagus sylvatica L.	10.2	26.4	15.5	32.2	74.3	41.4
Sorbus aucuparia L.	8.7	22.5	2.2	30.4	89.1	47.1
Fraxinus excelsior L.	–	21.2	1.2	34.6	98.8	44.2
Ulmus glabra Huds.	4.2	23.0	12.8	48.0	83.0	29.0
Sorbus aria L.	3.6	20.1	–	25.0	96.4	54.9

- The fence apparently did not prevent access by game.
- There was a high impact of game browsing on the non-fenced test sites on the following species: *Abies alba* Mill., *Fraxinus excelsior* L., *Sorbus aria* (L.) Crantz, *Sorbus aucuparia* L. and *Ulmus glabra* Huds. whereas *Picea abies* shows only little impact of browsing.
- Between 80% to 100% of all tree species have been browsed on non-fenced test sites.
- This report is supported by Liss (1988), who points out that according to findings in the national park of Berchtesgaden, Bavaria, the browsing effect of deer and roe deer on trees is much more influential than the grazing of livestock.
- In general, the ecological and conservation value of wood pastures and, with them the semi-open systems, can be attributed to the following characteristics:
  - Small-scale combination of open spaces, various successional stages and entire woody areas.
  - Sequence and change of moist, dry, light, dark and shady sites.

- Solitary trees of a great age and great variety of micro structures (e.g. dead wood, old bark, holes).
- Rich inventory of dead wood in various conditions (e.g. standing, lying, moist, dry thick, thin).
- High diversity of spatial structures.
- High diversity of terrestrial micro-structures (under-grazed and overgrazed patches, bare ground, ant heaps, dung heaps at different stages of decay).

Wood pastures consist of a complex of biotopes and are one of the few cultural ecosystems with no distinct frontiers but which harbour many internal and external eco-tones. Table 18.5 lists important parameters that can be used to describe the complexity of possible site conditions, which determine the individual characteristics of wood pastures. This overview by Sachteleben (1995) was originally intended to be used as a decision tool to evaluate the damage caused by livestock in woodlands but it mirrors very well the complexity of extensive pasturing ecosystems.

Ecological studies focussing on old solitary trees with dead wood structures and associated beetle communities are presented by Geiser (1983, 1992), Assmann (1994), Assmann and Falke (1997), Sonnenburg and Gerken (2004). In the small (30 ha) Hutewald reserve Borkener Paradies at the Ems River in northwestern Germany (Lower Saxony), 133 carabid beetle species were found, representing more than one third of all ground beetles known in the state of Lower Saxony. The reason for a high biodiversity in the enthomofauna and with special attention to saproxylic beetles is due to a large extent to the presence of old oak trees (Table 18.6). Studies by Burrichter et al. (1980), Pott and Burrichter (1983), Schwabe and Kratochwil (1987), Pott and Hüppe (1991), Hüppe (1997) highlight the remarkable structural and floristic value of solitary trees in semi-open grazing systems. Recent research focussing on semi-open grazing systems concentrated on the macro- and micro-scaling effect of spatial structures (Hensel and Plachter 2004; Lederbogen et al. 2004; Putfarken et al. 2004).

Table 18.5 Important parameters for deciding upon reason and severity of damage caused by livestock in woodlands (Based on Sachteleben 1995)

Site descriptors	Geology Soil Altitude Exposition Inclination Fodder source and availability
Factors related to farm situation and management issues	Relation open pastures to wooded pastureland Stocking capacity and stocking density Livestock species and breed Herded system/fenced system Grazing cycle, frequency Pasture maintenance (e.g. mowing, scrub clearing)

Table 18.6 Distribution and dependence of the beetles Ampedus species in wood pasture reserves (Hudewälder) in north-western Germany and significant affiliation to oak trees (Zeising and Sieg 1978; Assmann and Falke 1997); 1 = Herrenholz reserve, 2 = Hasbruch reserve, 3 = Baumweg reserve, 4 = Neuenburg reserve, red-data list status: 1 = extremely threatened, 3 = threatened

Species	Red data list status	1	2	3	4	Dependence on habitat structure
Ampedus erythrogonus, Müller 1821	3					Mouldy (red to black) wood, old stubs almost fully decayed with moss cover
Ampedus quercicola, Buysson, 1877	–					Mouldy (red) wood, lying dead wood
Ampedus nigerrimus, Lacordaire 1835	3					Humid, mouldy (red) wood at shady sites of old standing oak trees
Ampedus xfontisbel-laquei, Lablokov-Khnzorjan 1937	1					Dry to humid dead wood often mouldy (red)
Ampedus elongatulus, Fabricius 1787	3					Dry mouldy wood from old deciduous trees
Ampedus cardinaleis, Schiödte 1865	1					Mouldy (red) wood of standing trees with holes

Conceptual Ideas to Highlight Wood Pastures

In more recent years extensive pasture systems and with them the subject of wood pastures are becoming of increasing interest in the debate about management strategies for less favoured areas in Germany (Dierking 1993; Bunzel-Drüke et al. 1994; Bunzel-Drüke 1997; Riecken et al. 1997; WallisDeVries et al. 1998; Vera 2000; Kampf 2002; Luick and Bignal 2002). Mayer et al. (2002, 2003) present conceptual ideas to reassess the function and importance of alpine wood pastures. The objectives are as follows: to conserve landscapes rich in grassland of high nature value; to create areas of high biotic and structural diversity; to guarantee a minimum level of openness in the landscapes and to establish pastoral systems as low-input farming systems in terms of necessary financial support. In this context significant parts of wooded areas in extensive grazing systems can be of economic interest since they can help save the costly building of shelters and barns which otherwise are essential in order to conform to welfare regulations in grazing regimes.

Vowinkel and Luick (2003) showed, according to bibliographical data, that out of a total of 865 nature reserves with a total area of about 65,000 ha in the state of Baden-Württemberg, almost 30% of all sites were originally designated as nature reserves due to their pastoral heritage, which often includes features of wood pastures. However at present, pasturing as an essential ecological driving force is still regularly practised on less than 5% of all the sites, and the pasturing of woodland, which is part of many reserves, has disappeared entirely. The reasons for this decline were discussed earlier. Further investigations including interviews with stakeholders (NGOs, communal and other official authorities, farmers and scientists), surveys of management plans and the analysis of official correspondence have shown that:

- In many cases the scientific evidence behind the management plans proved (apparently) that grazing activities do not favour the conservationist objectives of German nature conservationists. The focus of management, therefore, was and is on static approaches such as mowing, sometimes in combination with the disposal of the biomass. In this context it has to be mentioned that wood pastures and semi-open grazing do not exist in the annex of the EU Habitats Directive.
- Conservationists often have a conservative approach to wood pasture areas which unfortunately often results in negative perceptions and weak policy to maintain the character and ecological value of these areas. The consequences of this are often that open pastureland is frequently designated as land suitable for succession which therefore, at some point, reverts to forest.
- In many nature reserves with considerable wood grazing, the hunting debate is a crucial issue. Often farmers have been confronted with the argument that, due to grazing livestock, the hunting possibilities have been heavily affected and, using the influence of forest authorities pasturing has been forbidden or heavily restricted.
- Up until recently, grazing strategies for the management of nature reserves were very unpopular and no, or very little, financial support (stemming from conservation programmes) was given to farmers as an incentive to manage semi-open pastures.
- Farmers who still continue to graze ground with significant portions of wooded or semi-open land are confronted with the fact that, according to existing EU regulations, only entirely open and productive grassland is eligible for funding (e.g. agri-environment programmes).

This results in wood-pastures being either abandoned or cleared. As a consequence, it is imperative that proposals and plans for the integration of wood pastures and semi-open grazing into a modern and dynamic land use concept be objectively examined both within the framework of cultural conservation and ecological benefit. New, promising model projects with wood pastures in the Solling Mountains in Lower Saxony or the Höltigbaum-project in Schleswig-Holstein have been implemented in recent years (Gerken and Sonnenburg 2002; Sandkühler 2004). The key to finding approval is involvement and good communication between stakeholders. What still has to be worked on is the inclusion of wood pasturing as a supporting conservation measure into agri-environment schemes and conservation programmes.

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Chapter 19
The Swiss Mountain Wooded Pastures: Patterns and Processes

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Abstract Influenced by the combined action of grazing and forest management, wooded pastures represent a traditional form of multiple use of natural resources in some European mountains. This fragile semi-natural ecosystem is characterized by the coexistence of high biodiversity and extensive land use. Based on experimental and observational studies carried out at various spatial scales in the Swiss Jura Mountains, this chapter provides an insight into patterns and processes occurring in this typical silvopastoral ecosystem. Summer grazing by cattle is the main driving force affecting vegetation dynamics. Large herbivores influence vegetation in three ways: grazing and browsing, dung and urine deposition and trampling. Field observations reveal a high heterogeneity of cattle activities at both fine and large scales. Cattle habitat use controls the dynamics of plant species and functional groups in the herb layer. Natural tree regeneration is also closely affected by cattle activity and related to the heterogeneous environment. Distribution of tree seedlings is spatially associated with specific physical structures or nurse plants that facilitate their survival in the herb and the shrub layers. Moreover, the growth of tree saplings is related to grazing intensity. Knowledge of ecological functioning of wooded pastures has allowed the development of a novel, spatially explicit, mosaic compartment model of the dynamics of silvopastoral ecosystems. This model is able to explain some aspects of the origin of vegetation heterogeneity in pasture-woodland landscapes. The conservation of such ecosystems is an important challenge considering its complexity and the present change in agricultural practices in mountain regions. A better integration of ecological and socio-economic processes

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into predictive multi-level models will permit the exploration of the conditions for sustainable management schemes compatible with biodiversity conservation.

Keywords Cattle activity, plant functional groups, modelling, spatial-temporal scale, tree regeneration

Introduction

Semi-natural silvopastoral ecosystems, such as wooded pastures, form traditional landscapes in Europe (Etienne 1996). Influenced by a combined action of cattle grazing and forest management, the wooded pastures represent a form of multiple use of natural resources. This type of land use is particularly interesting when considering the challenges in sustainable management of mountain areas. Due to changes in agricultural practices towards either local intensification or extensification, most of the silvopastoral ecosystems in Europe suffered a large decline during the last century (Gillet and Gallandat 1996b). Considering the high cultural, socio-economic, ecological and landscape values of this ecosystem, there is an increasing need to develop conservation tools.

Integrated management planning of wooded pastures requires an intensive collaboration between agronomists, foresters, ecologists and sociologists (Gmür and Wettstein 1986; Gmür et al. 1989; Perrenoud et al. 2003). In silvopastoral ecosystems, the question of management type and use intensity is critical. Strategic objectives may aim at the conservation of the state of wooded pastures, or to more or less severe restoration measures, even through re-creation starting from closed forests or open grasslands. Successful management, in particular for biodiversity conservation, requires traditional scientific observation and experimentation and is generally not yet founded on specific scientific tests, but based on anecdotal evidence or, at best, on inductive studies (Rook et al. 2004). The understanding of the main ecological processes occurring in wooded pastures is therefore essential for efficient management schemes of this threatened ecosystem.

In this context several studies were undertaken since more than 20 years in the wooded pastures of the Swiss Jura Mountains, where this ecosystem is still the most abundant type of man-made landscape (Gallandat et al. 1995). In this chapter we summarize results of our work and related studies describing ecological patterns and processes in wooded pastures. We first describe the management and the high biological value of this ecosystem. Second we present the hierarchical organisation of the system. Third we focus on three key processes participating in vegetation dynamics. Fourth we present a predictive spatially explicit model integrating all current knowledge. Finally we conclude with research and management perspectives.

The Swiss Wooded Pastures

A Multi-user Landscape

In the Swiss Jura Mountains, wooded pastures occur in the mountain and subalpine belts, mainly at an elevation between 800 m and 1,400 m asl. At lower altitude, they occupy a transitional zone between the cultivated areas close to the villages and the forest, whereas at higher altitude, they are widespread around the timber line (Gillet and Gallandat 1996b). The climate of this area is predominantly oceanic with a mean annual rainfall of about 1,600 mm at 1,200 m asl (including more than 400 mm snow precipitation) and a mean annual temperature of 7°C. At 1,200 m asl, mean day temperature is below 0°C more than 60 days per year and the ground is generally covered with snow from December to April.

As in other temperate mountainous regions the climate limits cattle management to the summer period, from the end of May to the end of September. Cattle herds are mainly composed of heifers, but dairy cows can be seen on about half of the pastures and in some areas horses can be the main livestock type. Livestock density ranges from 0.5 to 1.5 adult bovine units per hectare (Gillet and Gallandat 1996b), which is low compared to intensive grazing systems. For a farm unit, the surface occupied by pastures ranges from about 30 ha to about 300 ha. The vegetation is very diverse and four main structural types may be recognized in a typical pasture-woodland landscape (Gallandat et al. 1995; Vittoz 1998): unwooded pastures (open pastures with less than 1% tree cover), scarcely wooded pastures (tree cover between 1% and 20%, trees mainly scattered in a grassland matrix), densely wooded pastures (tree cover between 20% and 70%, trees aggregated in thickets) and grazed forests (closed forests with more than 70% tree cover). Two grazing systems are applied in wooded pastures (Gillet and Gallandat 1996b): (1) free range: the animals spend the whole summer season roaming freely through the pastures; (2) grazing rotation: the pasture is subdivided into paddocks and the animals circulate from one to another according to a variable rotation period (between two and seven rotations per grazing season, corresponding to a stay in each paddock of 10 to 80 days). More and more wooded pastures are now managed according to the rotation grazing system, with the aim of optimizing the utilization of the resources. Generally, pastures are fertilised with farm manure and mineral PK fertilisers, with rates that often exceed the official recommendations (Meisser 1993). In addition, mineral nitrate fertilizer is sometimes applied on pastures grazed in rotation by dairy cows, but this practice is illegal in wooded pastures placed under the Swiss forest regulation, in particular to protect water against pollution in the karstic areas. For the maintenance of the pasture, unpalatable weeds and shrubs are partially removed more or less regularly using mechanical or chemical methods, in order to prevent loss of grazing area.

The goal of forest management is mainly to maintain the overall tree cover and landscape heterogeneity, since logging is not generally a profitable activity, except in densely wooded pastures and forests. Foresters intervene in scarcely wooded pastures mainly to remove dying or affected trees and to check on natural re-growth. In general, the wood is not of high quality and its commercialisation no longer covers the costs of the tree felling, but was an important resource in the past. The stumps are usually left in place. If natural regeneration fails, new saplings may be planted, usually around the stump, and fenced for protection against cattle. The forester's personal experience and local tradition play an important role in planning spatial distribution of trees (clusters of trees vs. isolated ones) (Gillet and Gallandat 1996b). This know-how is an important requirement for landscape protection and to maintain its capacity to provide multiple goods and services.

From a socio-economic point of view, the main users of wooded pastures are farmers, even if in some regions revenues generated from forestry activities may be quite significant. Besides the farmers and foresters, a wide variety of occasional users become more and more important: hikers, skiers, horse riders, cyclists, picnickers, etc. The importance of this landscape for the tourist economy is considerable, although difficult to quantify. By interviewing visitors of wooded pastures, Miéville-Ott and Barbezat (2005) showed recently that almost two-thirds of those consider wooded pastures as a recreational place. The majority came to the site to walk, for exercise and to experience nature.

A Landscape Sheltering High Plant Diversity

Vegetation in wooded pastures ranges from open grasslands to closed forests including wood-pastures with scattered or clumped trees (Gillet and Gallandat 1996a). In typical wooded pastures, the regeneration of both grassland and woodland is natural compared to other types of agroforestry systems, where trees are usually planted and grass is sown (Rigueiro 1985; Silva-Pando et al. 1998, 2002). Nevertheless, the origin of trees could be different depending on the edaphoclimatic conditions.

Consequently, this landscape results from a balance between divergent ecological processes such as cattle pressure and tree regeneration. Coexistence of patches of pastures and woodlands or isolated trees is therefore a result of an unstable equilibrium between extensification and intensification, which can lead, if there is departure from this equilibrium, either to closed forests or open pastures with concomitant loss of biodiversity (Fig. 19.1).

In a large scale survey (Gallandat et al. 1995), one sixth of the Swiss vascular flora (about 3,000 species) was observed in the wooded pastures of the Swiss Jura Mountains. Moreover Vittoz (1998) listed 554 vascular plant species occurring within a 70 km^2 area. Plant biodiversity is also very high at fine scale (Table 19.1). The origin of this multi-scale high plant species richness is multiple. First, soil variability is important ranging from shallow calcareous to deep, acidic and silty soils. Spatial heterogeneity can also be very high (Havlicek et al. 1998). This can be observed at a very fine scale and induces at meter scale a fine mosaic of various

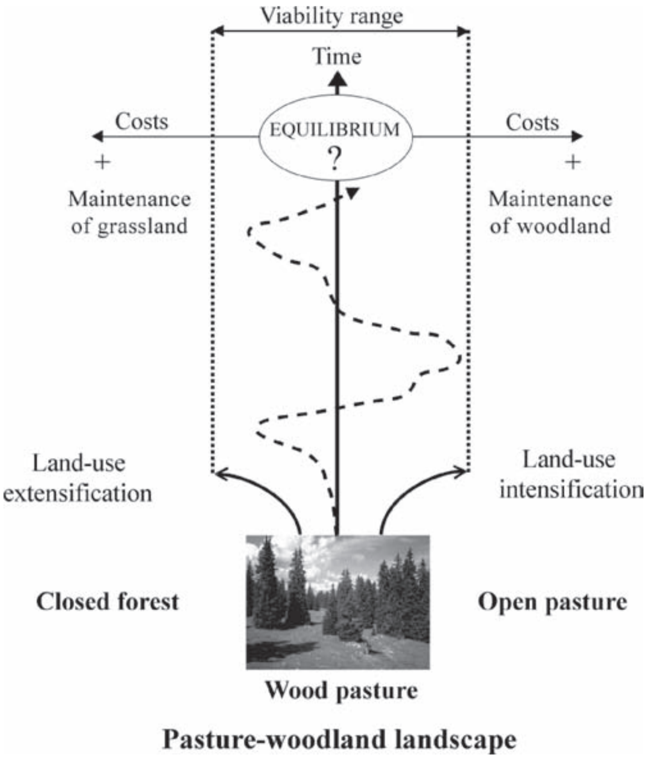

Fig. 19.1 Wood-pasture landscape dynamics as the result of extensification and intensification (From Gillet in press)

Table 19.1 Multi-scale plant species richness of the Swiss wooded pastures

Scale	Mean number of species	N	Source
10,000 m^2	196 (max.: 221)	5	Dufour (2006)
2,500 m^2	149 (max.: 178)	20	Dufour (2006)
625 m^2	106 (max.: 142)	80	Dufour (2006)
156 m^2	70 (max.: 106)	80	Dufour (2006)
1 m^2 of a grazed meadow	28 (max.: 41)	100	Kohler (2004)
0.01 m^2 of a grazed meadow	10 (max.: 20)	800	Kohler (2004)

vegetation types (Gobat et al. 1989). Second, a complex mosaic of trees, shrubs and open grasslands create various microclimates favouring different plant species. Gillet et al. (1999) determined a species richness optimum at 30% of tree cover. Third, as we will see in more details in the following sections, cattle activities can change plant species composition. Finally, as recently shown by Dufour et al. (2006), plant species richness is related to topographic complexity described by elevation variability and its spatial configuration.

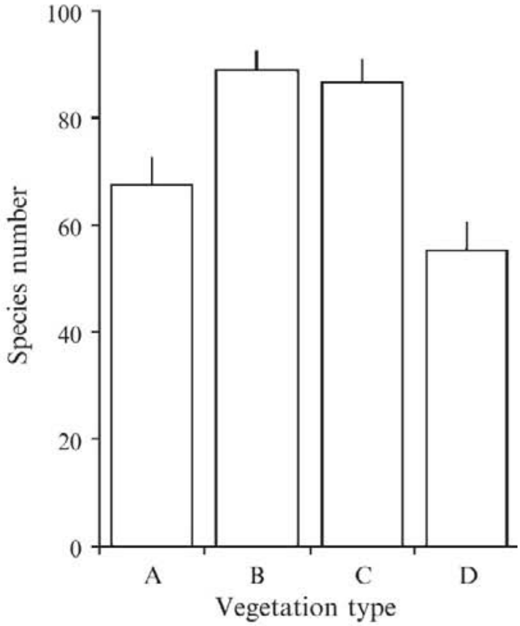

Fig. 19.2 Total vascular plant species richness in the four main vegetation types: A: unwooded pastures (tree cover < 1%, N = 19); B: scarcely wooded pastures (tree cover < 20%, N = 42); C: densely wooded pastures (tree cover < 70%, N = 33); D: closed grazed forests (tree cover ≥70%, N = 21). Error bars are standard errors of the means

Wooded pastures are therefore a good example of a landscape where high biodiversity can coexist with extensive land use (Fig. 19.2). Many transitional zones and boundaries occurring in a highly heterogeneous and fluctuating environment, including various tree densities, create optimal conditions for biodiversity.

The Hierarchical Organisation of Wooded Pastures

Hierarchy theory (O'Neill et al. 1986; Wu and David 2002) is a powerful framework to describe silvopastoral ecosystems. Different nested levels of organization can be recognized in the vegetation of wooded pastures (Gillet and Gallandat 1996a). At landscape level, a mosaic of phytocoenoses can be seen, ranging from unwooded pastures to grazed or ungrazed closed forests (Fig. 19.3). Each phytocoenosis is itself a complex system of elementary plant communities, i.e. moss, herb, shrub and tree synusiae. Each synusia is an assemblage of organisms belonging to a limited pool of plant species or plant functional groups (Fig. 19.3).

The same hierarchical approach can be used to describe cattle behaviour (Bailey et al. 1996). Different spatial scales can be defined functionally, based on characteristic behaviour occurring at different stocking rates. In wooded pastures, three spatial scales seem to be important. At large scale, the human (e.g. fences, water

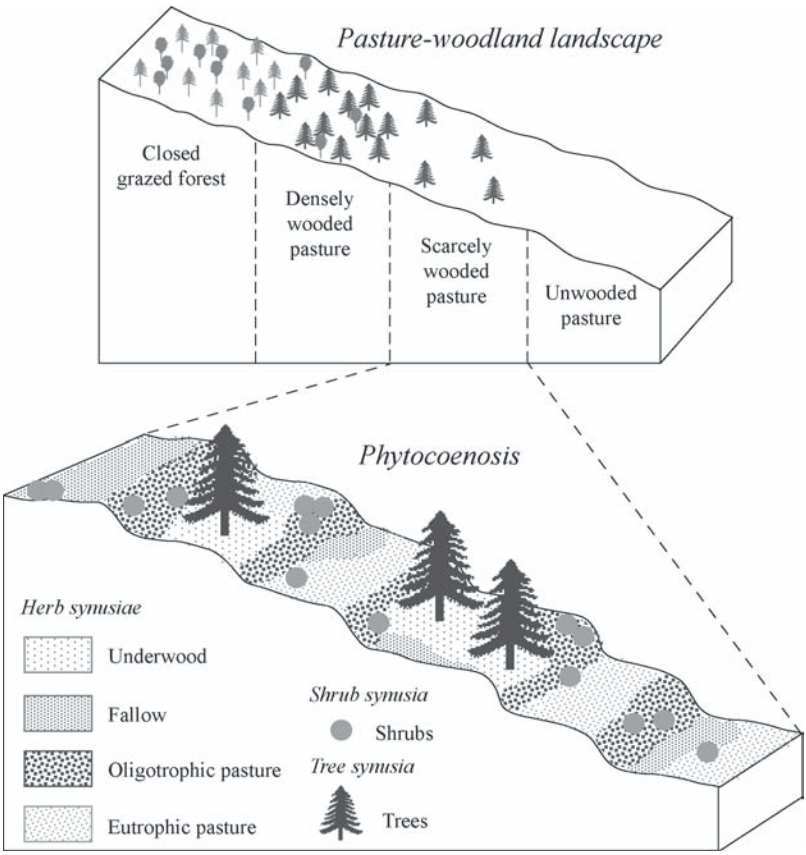

Fig. 19.3 Nested organisation levels in wooded pastures (Modified from Gillet and Gallandat 1996a)

points) and natural (e.g. slope, openness) landscape structures of the paddock will induce the first general patterns of cattle activity (Kohler et al. 2006a). At medium scale (few square meters), among plant communities, cattle choose communities with the best forage availability (Kohler et al. 2004a). At fine scale, within a given plant community, cattle avoid dung pats (Kohler 2004) and unpalatable plants (Smit et al. 2005).

Each entity or process considered in a silvopastoral ecosystem has a characteristic spatial and temporal scale (Fig. 19.4) and processes occurring at a certain scale may impact on entities at another scale. For example, a cattle foraging behaviour of few minutes can have an impact during decades on the tree pattern, or some political decision in relation to agriculture policy can have a long-lasting effect on the entire landscape. The integration of all these spatial and temporal scales has to be taken into account for sustainable management.

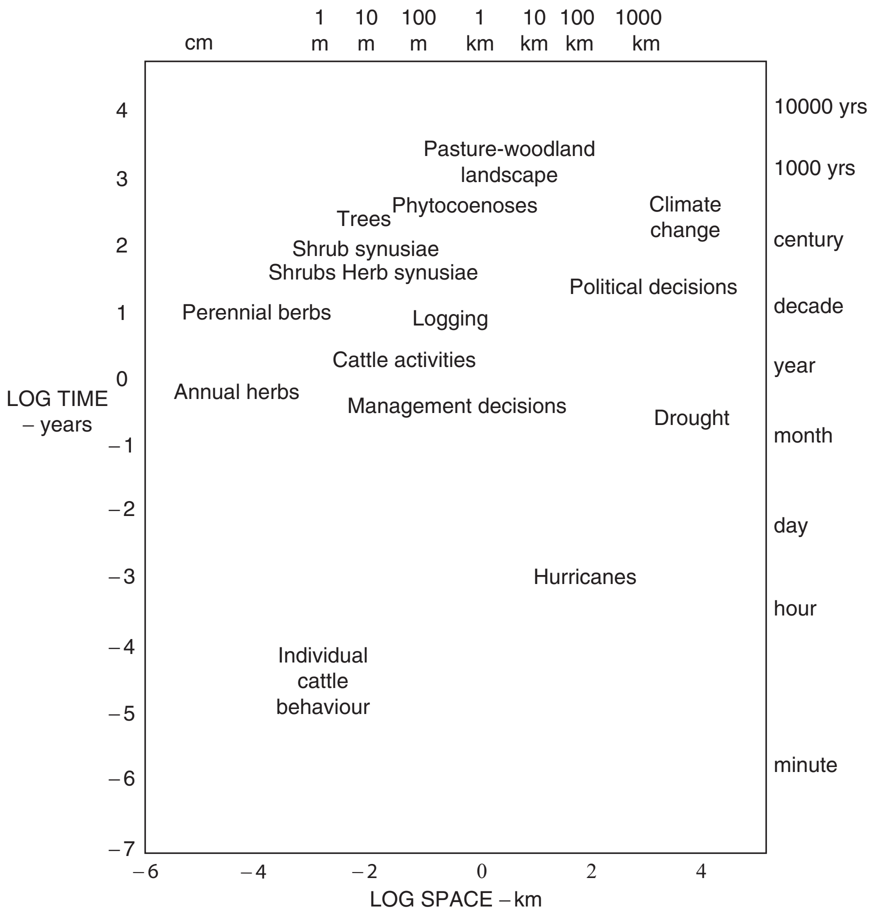

Fig. 19.4 Objects and processes occurring in silvopastoral ecosystems with their respective space and time scales

Three Key Ecological Processes

The Heterogeneous Patterns of Cattle Activities

Livestock activity is an important factor in structuring vegetation in silvopastoral ecosystems (Olff and Ritchie 1998). Large herbivores may influence vegetation in three ways: (1) herbage removal and tree-shrub browsing, (2) trampling, (3) dung and urine deposition. Herbage removal – or grazing *sensu stricto* – is the main biotic factor affecting herbaceous vegetation structure and dynamics in pastures (Rook et al. 2004). The effect of herbage removal on plants is principally the loss of above-ground biomass and consequently a change in light competition between species (Grime 2001). Furthermore, herbage removal induces an exportation of biomass, linked with a local loss of soil nutrients. Cattle generally select for a grass-based diet with a high digestibility and high N and P concentrations (Mayer et al. 2003). Due to the high levels of difficult-to-digest lignin and secondary metabolites, most woody species are generally avoided by cattle (Gordon 2003). However, browsing by livestock has been identified as an important factor preventing tree regeneration in wooded pastures (e.g., Bakker et al. 2004; Allcock and Hik 2004). Trampling affects the vegetation through detaching or destroying plant material with hoof action and by influencing the water regime in compacting the soil (Abdelmagid et al. 1987). By contrast to herbage removal, biomass stays in this case on the ground and nutrients return to the soil. Trampling can create gaps and produce competition-free space for plants. Dunging – or, more widely, fertilising – is also considered an important factor affecting vegetation productivity and composition of herbaceous or dwarf-shrub communities (Bakker and Olff 2003). Statistical comparisons between primary productivity and species richness across various community types generally lead to a "hump-shaped" model, with a peak of richness at a low to intermediate level of productivity (Grime 2001).

There is evidence that the fine and large scale spatial patterns of grazing, trampling and dunging are heterogeneous in wooded pastures:

1. The spatial pattern of foraging is the best-studied attribute of cattle activity (Senft et al. 1987; Coughenour 1991; Bailey et al. 1996). At large scale, the selection of grazing locations by cattle depends on herbage quality and quantity, water availability, relief, slope, elevation, aspect, natural and artificial barriers, herd social interactions, prior experience, and climate (Rice et al. 1983). Cattle preferentially graze plant communities of high nutritive value (Roath and Krueger 1982) and this preference seems to partially control the distribution of cattle in a paddock (Putman et al. 1987). From observations made on a complete paddock of 23 ha, we observed, at the beginning of the season when resources were abundant everywhere, that heifers grazed preferentially near the wire fence (Kohler et al. 2006a). Grazing patterns became less noticeable over the rotations resulting in a more homogeneous pattern at the end of the season. At very fine scale (decimetre scale) herbage removal also presented a heterogeneous pattern (Kohler et al. 2004a). For example, dung patches, and to some extent also urine patches, induce a reduction of the herbage attractiveness during the first months or years after deposition (Edwards and Hollis 1982) and consequently create a heterogeneous pattern of herbage removal (Fig. 19.5).
2. The distribution of trampling effects depends not only on the number and pressure of hoof prints in an area, but also on the sensitivity of the vegetation to trampling (Roovers et al. 2004), which is likely to be affected by slope, soil texture and water content. On steep ground grazed by sheep and red deer, Hester and Baillie (1998) showed that at low densities, vegetation was more affected by trampling than by herbage removal. In wooded pastures, Kohler et al. (2006a) observed that the paddock-scale pattern of trampling tended to concentrate in

wooded areas and in rocky areas with poor forage quality. At decimetre scale, by using vertically planted wooden sticks, which allow the measurement of cattle trampling when they were broken or flattened, we also observed a fine-scale spatial heterogeneity of the trampling pattern (Kohler et al. 2004a).

3. The spatial distribution of faeces and urine from cattle is not uniform and their concentration is often higher in areas of special attraction, such as near water sources, gates or fences, and in shade and shelter belts (Peterson and Gerrish 1996; White et al. 2001). In mountainous regions, cattle faeces are significantly associated with slope, aspect, topographic position and season (Tate et al. 2003). For instance, daily faecal load is higher in flat areas and during the dry season (Costa et al. 1990). In the Swiss wooded pastures, the pattern of dung pat density seemed to occur mostly in flat areas without rock outcrops and with low tree and shrub cover near the centre of the paddock (Kohler et al. 2006a). At fine scale the deposition of dung pats and urine by cattle create spots of small area with a high concentration of nutrients (MacDiarmid and Watkin 1972) (Fig. 19.5). Every year dung pats are dropped in other locations than in previous years creating a fine-scale shifting mosaic of nutrient availability.

Patterns of grazing, trampling and dung and urine deposition are therefore conditioned by different factors inducing non-congruent patterns. At large scale we observed a negative correlation between herbage removal and dunging and between dunging and trampling patterns (Kohler et al. 2006a). If, as we expect, the observed patterns of habitat use are consistent over many years, differences in spatial distribution of cattle effects at the landscape level may have important ecosystem implications (Gander at al. 2003; Jewell et al. 2005). In particular, the spatial segregation of feeding and excretion should lead to a transfer of nutrients from feeding places to resting places, with trampling effects concentrated in intermediate situations such as along paths. Jewell (2002) came to the conclusion that the soil P content of the most heavily used part of a paddock of an alpine pasture in the Swiss Alps could be reached after 200 years of grazing and that the nutrient-poor vegetation was the result of a long period of nutrient depletion by cattle. However, patterns might vary in warm and dry conditions, as suggested by results from intensive pasture systems, where the heterogeneity of the spatial distribution of faeces

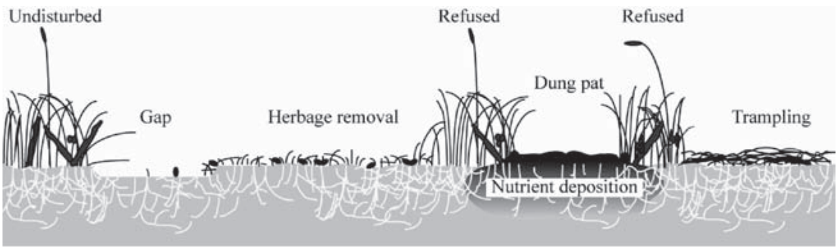

Fig. 19.5 Pattern of fine-scale vegetation heterogeneity induced by cattle activities (From Kohler 2004)

and urine was increased (White et al. 2001). A more comprehensive assessment of nutrient transfer and its implication on grass growth and nutrient leaching is still needed and requires a modelling approach (McGechan and Topp 2004).

At fine scale, we also observed non-congruent patterns of cattle activity (Kohler et al. 2004a) (Fig. 19.5) but, in contrast with the large-scale patterns, rapid changes in the spatial patterns should be expected. Patterns of dung and gaps created by heavy trampling obviously change from year to year and the grazing pattern is partly determined by the dung pattern (see above). At fine scale, pastured areas can therefore be considered as a patchwork of various levels of disturbances (trampling and grazing) and resources (nutrients from dung and urine), which can change from year to year and induce various changes in the herb layer in situations with a low to intermediate stocking rate.

A Shifting Mosaic Model to Describe Herbaceous Vegetation Dynamics

As shown in the previous section, in silvopastoral ecosystems, herbaceous plant communities undergo change in resource availability and disturbance regime at various temporal and spatial scales. The fine-scale aspects of these processes were explored by Kohler (2004), who showed that grazing, trampling and fertilizing (dung and urine) have different impacts on the vegetation, creating fine-grained mosaics in the herb layer. From experimental (Kohler et al. 2004b, 2005) and observational (Kohler et al. 2004a, 2006b) complementary approaches, six general plant species groups were defined by their response to cattle activities (Kohler 2004) (Fig. 19.6):

1. Group A: This species group is favoured by herbage removal and the absence of trampling. Beside an increase in biomass, interaction between herbage removal and addition of nutrients does not induce the appearance of new species. This group includes a large number of species and consequently herbage removal has a positive effect on species richness. These species are generally of small stature and are resistant to stress (*sensu* Grime 2001).
2. Group B: Interactions between herbage removal and trampling favours a species group indifferent to fertilisation, as for group A, but which contains small species and legumes. In condition of low light availability, the ruderal strategy (*sensu* Grime 2001) is related to this group.
3. Group C: This species group is favoured by trampling without herbage removal and is unaffected by nutrient addition. The number of species in this group is low and consequently trampling induces a species richness decrease, particularly when light availability is low.
4. Group D: This group of species is favoured by fertilisation in the absence of grazing and trampling. Tall grasses with a competitive strategy (*sensu* Grime 2001) characterise this group.

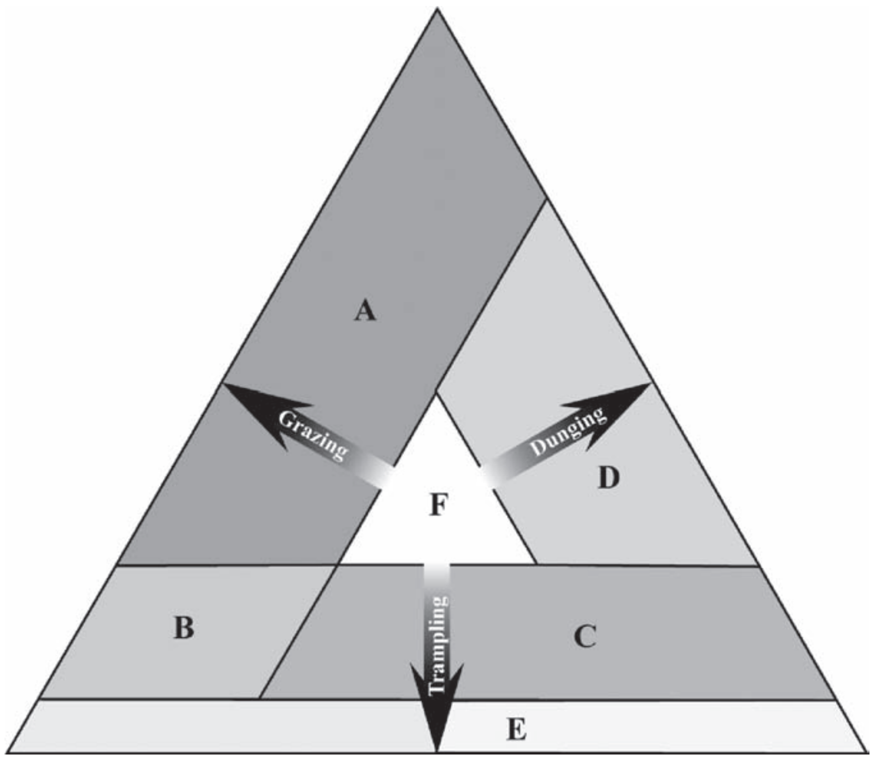

Fig. 19.6 Triangle representing the three factors acting at fine scale in herbaceous vegetation and corresponding plant response groups A–E. Group A contains species favoured by herbage removal and the absence of trampling. Group B contains species reacting to interactions between herbage removal and trampling. In group C, species are favoured by trampling without herbage removal. In group D, species are favoured by fertilisation in the absence of grazing and trampling. In group E, species are favoured by a high level of trampling and gap creation. In group F, species are favoured by the absence of the three cattle activities (From Kohler 2004)

5. Group E: This group is favoured when the level of trampling is high enough to create gaps. Species of this group have small seed weight, unspecialized seed dispersal, persistent seed bank and high vegetative spread.
6. Group F: This group is favoured by the absence of the three cattle activities. Species characterising this group are mainly tall forbs and some tall grasses.

These groups are not mutually exclusive. Traits, which are important for one response, are not necessarily essential for another. Moreover, Kohler et al. (2004b) observed that change induced by cattle activities were mainly quantitative, so that, in the short term (several years) most species were able to survive in all conditions. Consequently, depending on the cattle activity at local scale, certain species will dominate, while others may survive with a reduced abundance. In grazed meadows, it seems that only conditions with fertilisation alone induce a fast and important decrease of species richness leading finally to the disappearance of a group. Furthermore, field experiments (Kohler et al. 2004b) showed a continuum of species response as a rather high number of species did not show any reaction to the simulated cattle activities. This suggests that several species assemblages can occur.

These observations support the dynamic keyhole-key model (Gigon and Leutert 1996), which explains the coexistence of a high number of species in grasslands. Where species α-diversity (keys) and microsite diversity (keyholes) match, coexistence is likely to occur. A great number of potential microsites can be defined by crossing the various biogenic effects induced by cattle activity (but also by small herbivores such as voles – *Arvicola terrestris* L.), trees and shrubs (light conditions), with abiogenic microsite diversity, in relation to soil properties or microtopography. Moreover, we must also consider the temporal variability of the biogenic factors. First, at decades and landscape scales the spatial pattern of the tree mosaic that induces the light conditions will change ("shifting mosaics", Olff et al.1999). Second, from the results of Kohler (2004), we can describe at a finer and shorter scale another shifting mosaic in the herb layer. At fine scale (few square decimetres), the combination of effects induced by cattle will change from year to year depending, for example, on spatial distribution of dung pats which influence grazing behaviour (see last section). It is therefore possible to define a pasture as a patchwork of micro-successions at various successional stages, depending on the major and changing constraints in relation to cattle activity. These phenomena induce a rapid local species turnover while plant composition persists at larger scale. This is possible in this type of grassland because of the high resilience (rapid recovery) but also of the high resistance (few species loss in most cases) to disturbance. This is probably due to the importance of clonal growth compared to species extinction/colonization processes in the perennial vegetation of mountain pastures.

Tree Regeneration: Between Competition and Facilitation

Trees are key organisms in silvopastoral ecosystems and interactions with cattle and herbaceous vegetation are critical to understand patterns and processes in these highly heterogeneous landscapes. The regeneration of trees is also crucial for the long-term sustainability of wooded pastures (Diaz et al. 1997). In the wooded pastures of the Swiss Jura Mountains, one conifer species (*Picea abies* L.) and two deciduous species (*Acer pseudoplatanus* L. and *Fagus sylvatica* L.) can dominate, *Picea* being the most abundant. Four life stages can be distinguished, each one corresponding to different interactions between individual trees and the other components of the system (Fig. 19.7).

The first stage (Fig. 19.7) is seed establishment after dispersing. There is poor information on the spatial distribution of seed dispersed and it seems that seed trapping by small shrubs do not play a crucial role in this ecosystem (Smit 2005). Moreover, for *Picea abies* seed predation is considerable (almost 90%) (Smit

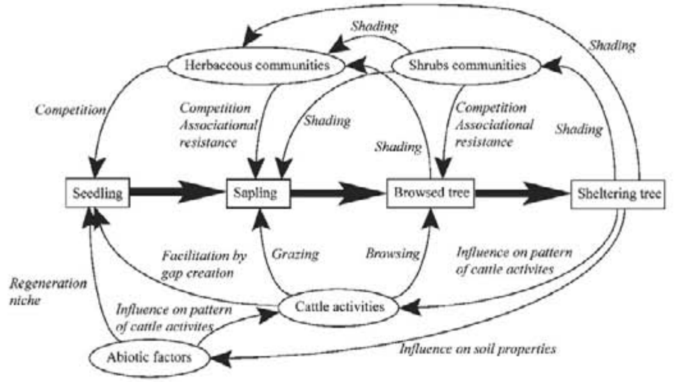

Fig. 19.7 The different life stages of a tree and the interactions with other components of the wooded pastures (Adapted from Béguin 2007)

2005). Selective exclosure experiments in open and dense vegetation showed that insect predation contributes to 74% of the seed removal. The germination rate of seeds is generally low in natural conditions (*Picea*: 17%; *Acer*: 5% and *Fagus*: 2%, Vandenberghe et al. 2006a). After germination, tree seedlings often experience competition from herbaceous vegetation. At this stage, since plants compete for light, water, nutrients and space, gaps (openings in swards) are expected to have positive effects on tree seedling emergence (Nilsson et al. 2002), survival and growth (Davis et al. 1999; Meiners and Handel 2000). A reduction in height of the surrounding vegetation, for example caused by grazing, may also reduce competition and create enhanced conditions for tree seedlings to establish (Karl and Doescher 1993). However, under dry weather conditions, moist microclimatic conditions within the sward may be more favourable than exposed soil. Therefore, gaps may also have negative or neutral effects on tree seedling emergence (Burton and Bazzaz 1991; DeSteven 1991) and survival (Berkowitz et al.1995). In an experiment manipulating gap size (four gap sizes including zero) and herbaceous competition (mown vs. unmown) Vandenberghe et al. (2006a) showed that gaps had a positive effect on early stages of tree development of three typical species of wooded pastures (*Picea*, *Acer* and *Fagus*). Moreover, seedling growth was higher when surrounding vegetation was mown. Nevertheless, even in more favourable large gaps, only a small percentage of seedlings emerged and survived.

The second stage (Fig. 19.7) corresponds to small saplings of more than one year old, which have not yet emerged from the herbaceous layer and are therefore not selected by cattle, and consequently grazed together with the other vegetation. The spatial distribution of the *Picea* saplings is positively correlated with rocky outcrops, tree stumps and unpalatable plant species (Smit et al. 2005). Considering the last factor, it seems that *Picea* may benefit from associational resistance (or facilitation): cattle may browse the unprotected saplings by chance because of their inhospitable surroundings and avoid an unpalatable patch with a sapling more likely to survive. Experimental approaches confirmed this hypothesis (Smit et al.

2006). Moreover the importance of this facilitation process is unimodal relative to the grazing pressure, with a maximum at intermediate grazing pressure (Smit 2005). At low grazing pressure, saplings do not need to be protected, and at high grazing pressure the unpalatable plants are damaged by cattle and do not serve a protective role.

In the third stage, trees emerged from the herb layer and are directly affected by cattle browsing (Fig. 19.7). The percent of browsed or otherwise damaged trees seemed linearly positively related to the stocking density (Mayer et al. 2005). Apparancy, i.e. the probability that an individual plant will be discovered by herbivores (Feeny 1976), is not only dependent on the characteristics of the plant itself, e.g., size, foliage abundance and duration (Zamora et al. 2001; Renaud et al. 2003), but also on the relative abundance and nature of neighbouring plants (Milchunas and Noy-Meir 2002). Therefore, the probability for a sapling of being browsed might be lower when protection is provided by surrounding vegetation (Canham et al. 1993). Conifer species are likely more apparent, but might be avoided by cattle because of a lower leaf nitrogen content (Pagès et al. 2003) and stiff and tough needles. Furthermore, deciduous species have the advantage of greater ability for compensatory growth than evergreen woody species after browsing damage because conifers store most of their nutrients in the needles, whereas deciduous species have greater stores in roots and old wood (Hester et al. 2004). By exposing saplings of four genera (*Picea*, *Abies*, *Acer* and *Fagus*) to different grazing intensities, Vandenberghe et al. (2006b) showed recently that only 1% of large saplings (41–59 cm) escaped browsing either at low or high grazing intensity. However, browsing effects tended to be smaller at the lower grazing intensity. Furthermore, the proportion of saplings browsed was not significantly different among species although evergreen tree saplings lost a larger proportion of biomass than deciduous species.

Finally when the trees reach a height of about 1.5 m, they can escape from cattle browsing and grow without constraint. To reach this size trees such as *Picea abies* may need to be more than 100 years old (Gallandat et al. 1995). Growth can therefore be very slow during the first stages of tree life. Once adult, trees influence the behaviour of cattle (Kohler et al. 2006a) and the understorey vegetation. Moreover, they can also affect the soil chemical status through litter deposition and by changing the chemical content of the rain water by leaching of the leaves or needles (Douard 1994).

Models of Ecological Processes

The knowledge of complex interactions between cattle activities, vegetation and landscape structure, shifting mosaic in the herb layer and tree regeneration has allowed the development of a novel, spatially explicit, mosaic compartment model of the dynamics of silvopastoral ecosystems, WoodPaM (Gillet in press). This model has its origin as a spatially implicit model of vegetation dynamics in wooded pastures, PATUMOD (Gillet et al. 2002), which has been successfully used as a decision tool in management projects (e.g. Perrenoud et al. 2003). WoodPaM is a deterministic model considering three hierarchical levels: the focal level is the phytocoenosis, represented by a cell or a patch in the landscape with a variable stock density; spatially implicit herb and shrub communities as well as size-structured tree populations are the components of each patch at the lower level; patches are aggregated in a pastoral management unit building the higher level, with externally controlled global stock density. At the chosen time resolution of 1 year, interactions between neighbouring patches are not considered, except for tree seedling recruitment. However, local patch dynamics influence some global constraints at the upper level, so that dynamics in a single patch is depending on changes in all patches of the landscape mosaic.

As an example, the result of a simulation made from a real pasture-woodland landscape, the Metairie d'Evilard, is presented. In this mosaic model, patches corresponded to the 393 cells of $25 \times 25\,m^2$ squares of a paddock described in the observational study of Kohler et al. (2006a), for which detailed information was available for vegetation, environment (natural and management-induced structures) and cattle activity. The year 2001 was used as a baseline to set up the management and initial conditions of the system in the model. For this scenario, environmental and management constraints were fixed to the initial values. Over a simulation period of 500 years (Fig. 19.8), the landscape configuration is heterogeneous with grazed forests mainly in the southern part of the paddock, at lower altitude, higher mean slope and far from the watering places. The simulation also shows that the initial stock density seems insufficient to maintain the general landscape openness.

The present version of WoodPaM is able to explain some aspects of the origin of vegetation heterogeneity in silvopastoral landscapes. It revealed the crucial role of livestock selectivity and the consequences of complex interactions between landscape structure, vegetation and cattle behaviour (Gillet in press). Nevertheless, there is still a crucial need for long-term time series of vegetation dynamics for a better calibration of the model.

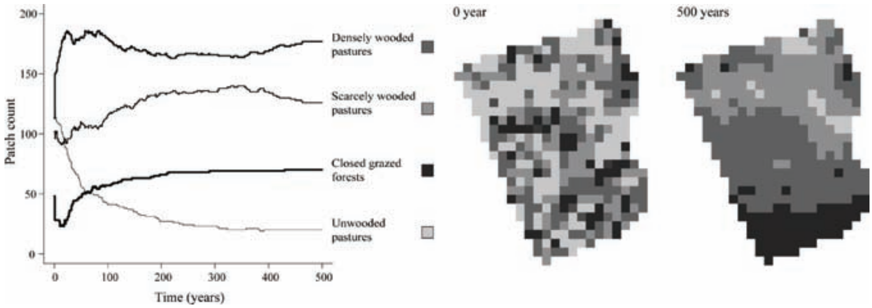

Fig. 19.8 Time series and maps of the dynamics of phytocoenoses (four types, see Fig. 2 for details) of a 500-year simulation with environmental and management conditions fixed to their initial values (Gillet in press). Initial values are from a real pasture-woodland landscape, a paddock of the Métairie d'Evilard (Kohler et al. 2006a)

Conclusion and Perspectives

The recent studies revealed the high ecological complexity of silvopastoral ecosystems and highlighted the link between land-use and biodiversity despite several questions remaining unanswered. The conservation of such ecosystems is an important challenge considering its complexity and the present change in agricultural practices. Moreover, in this case we considered only the ecological aspects of this man-made ecosystem and there is also a need to integrate social aspects so that land-use change and its consequences can be investigated in a more holistic way. In such sensitive ecosystems, agricultural policies are key drivers of land-use and then of biodiversity (Mattison and Norris 2005). A better integration of ecological and socio-economic processes into predictive, multi-level models would permit the assessment of how biodiversity is likely to respond to policy reforms and to identify how policy might need to be reformed to generate land-use that is compatible with biodiversity conservation.

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Chapter 20
In Slovenia: Management of Intensive Land Use Systems

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Abstract The abandoning of agricultural use of land occurs in Slovenia on Karst and hill regions where the ground is very stony or land is very steep. Such abandoned land has become overgrown by shrubs and forest. Grazing animals are the cheapest source of power, the only available labour, the most natural way of returning plant nutrients to the soil and nowadays can be used for recultivation of such land. The oldest silvopastoral system in Slovenia was introduced 400 years ago in the low Karst region. Mountain pasture in Vremš ica can be considered to be one of the earliest trials with silvopastoral systems. Sheep and goat grazing was extended from pastures to shrublands with controlled browsing. The results showed that green leaves in pure hazel shrubbery amounts to 5.2 t ha^{-1} with a total aboveground biomass up to 11.7 t ha^{-1}. But with 310.9 mg kg^{-1} of Manganese hazel shrub dry matter exceeds recommended nutritional level for two times. Such land should be subdivided into paddocks to apply systems to control grazing, and to achieve even distribution of excreta over land under utilization. Stocking rates must be higher than the available herbage mass would support to return depleted nutrients with supplementary feeding on grazing land. Out-wintering on silvopastoral land is a very efficient way to achieve this objective. In most cases silvopastoral land is found adjacent to a forest. Efficient predator damage prevention should be applied as wolf, bear and lynx are highly protected in areas where the environment is poor enough to introduce a silvopastoral system. Predator attacks amounted in a 6 years period up to 1,000 with more than 3,500 animals killed. Among killed grazing animals sheep prevailed. From current experience, silvopastoralism must be investigated and presented as a management option for intensive land use systems.

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Silvopastoralism deals with soil, herbage plants, woody plants, farm animals and predators. Extensive management has normally been applied where land has traditionally been relatively cheap. With all the information available about grass-fed products (meat, milk) there is no need to promote silvopastoral products as a source of cheap, healthier and safer food, than food produced with conventional farming. Consumers are willing to pay more for grass-fed food if they are told more often what is good for them in.

Keywords Krast, grazing, silvopastoralism, herbage, fencing

Introduction

The total area of Slovenia is 20,273 km^2, of which more than half is covered by forest. Though small in size, Slovenia is climatically not homogeneous. In the northeast, a continental climate prevails with relatively low precipitation (800–900 mm year^{-1}) and relatively hot summers (mean monthly maximum temperature 27°C) and cold winters (mean monthly minimum temperature 10°C). The southeast of Slovenia has a Mediterranean – type climate where the growing season lasts 7 months or more. Characteristics of the region are hot, dry summer periods which induce a period of dormancy and an average precipitation of around 1,500 mm. In the north and northwest of Slovenia, in the Alp region, an alpine climate type prevails, characterized by high precipitation (the maximum being above 2,500 mm year^{-1}) and cold winters (monthly minimum mean temperature of −15°C). The climate of central Slovenia shows certain characteristics of the continental climate type and others of the Atlantic climate type. Precipitation ranges between 1,000 and 1,500 mm. Slovenia is located in the temperate zone with good conditions for forest growth. An exception is the zone above 1,800 m asl (in some places 1,700 m) where the forest merges into an alpine steppe (pastures).

In the last century, and especially in recent decades, the forest cover has increased due to reduction in agriculture and rural depopulation. In 1875 the percent of forest area was only 36.4%, in 1990 it was 53.2% and in 2004 59.3% (Valen i 1970). Between 1875 and 1990, forest cover increased by 0.33% per year, while in the period 1990–2004 it was increasing by 0.78% (Rajšp 1995). If the process of forest expansion continues, Slovenia will lose its unique (cultural) landscape and its biotic diversity. Although Slovenia occupies 0.014% of the Earth's surface and has the same percentage of the total human population, it boasts more than 2% of known animal and plant species and has over 850 endemic species. Hence Slovenia has every right to be called the "biotic park of Europe". However, with the looming increase of forest cover, the landscape diversity will decrease and consequently biodiversity will also decrease. The abandoning of agricultural use is a consequence of low income. Grasslands mostly used for cut meadows in the past are now not economically attractive for farmers, who therefore abandon them, especially in areas where the production of biomass is very low.

Because of the high cost of farm land in Slovenia it is unlikely that pastoral farming will be an important source of food production in the future. Commodity prices and subsidy will always be maintained because the strong lobby which small farmers have. By the same reasoning, the bigger farms, mainly owners of good land in areas of arable crop, will always operate high input (capital investment) agriculture. In Slovenia farm land for silvopasture can be introduced and expanded on abandoned hill and karst land. This is where bushes and poor quality trees have already spread. Silvopastoral systems provide pasturing, wood-production and in some cases fruit production on some land, and if the silvopastoral system includes shrubs, also additional browsing. Developing sustainable farming through silvopastoralism in such an environment is more difficult than establishing it on good farm land as silvopastoralism is generally presented as an extensive land use method. However, this is not the correct approach as silvopastoralism as a holistic way of farming deals with soil, herbage plants, woody plants and animals. If all these are to be managed in a sustainable manner in a very poor (extensive) environment, as is the case on abandoned farm land in Slovenia, than silvopastoral farming must be investigated and presented as an intensive land use system.

Silvopastoralism in Slovenia

In the past two types of silvopastoral system were practiced in Slovenia. Grazed forest has been used in the mountain regions of the north part of Slovenia (Jelovica, Pokljuka, Pohorje). The animals (mainly young cattle, but often mixed with dairy cows and calves) spent the whole summer roaming freely through the forest with the rich grass and herb layer in the understory. This would be a so called free range type of wooded pasture (Gillet and Gallandat 1996). This type was and still is traditional, extensive use of common land managed by the local society and still widely used in mountain forest where Norway spruce (*Picea abies* L. Karsten) and sometimes fir (*Abies alba* Miller) and beech (*Fagus sylvatica* L.) are found. The second type of silvopastoral systems is also very old and was introduced hundreds of years ago in the Low Karst region, when the Lipica stud farm was founded breed the Lipizzaner breed (Dov et al. 2006). Sessile oak trees (*Quercus petraea* (Mattuschka) Liebl.) were planted in a widely spaced arrangement on Karst pasture.

Nowadays on the basis of climate, relief, bedrock and intensity of changes in land use in Slovenia, the introduction of silvopastoralism would be advantageous on:

- Low Karst
- High land in the west of Slovenia (Tolminsko, Idrija-Cerklje hills)
- Hilly land in the southeast of Slovenija (Bela krajina and partly Suha krajina)
- Steep parts of hilly land in the eastern part of Slovenia (Haloze and Kozjansko)

Low Karst

The land in this region was almost bare 150 years ago because of the harsh climate and overgrazing, too dense a human population, and other growing conditions. During the period 1859–1954 more than 15,700 ha of barren Karst land were reforested by planting of Austrian black pine. What was almost a stony desert gradually became vegetated. Black pine (*Pinus nigra* Arnold) plantations improved growth conditions on the Karst to such an extent that the growing of other forest species was possible. The great social changes (rural exodus and urbanization) following the Second World War supported the major natural spreading of forest in the Karst area. The abandoned agricultural areas were encroached both by Austrian pine (which is not native in this area) and by native deciduous broad-leaved trees and shrubs. This process was and is still continuing. Forest cover now amounts to more than 50% of the Karst area (Kaligari and Culiberg 2006). A high percentage of forest is necessary in this region, because forest protects the land under agricultural use. The forest has to be dispersed in the form of a mosaic among pastures, meadows, vineyards and arable land, especially on steep slopes and where the soil layer is very shallow. The income from pastures in this region is very low and so farmers are giving up livestock production. The agricultural land is consequently being encroached by shrubs and forest. It would be reasonable to introduce widely spaced tree plantations on abandoned pastures and meadows in this region, with grazing for sheep and goats. At lower altitude (up to 600 m asl), the following tree species would be suitable as a crop-tree: sessile oak (*Quercus petraea* (Mattuschka) Liebl.), wild cherry (*Prunus avium* L.), whitebeam (*Sorbus aria* (L.) Crantz.), wild service tree (*Sorbus torminalis* (L.) Crantz) and whitty pear tree (*Sorbus domestica* L.). All of these species produce good quality timber. A suitable density of trees in the silvopastoral system is up to 50 trees per hectare. The trees diminish the effect of wind on soil drying (evaporation), the transpiration of grasses and herbs and protect the soil against wind erosion. Their litter increases the soil organic matter and the nutrient uptake efficiency by the crop. The litter layer which is under the trees increases the water retention capacity in the organic horizons (Kotar 2006).

At higher altitudes in the Low Karst region (above 600 m asl), Austrian pine (*Pinus nigra* Arnold), whitebeam and rowan (*Sorbus aucuparia* L.) could be used as crop-trees.

It has been shown that in these areas, trees reduce wind velocity, decrease air and soil temperature and, in consequence, increase relative humidity. July and August are the dry months on Karst (Vidrih and Lobnik 2003) and are the time of so-called summer dormancy for grasses and herbs. Water content in soil was measured at the end of the dry period, i.e. at the beginning of September. The water content in soil on pasture was 15.8% but this value increased to 17.7% on areas covered by trees (pine trees). It was found that that in pasture during windless conditions in May and June, evaporation was 5.9 mm day^{-1}, but this reduced to around 4.4 mm day^{-1} on the area covered by pine trees (Kotar 2006). But when the strong wind called "burja" or "bora" was blowing, the evaporation on pasture was 16.7 mm day^{-1} and it w as around 13.2 mm day^{-1} on the area under pine trees. It has to be emphasized that pastures on Low Karst can exist for a long period, either they are covered by widely spaced trees or within islands of bush or shrubs, i.e. shrub-refuges.

The Karst pasture ecosystem is maintained in a fragile state and for its sustainable functioning needs 'islands' of trees or shrubs. These refuges do not diminish biomass production and do not decrease the forage available to sheep and goats. The shrub species play an important role in protection against wind and erosion. The most common shrub species on the low Karst is hazel (*Corylus avellana* L.). The hazel buds, young sprouts and leaves serve as forage especially during the dry periods (dormancy period) when there can be a fodder shortage. Therefore the amount of fresh leaves, shoots and buds available for feeding animals is of interest and strategic importance. In a study of the leaves in total biomass production of hazel, production of fresh hazel leaves in kg per 100 m^{-2} was 51.55 ± 15.1. Production of hazel oven-dried leaves in kg per 100 m^2 was 20.45 ± 4.6 SE.

Production of total hazel biomass in kg per 100 m^{-2} was 117.09 ± 20.4 SE.

The yield depends on size of hazel, i.e. its diameter and height. The relations between yield, diameter and height of species are given with following equations:

$$X_1 = 101.6461 + 8.1 \cdot 10^{-16} d^{2.3082} \cdot h^{5.0472} \, (R = 0.87)$$

$$X_2 = 41.4448 + 7.1 \cdot 10^{-17} d^{2.4975} \cdot h^{5.1646} \, (R = 0.88)$$

$$X_3 = 92.3069 + 2.7 \cdot 10^{-9} d^{1.9921} \cdot h^{3.0053} \, (R = 0.94)$$

Where:
X_1 = weight of fresh leaves in grams per species
X_2 = weight of oven-dried leaves in grams per species
X_3 = weight of aboveground biomass in grams per species
d = diameter at the base in millimeter
h = height of hazel in centimeter
R = correlation coefficient

The correlation between both yield and independent parameters is high. The results show that annual production of green leaves in pure hazel shrubbery (calculated if the area has 100% hazel cover) amounts to 5.2 t ha^{-1}, which is equivalent of 2 t of dry leaves. Total biomass (above ground biomass) of hazel shrubbery is 11.7 t ha^{-1}. The biomass production depends on the amount of annual precipitation and natural plant community. In the given case the precipitation amounts 1,200–1,400 mm $year^{-1}$, therefore the annual production of hazel leaves is high. The established amount of leaf biomass agrees with the values found by other researchers who have investigated primary biomass production on the rangeland in Mediterranean basin (Rogošič 2000).

West Slovenia

The region has high precipitation and as a result erosion occurs on pastures with a shallow soil layer. The altitude of this area is above 800 m asl. In exposed places it is advisable to establish small clusters (groups) of trees. In this case the arrangement of clusters is not uniform as it is in the case of silvopastoral systems on the lower Karst. Suitable tree species are wild cherry (*Prunus avium* L.) and sycamore (*Acer pseudoplatanus* L.). On pastures with groups of trees, grazing for sheep, goats and cattle is suitable. The primary role of trees is protection against erosion. Besides the level of production, also quality of biomass is important and one of the most important aspects is the content of minerals in herbage (Table 20.1). Content of minerals in herbage of white clover is substantially higher than in other forage available for grazing/browsing during mid summer. Because of scarce supply of sodium when grazing on native grasses and browsing on shrub leaves, the animals must have salt available on pasture all the time. Manganese is washed from top soil into deeper horizons and this is the reason that deep rooted plants have its higher content in their leaves. The concentration of manganese in leaves of hazel shrub is ten times higher than in grasses, then hazel leaves are needed for adequate supply of grazing animals with this mineral.

The Southeast of Slovenia

The climate in this region is mild and humid, therefore very suitable for grass, herbs and woody plant growth. Wild cherry, wild service tree, whitty pear and wild pear can be used as crop-trees. Widely spaced tree plantations for grazing cattle and other ruminants is a suitable silvopastoral system. Promising results have been achieved with fallow deer, but in this case the area must be fenced.

Table 20.1 Content of minerals in different kind of herbage available for grazing in paddock with white clover over sown on thinned shrubland (Vidrih et al. 2004)

Mineral in dry matter	Sheep's fescue	Chalk fals- brome	Upright brome	Hazel shrub	Beech tree (leaves)	White clover
Ash (g kg^{-1})	42.8	55.8	49.7	60.0	46.4	104.8
Phosphorus (g kg^{-1})	0.98	0.97	1.25	2.65	2.63	2.64
Calcium (g kg^{-1})	2.74	5.33	4.11	13.2	8.1	15.9
Potasium (g kg^{-1})	9.1	11.3	14.1	10.9	10.9	29.6
Sodium (g kg^{-1})	0.04	0.16	0.24	0.17	0.15	0.89
Zink (mg kg^{-1})	15.8	22.6	21.2	32.9	26.7	27.9
Manganese (mg kg^{-1})	42.2	49.9	94.1	310.9	199.6	107.5
Iron (mg kg^{-1})	84.1	98.6	91.4	75.0	89.8	112.9
Cupfer (mg kg^{-1})	3.7	8.0	7.1	11.9	14.7	7.4
Selenium (mg kg^{-1})	0.03	0.04	0.02	–	–	0.05
Latin name of the plant	*Festuca ovina*	*Brachypodium p.*	*Bromus erectus*	*Corylus avellana*	*Fagus silvatica*	*Trifolium repens*

The Eastern Part of Slovenia

Farmers are abandoning the agricultural use of land in this region because the terrain is very steep, although the altitude is relatively low. The weathering of parent material is fast, and the soil is susceptible to erosion. Widely spaced plantations for grazing are a good solution for abandoned pastures and vineyards. Wild cherry, wild service tree, whitty pear tree, sycamore, common ash (*Fraxinus excelsior* L.) and wild pear (*Pyrus pyraster* (L.) Burgsd.) can be used as crop-trees. All of these produce timber of the highest quality, but the lower part of trunk must be pruned to realise this. The primary role of crop-trees is timber production of the best quality.

Subdivision of Grazing Land

Subdivision is one of the widest used and least researched inputs into grassland farming. Very little research has been carried out on the direct measurement of the benefits of subdivision (Squire 1986). The benefits from internal subdivision can be classed as: (1) those that improve the pasture to animal conversion process (improved pasture utilisation, allow optimum spells for grazing and allows animal requirements and feeding priorities to be met), (2) those that protect property (avoid danger areas or protect shelterbelts, planted trees, gardens, etc.), (3) those that minimise labour (facilitate easier and faster mustering), (4) helps aid management decisions (smaller areas for feed budgeting and prevention of weed invasion), (5) to be more efficient in protection against carnivore predators. Subdivision is an aid to management and, if adequate, it will allow managers to ration and allocate feed to priority stock. This may improve utilisation of grazing land and permit early recognition of feed deficits. The land with contrasting pasture growth rates and types can be kept separate, i.e. pasture in the open or shade, gentle or steep slope, developed or undeveloped land.

Trials have been set up to compare different levels of subdivision (e.g. Radcliffe 1973 at Tongoio and Waerenga-o-kuri; Clark et al.1982 at Ballantrae), or to compare different lengths of rotation (e.g. Campbell 1969; Miller 1971). Because of difficulties in trial design, they are often simplified to one stock type, e.g. breeding ewes, lambs, or beef steers alone and usually have relatively small numbers of paddocks in each treatment. Those trials that show worthwhile responses show that low numbers of paddocks are adequate for high levels of animal production. For this purpose grazing land should only be subdivided into few paddocks to have better control over spring grass growth. The cost of subdivision rapidly exceeds benefits from income in extensive environments. It is advisable to have four to eight paddocks per grazing unit. At the stocking rates currently recommended as suitable for Slovenian hill and karst pasture, any live weight gains in response to more intensive management are usually small (Vidrih 1993). Like other inputs, subdivision suffers from diminishing returns. On many hill country properties maximum gains will probably be obtained at subdivision on about four to five paddocks for each different group of animals. But to achieve other objectives set in the declaration for silvopastoralism (Mosquera-Losada et al. 2006), more intensive subdivision of grazing land than this may be needed. The costs of subdivision of grazing land under silvopasture must be weighed against the benefits of silvopastoralism recognised and accepted by society. The time is now right, to set a value on these systems.

Fencing

To achieve the objectives silvopastoralism may have for the region, fenced grazing land must be efficient for better animal management, protection of young woody plants against browsing, and grazing animals against predators must be established. There is no need to use just one type of fence and there are opportunities to reduce the capital and annual costs associated with fencing by using more modern fencing materials. Electric fencing had widespread acceptance for permanent boundry fences and subdivision of grazing lands. The development of high powered energisers provides the ability to electrify long lengths of fence, and makes permanent electric fencing more attractive at about a quarter the cost, and with a quarter the construction time, of conventional fencing (Jones 1988).

Many land owners in Slovenia have to take work off the farm to supplement their income because the size of the property they have is too small. Silvopastoralism could be a viable solution for them to continue with livestock farming and to stop shrub encroachment over their farm land. Low cost fencing is of great importance for them to keep the land they have under cultivation. They could set-stock their grazing animals in smaller mobs in smaller paddocks, to reduce walking, pasture damage, nutrient transfer, animal competition and stress. In addition, electric fencing is a low cost means to control disease and parasite spread in domestic and wild animal populations.

Wolf, bear and lynx have high level of state protection in Slovenia. An efficient carnivore damage prevention (CDP) is of great value for the region where silvopastoral systems should likely be applied. Brown bear, wolf and Eurasian lynx are perceived as a major threat to domestic livestock in a greater part of Slovenia. The size of Slovenian bear population has been estimated to be about 500–600 animals, wolf about 50–80 animals and lynx about 100 animals (uk 2001). Between 1995 and 2001 there were over 1,000 attacks by predators on domestic grazing animals, pigs and fallow deer (Fig. 20.1) with the peak of the attacks in 1998 (Fig. 20.2). There are some differences in number of attacks and killed animals between the years (Fig. 20.2), however sheep as prey undoubtedly occupy by far the first place among domestic animals. It is followed by goats, other domestic animals and fallow deer (Fig. 20.1).

For livestock producers and government, predation can be frustrating and costly. In the period 2000–2003, the claims for compensation of damage, mostly to livestock,

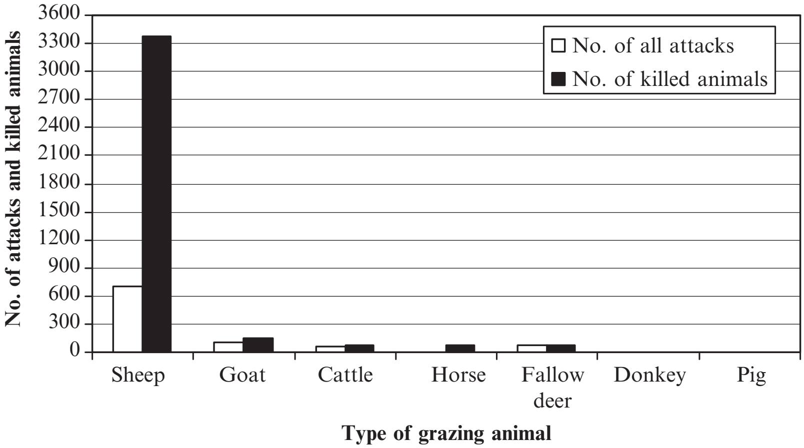

Fig. 20.1 Number of all large predators attacks and killed grazing animals regarding species (years 1995 to 2001) (Vengušt et al. 2006)

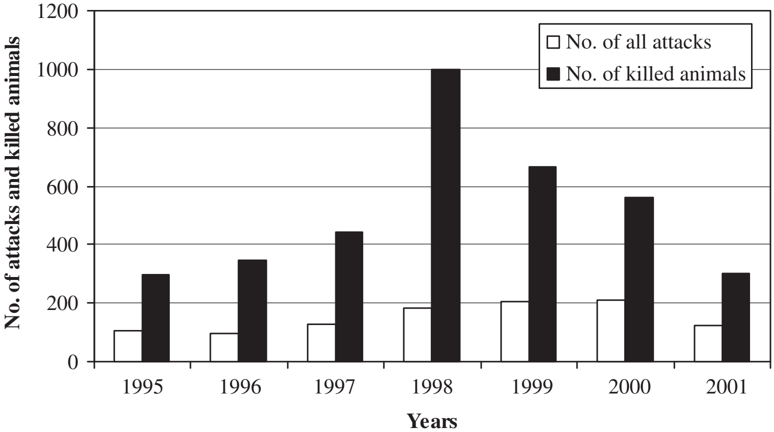

Fig. 20.2 Number of large carnivores attacks and killed animals regarding years (1995 to 2001) (Vengušt et al. 2006)

amounted to around 700,000 euros. In the same period more than 1,400 predation claims were registered. Controlling the numbers of large predators has long been the favored method to reduce depredation on livestock. In recent years many farmers have found electric fencing a highly efficient and low cost method to stop conflicts. The modern approach to resolve predator-livestock conflicts entails the selective removal of certain individuals in highly conflictive areas and through preventive measures using mechanical protection or guarding of livestock in combination with an efficient compensation system.

In many cases there will be a forest next to the silvopastoral land where predators may live undisturbed, but they do tend to feed on grazing land. Only with the use of efficient electric fences can prey animals live next to predators. Large carnivores can live in coexistence throughout natural habitats of Europe and survive in the long term in freedom; only if they have a strong enough fear of people and their property (livestock). This fear is the most natural and only efficient method that enables different kinds of carnivores to live in coexistence with each other and with man. Many of the learning events in the natural world operate around punishment, especially between predators. Animals learn by trial and error-only if they are 'punished' do they learn to leave certain "bad" things alone (Kilgour 1983).

Some of these statements were tested under environmental conditions prevailing in the south western region of Slovenia, where most attacks on sheep were recorded. Four enclosures each 72 × 25 m and using different in kinds of electric fence were set up enclosing sheep to observe the behaviour of the sheep when predators approached it. The aim of the trial was to find out how large the enclosure must be to prevent panicking sheep breaking through the fence. This is important where sheep grazing is carried out with a safe night paddock during the period of highest possibility of attack by wolves. Because the fence is a psychological, rather than physical barrier, the wild and farm animals must learn and be trained to the electric fence before control is attained. Predators could penetrate the fence by accidental wandering if the fence is laid across traditional migration routes. The whole idea of predator training should be that first shock is delivered to the nose. If the shock is delivered to the back of the head the tendency is often to go forward through the fence rather than back up.

There are several ways to get predators to investigate the fence in a slow and cautious manner. The first one is to make the fence must visible to encourage the predator to bring its nose close to fence. A bait (chicken wings, fresh livers) can be hung on the live wire in the fence to attract the predator. The predator does not need to grab the bait, only to put its nose close enough to it to get a shock. The strength of the first shock will often determine how the animal is going to react to the fence in the future. Early control measures will be the most difficult ones while later control problems for wild animals should not be so formidable. The next generation of predators will learn the traits and behavioural response-patterns of their elders. There are still very few electric fences designed for predator control on a whole year basis, and so not much opportunity for large carnivore to learn to respect electric fences. One basic rule that is overlooked more often is that the fence must be effective when the predators are active. In other words if the predators operate at night, check the fence out at night, when dew or other night things may be causing a short. Livestock fences can even be switched off out of the grazing season, but this is a time when migration of predators can be very frequent. Despite a number of essential differences between conventional electric fencing for controlling livestock and electric fencing for CDP needs there are some basic rules to observe when building an electric fence. Visibility, design, power level, training and maintenance must be carefully followed to make an electric fence effective for carnivore damage prevention (Linhart et al.1982).

Nutrient Transfer

Hill and karst grassland in Slovenia was mainly used as cut meadows (hand cut) in the past. The hay produced there was then used to feed house animals and this created a large volume of farmyard manure. This was used on arable land to keep its fertility high enough for good crop production. Therefore, part of the plant nutrients (P, Ca, Mg, Na, S) were removed from the grassland soils to the cereal land. Rendzina soil type can mostly be found on tops and steep slopes. It is strongly rocky and sinkholed relief that prevents rural use of soil. Therefore expressive forest vegetation appears on limestone. By texture, the soil of rendzina on limestone, is clayey, while on dolomite, it has a larger capacity for moisture retention than on limestone (Table 20.1). Rendzina has a high level of saturation with basic cations. On gentle positions, mostly in dolomite, it is suitable for pastures and meadows.

Currently the low availability of phosphate in these soils limits herbage growth and quality for feeding grazing animals. Because of very low biomass production, meadows on steep land or those with rock outcrop (hard to use machinery), are no longer used by farmers. The abandoned land has become a good place for encroachment of woody plants. Because the old system of land use is no longer possible due to the lack of suitable manpower and in view of environmental circumstances, a strategy for sustainability of the area by sheep and goat farming has been adopted. The grazing system which can be applied in the region should be a modification of the old limited transhumance in which the grazing land is some distance from the place where winter feed is obtained for the animals (Vidrih et al. 1998a). Thus the grazing animals will play a very important role in the process of restoration of farming on such land through the nutrient cycling in the ecosystem (Haynes and Williams 1993). In future there will be even more limitations on using agrochemicals to modify the fertility of the land. To get higher income from direct payments, organic farming will be the main practice for silvopastoral land. The importance of nutrient return through dung and urine of grazing animals, fed even during the winter on grazing land, will have great value. Although beneficial in returning nutrients to the soil in a plant-available form, the uneven distribution of this return causes accumulation of nutrients in excess of plant requirements in small areas with the risk of high losses of some nutrients through volatilisation. Since most nutrients ingested by grazing animals are returned to the soil in excreta it is very important to achieve even distribution and to prevent nutrient transfer or accumulation on camp sites.

Cornforth and Sinclair (1982) estimate an increased animal-related P loss per stock unit with increasing land slope. Significant quantities of nutrient are transferred from adjacent pasture to stock camp areas. Gillingham (1982) has presented evidence indicating more uneven dung return in paddocks where a small proportion of easy terrain wasassociated with a large proportion of steep terrain. Stock camps are areas where grazing animals tend to congregate. Animal stock camps are near hedges, while in hill country stock tend to camp on gentle slopes (<10°) and ridges. For the hill pastures it has been found that up to 60% of urine and dung is deposited in the stock camps which make up only 15–30% of the total land area. This in turn leads to considerable accumulation of nutrients in topsoil at camp sites (Haynes and Williams 1999). Higher concentration of nutrients on camp sites may lead to nutrient losses during periods of high precipitation. These losses may be smaller in silvopastoral systems, as trees and shrubs can sequester nutrients from leaching in deeper soil layers (Lehmann et al. 1997). Gillingham (1982) suggested that subdivision of paddocks into slope classes would improve the evenness of dung return. With increased subdivision and stocking rate the effects of camping on nutrient transfer decreases.

Camping behaviour in sheep has seen to be connected with the pattern of dung return. Donald and Leslie (1969) found that under sheep grazing dung accumulated initially in areas which were not grazed during the day, and that the site of accumulation shifted over time. Increasing intensification of farming in the hill grassland has an impact on changes in animal behaviour and dung distribution. Factors which increase the evenness of dung return could have important implications for nutrient cycling and reduced fertiliser requirements (Hilder 1966; Gillingham and During, 1973; Gillingham et al. 1984). The major changes in dung distribution were related to stocking rate with the high stocking rate producing a more even dung distribution than the medium or low. The influence of residual herbage mass on animal grazing behaviour is reflected in changes in the dung distribution pattern too. Grazing has been found to increase species diversity (Kooijman and de Haan 1995; Bati et al. 1999) and favour denser vegetation with a longer growing season and thus nutrients can be used more efficiently. Translocation and losses of nutrients brought about by grazing animals can be controlled to considerable extent by fencing-off the camp sites or limiting access to areas with a high potential for leaching during the wet season and divert losses to less vulnerable areas.

Liming

Most of the abandoned farmland overgrown with woody plants suffers from a lack of basic cations, e.g. Ca, Mg. The pH of the top layer is decreasing because of mineralisation of organic matter derived from woody plants on the surface of soil. In addition, the land was under the influence of increased atmospheric inputs of protons and nitrogen for several decades. These anthropogenic loads have led to acidification and eutrophication of soils. Nutrient impoverishment and changed environmental conditions in soils are characterized by decrease in autotrophic bacteria (Anderson and Domsch 1993). A diminution of the biological diversity may cause a partial loss of important biological processes in soils where woody plants have spread on abandoned grassland.

To counteract soil acidification in the top layer of soil, only lime must be applied as a first measure to improve efficiency of sward establishment and the quality of feed for grazing animals grown in coexistence with woody plants on abandoned land. From many lime trials conducted on grazing land, it is known that better growth of herbage plants may occur after increasing the soil pH (Vidrih 1991). Lime responses may be due to the effect changes in soil pH have on soil chemical, physical and microbial properties. Responses in pasture have been attributed to increased plant availability of nitrogen (N), phosphorus (P) and molybdenum (Mo), and increased soil moisture. The natural pH of dead vegetation derived from woody plants and lying on the surface of soil is around 5. The biological processes in the soil of abandoned land are withheld for this reason and a mat of coarse vegetation or 'thatch' will build up on the top of soil. Dead organic material is only partly worked into deeper mineral layers, because in the acidified top layer the endogeic and anecic earthworms are absent. The thatch favours growth of deep rooted plants and reduces germination of more desired over-sown herbage seeds in the grazing sward.

Most of the land where silvopastoral farming may be practised in Slovenia has shallow soil on stony ground, or is steep and unsuitable for cultivation. The volume of thatch on abandoned land is small, and it takes only 1 t of lime per hectare to correct the acidity of the top layer. Lime applied on such land will be left on soil surface, and care must be taken to avoid over liming. This can bring on imbalances in mineral content such as high molybdenum or low zinc and boron uptake by herbage. At the start it is important to achieve a higher pH only in the top layer of soil. Depending on the initial state of the organic layer and on the amount and quality of lime applied, the organic layer trampled into the soil by grazing animals (hoof action) will be modified to varying degrees. The typical dark coloured horizon of the organic layer will be turned into a loosened, well mixed state by epigeic earthworms. The cause of this modification is an increase in biological activity (Shah et al. 1990). The biomass balance between the fungal and bacterial population shifts towards the bacteria (Zelles et al.1990). An increase in microbial biomass provides a better nutritional base for meso- and macrofauna, and because of the simultaneous lack of acid stress, the density of the remaining population of epigeic earthworm increases after liming. Increases in earthworm and microbe numbers over time improve soil structure and break down animal dung faster.

Liming in conditions similar to those found in abandoned land overgrown with woody plants does not contribute to higher CO_2 release in the long term. The carbon loss through increase of microbial activity is quantitatively small compared with the carbon storage in the organic layer. The effect of liming on N_2O emissions indicate that the fluxes will decrease or be unaffected. Larger populations of earthworms alter the structure of the top layer and thus create more aerobic conditions due to better oxygen diffusion into the soil and reduce N_2O formation. In the long-term, liming can lead to an improvement of soil structure and thus an increase in CH_4 uptake. An improvement in the physical state of the organic layer and the mineral soil, which is performed by earthworms, increases gas diffusion and thus the supply of atmospheric CH_4 to methanotrophs. It is suggested, that CH_4 uptake is determined not by intrinsic biological factors, but by soil physical conditions (porosity, moisture content, temperature), which regulate CH_4 diffusion towards the microbes (Borken and Brumme 1997).

Out-Wintering

Out-wintering involves keeping livestock outside for some or all the winter and is a practice that remains somewhat controversial among conventional livestock farmers and with the general public because confinement feeding on a whole year basis is still mostly used in Slovenia. To solve the present problems with abandoned farm land there is an urgent need to change some practices of ruminant husbandry. These animals have an internal source of heat generated by bacterial activity in the rumen, which keeps them comfortable at sub-optimal temperatures. Most experiments on out-wintering mainly deal with animal health and welfare (Wallbaum 1996; Heikens 1999) but there is a need for to develop farming systems where animals could do some valuable work on farm land even during winter, without jeopardising their welfare. It is most important that farm animals out-wintering on abandoned land could slow down the process of shrub encroachment and build up soil fertility if proper feeding management is given during winter. To investigate pasture feeding and water supply to animals during winter, a group of 25 dairy replacements were out-wintered on pasture at Ko evska Reka farm (Vidrih et al. 1998b). A broad estimate of the cost of out- wintering and some other advantages are presented in the article.

Sheep farming has gained popularity of smallholders on farms in Slovenia. Most of these animals spend the grazing season some distance away from the farm on mountain or communal pastures. For wintering, sheep are sent back on farms and often put into dark, small and unsuitable stalls.

Many of the extensive orchards (fruit tree gardens) in Slovenia are also abandoned. Weeds flourish under old trees and woody plants from nearby hedges invade the formerly cultivated land. Keeping sheep to out-winter on these extensive orchards close to the farm buildings can also be seen as a kind of silvopastoralism. Sheep are provided with insulation in the form of subcutaneous tissue, skin and wool (Kotnik et al.1996). Animals, soil, fruit trees and people might profit from out-wintering sheep in an extensive orchard with appropriate feeding management. As long as the ground was not covered with snow, the flock was rotated using a temporary electric fence to achieve as even as possible distribution of excreta over the whole area. After heavier snowfalls feeding started on bed pack prepared nearby to supply winter feed. Straw, wood chips, sawdust and poor quality hay were occasionally added to the bedding pack providing the sheep with a clean place to bed. Occasionally ground lime was spread over the bedded pack to reduce its smell. Electric netting was used to manage sheep grazing/feeding and to protect them from stray dogs. Most extensive orchards have a wide spectrum of environments (near buildings, boundary hedges) and preferential sites can be selected to place the bed pack (Vidrih and Vidrih 2001). Planning an outwintering strategy to avoid problems is not difficult, but often requires ingenuity and flexibility with good management being a key factor as with many other grazing systems.

Conclusions

Much too often silvopastoralism is presented as an extensive land use method. But this is not the correct approach if the aim of our work is to develop sustainable farming methods in hill and karst land. Silvopastoralism should be investigated and presented as an intensively managed land use system. Silvopastoralism is a holistic way of farming which deals with soil, herbage plants, woody plants and animals under natural conditions on a year-round basis if possible. To manage silvopastoral systems, more experience and knowledge is needed than for just field crops or animal husbandry production alone where farming is supported by inputs from the chemical industry, big farm machinery and selectively bred plants and animals.

Extensive management has normally been associated with an extensive environment, where land has traditionally been relatively cheap in relation to the value of the animal. According to what was written in the "declaration for silvopastoralism" (multipurpose land use, biodiversity, protection of environment, health protection) the resources of an extensive environment nowadays cannot be presented as cheap. Extensive management is geared towards exceptionally low cost per unit of production and production levels are also low. Little input is made to the animals, and little is expected in return. With all the information available about grass-fed products (meat, milk) there is no need to promote silvopastoral products as a source of cheap food. They deliver healthier and safer food, than food produced with conventional farming and consumers are willing to pay more for it if they are given the correct information and given it more frequently.

Silvopastoralism must be promoted to the end consumers as a recent way of managing pasture land, other than for direct production. There must be awareness of the importance of keeping the cost of the food produced from grazing animals down. There must also be a movement away from an obsession with low cost grassland production and a promotion of what is really valuable about silvopastoralism so that farmers will get the financial benefits from the system. It must be borne in mind that silvopastoralism must be an intensive form of management, fulfilling most of the consumers' expectation and obtaining their confidence in the quality of the goods that silvopastoralism can offer. More intensive land use methods require much higher inputs of knowledge developed at farm level and experience gained under local environment conditions. Management of extensive environments is every bit as intensive and necessary as on the most intensive strip-grazing farm. The differences between land sustaining one animal per 10 ha and one animal per hectare are one of climate and the fertility of the soil. The level of management should be exactly the same, if in fact not greater on the lower stocking rate because of the extensive environment. Less Favoured Area farm land is more handicapped in many ways than lowland fertile soil; hence it requires more attention and care. Silvopastoralism can become a way to manage pasture land in the future and can have a major role in developing sustainable farming practice (better soil fertility, higher biodiversity, clean water and air, less pollution in atmosphere) on hill and

Table 20.2 Physical and chemical properties of two different profiles (Vidrih and Lobnik 2003) [Au5]

Horiz	Depth (cm)	Clay (%)	Silt (1%)	Silt (2%)	Sand (%)	C (%)	N (%)	pH	Ca Ex	Mg (meq/100 g soil)	K	Na	V (%)
Rendzinic leptosols (Forest land use)													
Oh	0–10	30	43	17	10	42	1.5	6.2	38.9	16.8	0.5	0.2	70
A	10–25	54	29	10	7	8.6	0.5	5.9	30.7	5.8	0.2	0.1	60
Chromic cambisols CMx (Agriculture land use)													
Ah	0–18	37	32	17	14	2.6	0.1	4.5	9.0	0.7	0.1	0.1	46
BW1	18–25	48	26	13	13	1.0	0.1	4.7	10.8	0.6	0.1	0.1	56

karst land of Slovenia. To achieve this goal, however, herbivores need to be used and this can only be achieved if domestic animals can be protected effectively from large carnivores. The current level of knowledge and experience of building livestock fences is not sufficient for carnivore damage prevention (CDP). The ability to think and develop new ideas that will work for CDP is the only limitation that the electric fence has.

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Chapter 21
The Traditions, Resources and Potential of Forest Growing and Multipurpose Shelterbelts in Hungary

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Abstract Livestock-keeping in forests is a traditional practice in both the plains and mountain areas of Hungary. It has ensured the stability of marginal areas and sustained diversity. Following ownership changes in 1989, Hungarian agricultural activities diversified again and, on private farms, opened a range of options to plan and revitalize agroforestry systems, mainly based on the shelterbelt-systems of the 1960s. This paper reviews trends and possibilities in landscape-management both in specific locations and countrywide. In addition to the agroforestry potential there are examples of conservation, landscape protection and ethnic heritage of these farming methods. Because of changes in land structure and the accession of Hungary to the EU, the economic objectives of afforestation are increasing. The protective functions of forests as shelterbelts, landscape enhancement and settlement-protection are also being felt. It is expected to be an increase in shelterbelts, windbreaks, forest belts, hedgerows and alleys. Surveys in forest, and non-forest scenarios need to be followed by long term planning, which should increase forest protection. Examples of experience, with potential uses of agroforestry in Hungary are given, but optimal exploitation needs further research and collaboration of all sectors concerned.

Keywords Livestock, multipurpose management, landuse, silvopastoral, restoration

Introduction

Nowadays the concepts of land development, agriculture and forestry are being more closely integrated. Hungary is committed to soil conservation and sustainable utilization through the recognition and the protection of environmentally-friendly

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cultivation of plants and livestock-farming. Traditional management methods, like agroforestry, ensured the economic stability of the countryside until the 1940s.

There is a need for parallel management of the outskirts and the inner areas of rural settlements and villages. The basic goal is to build organic, natural units to permit ecological circulation through decentralization and bringing regionality to the fore by supplying small regions with independent infrastructure. Silvopastoral systems – livestock-farming and timber growing (forestry) on the same area – could be increased, modified and developed to help achieve these goals.

Livestock-breeding is an ancient tradition in Hungary. The benefits of ancient, traditional extensive stock keeping is currently being recognised and attracting attention in relation to the management of small scale farming. There is a tradition of keeping cattle, horses and sheep on the lowland plains or the pasturing of pigs in the uplands of Hungary. This type of extensive keeping is known as "*acorning*" or *pannage*. It is important to note that pasture-forests (where pasturing is one of subsidiary uses of forest) were primarily established for timber production, soil conservation and protection, but were used by local people for firewood and crops (Hegedűs and Szentesi 2000).

After 1945, collective farming and social reform almost eliminated such semi-natural types of farming. After both world wars the development of agriculture, including livestock-farming, occurred at a great rate. Large state farms, with intensive cattle and pig keeping and the socialization of private forests, signalled the demise of forest pasturing.

Current land-structure, is made up of shelterbelt-systems (established around the 1960s; and accounting for around 16,415.7 ha in 2001) (Bán et al. 2001). The connecting forest areas could permit the reintroduction of multipurpose management, e.g. semi-natural livestock-keeping combined with wood-management on agricultural areas. The modern concept of organic farming embodies principles of environmental sustainability, good farm management practices and animal welfare. However, forest law in Hungary forbids livestock keeping in state owned forests. Hence the integration of shelterbelt-systems, farm-afforestation and those small forest-sites (area < 1,500 m^2), which do not fit into the forest land use category come under the Hungarian "Forest Protection Laws" (1996. 54th Act), could be used for the abovementioned purposes.

One of the main aims of our research ("Woody biotop systems project", supported by The Hungarian Scientific Research Fund – OTKA, T043417), is to come up with acceptable ideas to reform agroforestry practices in Hungary.

History of Agroforestry in Hungary

Development of agroforestry-systems in Hungary started with *pannage*, through defforestation of forest to increase grazing areas. Initially, settlements of ancient tribes in the Carpathian-basin deforested areas to increase the available grazing lands. Besides the traditional transhumance grazing, *pannage* in oak-forests was mentioned in 1353 and these with the similar "pick-feed" grazing forests were common for centuries afterwards.

High densities of goats caused soil compaction and grazed seedlings, preventing regeneration. Hence, in 1769, during Queen Maria Theresia period a Regulation prohibiting goat grazing in forests was established. The use of cattle to graze seedlings was permitted. Until the 19th century (and further) the problem of forest grazing could not be solved, because the liberated tenant farmers were rewarded with areas of forest. By the end of the 19th century, the definition of "grazing forest" and "protection forests" became embodied in contemporary law. Grazing forests as a landuse option was defined when tree cover of 20–40% built up as forested tracts or by thinning of existing forest. The concept was familiar: forest management alone could not affect the development of a region. Also needed was modernization of infrastructure of sectors like agriculture. In 1923 an Act (XIX) "afforestation of plains" ordered the establishment of shelterbelts, tree rows and hedgerows, particularly on farmlands bigger than 50 ha and on grasslands with more than 20 ha. Forest grazing was prohibited in 1939 after the renewal of forest law.

The establishment of modern Hungarian forestry started after the Second World War (WW). The transfer of forest areas and forestry properties to the state ensured the establishment of an intensive forestry industry. This act basically changed the ownership structure and it introduced modern techniques in all forests in the country. Besides centralized control, it laid the foundations for long-term management. Before the Second WW the main aim of silviculture was profit, which caused irreversible damages to the sustainability of forested lands. After the war, reconstruction and restoration used up the forestry resources, but it was the start of a 10 year period of rapid forestry revolution. Reforestation happened to be the most important task of silviculture: establishment of new forests started quickly and the following 25 years were described as "the era of great establishment of stands" in Hungarian forest history.

Between 1946 and 1950 – as the first step in the great afforestation program – 136,000 ha were reforested (46% was naturally regenerated, 79,500 ha artificially regenerated). Trees were planted at a rate of 10,000–20,000 ha year^{-1} between 1951–1960 and the naturally reforested area was around 3,000–5,000 ha. Among the results achieved during this decade was the establishment of new forests in huge areas at higher level and of higher quality than previously. Natural regeneration priorities such as species selection were determined by research in the Silviculure Department between 1952–1968. Fast-growing species were preferred and the mechanization for stand establishment operations was imported from the Soviet Union. These events brought about changes in the type of technology used and determined the future operation of forestry over the next 50 years.

The natural climate is unfavourable in many ways in Hungary. Therefore forests with protective functions were important for a long time in ameliorating living conditions and environment, e.g. protecting urban or rural areas from dust storms caused by spring winds. Evidence can be found of efforts to establish forests on bare hilly areas and on the Great Plain of Hungary over a hundred years ago.

The Council of Ministers No. 1040/1954 decree was the first order which declared the multipurpose use of the forests addressing the enforcement of the environmental role of woody areas: "Care should be taken that forests fully meet their wood-producing, arable land sheltering, water-management controlling, soil protective, climate modifying, health-protective, aesthetical and other functions". The main functions of protective afforestation was to prevent soil erosion, avoid floods, to protect forest roads, railways, bridges and buildings on hillsides or other exposed areas. Trees were planted to provide shelter from the wind around hospitals, sanatoriums, farms and other estates (Keresztesi 1991).

On the other hand, the rapid development of agriculture in the 1960–1970s resulted in the establishment of farming systems forming large fields, in which use of heavy machines and aerial chemical control were widespread. Biodiverse good quality agricultural lands became bare, erosion and deflation occurred, the fauna of these areas, which also play a role in biological protection, started to decline. Only roads, railways, open surface water and the infrastructure of settlements and farms limited the expansion of these large fields.

To counteract this, protective afforestation needs to be established in cultivated areas with forest-belts and hedgerows which are be resistant to biotic and abiotic changes and suitable for multipurpose management. These forested areas can also be utilized for local timber needs.

After 1989, following political changes in Hungary, about 23.6% of the forest area was privatised. Most of the forest areas and properties remained in state or other common ownership (60.3%) and there is still 16.1% of forest area with uncertain ownership, due to the privatisation (Keresztesi 1991). Table 21.1 shows the protective forest areas of Hungary. To control and protect sustainable forestry with a legislative tool, the Parliament passed the LIV. Act of 1996 concerning forests and their protection.

The major goals of the current forest policy are (i) to organize co-operation between the interests of the management, owners of the land and the demands of society to run forestry in a sustainable way and (ii) to maintain the current rate of natural and semi-natural types of forest stands, made up of a high proportion of native species (Barátossy and Verbay 2001).

Table 21.1 Forests with primary function of environmental protection between 1975–2001 (After Keresztesi 1991 and Bán et al. 2001)

	1975	Planned for 1976–1990	2001
Type	(1,000 ha)		
Green belts	8.8	20.6	16.4
Soil protective forests	86.5	59.6	121.8
Forests for landscape and nature conservation	46.4	19.0	10.5
Protective plantations outside the forest	22.6	10.8	77.2
Total	164.3	110.0	225.9

Ecological Implications of Agroforestry Systems in Hungary

In the last few years the role, function and the protection of the countryside have been significantly re-evaluated. It is accepted that the countryside is not just for agricultural production, but also biological and social living-space, in which these functions complement each other.

The main types of agroforestry ecosystems in Hungary are areas such as forested pastures, shelterbelt-systems and other non-forest areas (where there are some trees but which are not classified as forest under the law). For example windbreaks (3–6 rows wide afforested belts made out of tree rows and/or hedgerows, protecting again wind, snow or sandblow) in agri-environment areas aim to protect crops and pasture growth against the harmful effects of the wind, as well as enhancing biodiversity by providing ecological corridors and promoting animal welfare. They also assure protection and cover for farming practices, stock-breeding, cultivated areas and their associated infrastructure. Establishing new windbreaks can also counteract the annual snow risk and also enhance the landscape, helping to change the whole region for the better.

Shelterbelt systems (meaning all protectional afforested areas bordering cultivated areas, where the area of the shelterbelt is less than 10% of the agricultural areas) are very important to agricultural production as they conserve soil and add spatial heterogeneity to the ecosystem. A well constructed shelterbelt can provide connectivity between the biotop-mosaics and the migration of wild animals (e.g. pheasant, roe-deer) connected to farmlands.

Special attention must be paid to the maintenance of afforested belts especially along roads and railroads, where the afforested belts act as a barrier from agricultural land. Another objective of shelterbelts is to protect against build up of drifting snow. Experiments have shown that artificial snow-catching barriers are only temporary, less efficient and more limited in protecting the traffic against snow accumulation than natural ones.

By establishing new shelterbelt systems we can achieve landscape variability and amenity especially in treeless areas. Well designed shelterbelts with a native species, proper structure can connect core-areas (greenways). The planted greenways have a slightly lower ecological value than wildlife corridors and will evolve into self-sustaining systems through time, by using well-chosen management and methods.

The importance of these afforested belt systems has promoted research during the 20th century. Some experiments dealing with agroforestry systems have been carried out in the recent past. Shelterbelts on farms to prevent snow drifting were established in the region of Sopronhorpács, Sarród from the late 1940s till the early 1970s, by the Department of Silviculture. One of the main goals of this research was to survey the existing shelterbelt systems to estimate their actual functions. We also tried to classify the main windbreak types established in 1950–1960s by their functions, structures and species composition, evaluating the effects and results of the applied silvicultural operations. From this work and including nature conservation and economic objectives, new recommendations for the formation, maintenance and regeneration of new types of windbreak can be proposed.

On the other matter, several agroforestry research experiments have been planted between 1957 and 1965. Although the experiments were mostly focussed in afforested belts (windbreaks and shelterbelts) the tree effect could partially be extrapolated into other types of agroforestry systems like silvopasture or forest farming. The results aimed to compare afforestation programmes between different parts of the country with similar conditions and to present techniques for establishment and management of afforested belts and other types of agroforestry. The main aspects evaluated in these experiments were afforested belts-microclimate (measuring wind speed, soil- and air temperature, air humidity, soil humidity, snow and rain distribution), the positive and negative effects of afforested belts on air pollution, plant protection and phytocoenological studies, shadow-effect and heat-stress. They also aimed to make an economic evaluation of the effects of the afforested belts on tree and pasture or crop production. This analysis would help form the basis of new recommendations for the delivery of new agroforestry practices (Frank and Takács 2003).

Microclimate (82 afforested belts) and snow-distribution (23 afforested belts) measurements were made over 3 years on 14 agricultural areas in Hungary. Air pollution analyses were carried out in a system over the year by measuring dust deposition and phytocoenological studies were conducted in 52 afforested belts. Pasture yield was assessed over 4 years and timber production of the shelterbelts was evaluated in some plots. The role of different tree species in windbreak systems was assessed.

The main results from this research can be summarized as follows:

1. Forest belts improve all the climatic, edaphic and biological factors and, as a result of this, they protect the soil in agricultural areas and improve yield and timber production.
2. Windspeed suppression in the area protected by the forest belt changes climatic and edaphic conditions and has an effect on biological processes. Wind reduction in front of the forest belt depends on distance from the belt. In the case of dense belts, the effect is felt 2–22 times the belt's height, 4–42 times for porous belts and 5–10 times for permeable belts. At the protected side of forest belts, the protected zone is 10–29 times wider than height in the case of closed belts. In gappy belts this zone is 20–51 times wider. In open belts, the protected zone is 10–20 times wider than its height.
3. Forest belts do not affect the amount of precipitation falling on the field, but their favourable effect on the precipitation of rainwater and snow is demonstrable. On the windward side, there is more rainfall (17%). In the case of wide, dense forest belts, the snow accumulates inside the belt, in medium-wide porous belts. The snow fortification's maximum height is on the windproof side, while in narrow, open forest belts snow aggregation risk is reduced.
4. Forest belts ameliorate the effect of evaporation on protected fields.
5. In daytime, up to 5 × tree height distance from the shelterbelt, the average air temperatures are lower than in the middle of the field. The opposite effect occurs at night time.

6. In fields protected by forest belts, the relative air humidity of the air layer above the ground surface is higher than on open, non-protected fields. In the forest belts' protected zones, the relative air humidity is 5–10% greater in most cases, and in extreme cases can be 38% above that found in open fields.
7. The snow catching capacity of a 15 m height shelterbelt at different distances from the shelterbelt was highest in a north-south orientation (Fig. 21.1).
8. Forest belts have an important function in protection from deflation and in diminishing air pollution. The air pollution study showed that on peat and on mull soil the dust content of air can reach 1,100 t^{-1} km^{-2} $year^{-1}$ (200 t^{-1} km^{-2} $year^{-1}$ on industrial fields, 50 t^{-1} km^{-2} $year^{-1}$ on living space).
9. The phytocoenological results showed that specific forest plant associations do not evolve in forest belts.
10. Pasture and crop yield was significantly increased by the presence of shelter-belts in proportion to the belt's site corrective effect. Where the protective effect is high, yield increase is greatest and where the affect is low, the yield is low also.
11. In forest belts the volume growth is especially rapid. From this it could be established that forest belts and belt systems have particular roles in controlling wind damage, increasing yields and have an important function in landscape aesthetics and in habitat improvement.

From the study of created forest belts it was found the following main technical conclusions:

a. Creating a regular grid at right angles to the prevailing wind in densely populated areas with roads, canals and intersected by water-courses is not possible and unnecessary.

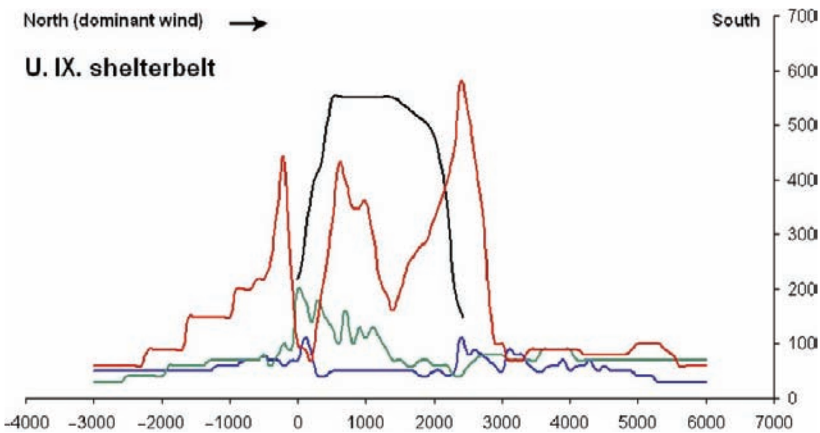

Fig. 21.1 Snow accumulation in a forest-belt at Sarród, 2004. Horizontal axis is distance in centimetres, vertical axis is snow deposition in millimetres

b. In locating forest belts, site conditions and rural output are more important factors than size.
c. Forest belts should be as wide as possible.
d. More attention should be paid to silvicultural properties in choosing tree and shrub species, especially their compatibility, sproutability regenerative capacity and their conservation and environmental protection value. Only use native and non-invasive species.
e. Effective protection can only be achieved by using structurally well-developed forest belts (snowbreak, deflation protection). Maintenance of this structure is necessary along the whole length of the belt.
f. It is very important to ensure the support and co-operation of private owners and state organisations when creating and maintaining forest belts. An agricultural subsidy support system needs to be supplied.
g. Do not forget that afforestation and tree planting will only give effective protection if they follow a standard system with the current forests, and clusters of trees. Afforestation has a similar effect but needs the requisite of spatial interconnectivity.

The Potential of Hungarian Agroforestry Systems

How can agroforestry systems contribute to the expansion of the Hungarian forested area? How can these spatial arrangements of woody plants be harmonised with the landscape, or how would new plantations integrate with or modify the current (or proposed) protection areas with or without tree cover? These are ongoing questions which should underlie the principles of environmental protection.

It must be realised that the integration of agriculture, forestry and their associated infrastructure make up what we understand as the natural and built heritage. Hungary is basically an agricultural country, as most (84%) of its land is a cultivable plain under 200 m and is highly productive. Over time the transport infrastructure (all road and railway networks) of the countryside was developed to meet the economic needs of the population. Agriculture, forestry and hunting developed side by side to form the regular and regional institutions which exist. Although we are taking forestry as the cultural landscape, the task is to put new thinking into issues of the landscape and traditional forest-management, based on such integrated studies. A strategic goal is to increase forest cover up to 25–27%, which would be reached by planting 15,000–18,000 ha year^{-1}. It is important that this aligns and evolves with current EU agricultural policy. One of its main elements is the utilization of specific agricultural areas for afforestation. There are potentially about 700,000 ha of arable land, which could be potentially taken from that land use category (Bán et al. 2001; Mészáros et al. 2003). To develop a region it is essential to look closer at its characteristics and to find the significant influences which shape the landscape. This information is necessary to introduce the conditions of the studies.

In 2000 the land area of Hungary was 93,030 km^2, which included 49% arable land, 15% other rural and 19% forest area. The distribution of land use in the Györ-Moson-Sopron County (GYMS) is similar to the country as a whole – 53% arable land, 10% other rural activities and 19% forest (Bán et al. 2001). The area is flat plain (Little Alföld of Hungary), but the climate is considerably influenced by the Alps and the dominant cold, strong north winds coming from the Wien basin. The region's natural potential (e.g. hydrogeology, productive soils) and geographic position (it has boundaries with two EU countries) with rich cultural heritage makes the county well placed to consider new, innovative land use ideas.

The potential of agroforestry systems will be evaluated in the GYMS region, but most of the results could be applied in the rest of Hungary. The evaluation of the different agroforestry systems will be structured in shelterbelts, windbreaks and roadside forest belts as well as alley crops (crops for interrow use on afforested areas) and silvopastoral systems, highlighting recent tree planting in grasslands.

Shelterbelts, Windbreaks and Roadside Forests

The area of all protection forests (soil, water, settlement, etc.) in Hungary is 225,862 ha (12.6% of all forest areas) (Table 21.1). There are only 16,416 ha of woodlands protecting agricultural fields. These are mostly shelterbelts and windbreaks with valuable timber. It is also worth mentioning that there are 11,393 ha of forest for other settlement protection functions.

At a regional level, estimates are more accurate and the total area of protectional forest is 4,726 ha. Thus, only 17% of the forests in GYMS-county have any protection function. From official forest data, 799 ha are for soil protection, 1,864 ha protect agricultural areas, and 570 ha are for further settlement protection.

Protected forests have well defined boundaries although they differ in management from the classic forestry management in Hungary. Hence we would like to deal with the afforestation of verges of motorways and ordinary roads. We find similar situations for roadside alleys, shelterbelt systems and road trees: all were planted (some of them restored) in the 1950–1960s. Most of the plans and documentation has been lost, only fragmentary records and examples of successful scenarios give an indication of the original aims and objectives.

Motorways and ordinary road verges have some important functions. They have a multifunctional use as protection, a habitat for wildlife, economic value, subsidiary use and wood production. This paper is concerned with such collections of trees and the economic, social and other additional benefits they bring. These trees can be categorised as belts like tree rows or alleys along railway tracks, windbreaks, shelterbelt systems, forests with protective functions and other continuous forestations/plantations (alleys, hedgerows, green-junctions). The margins and buffer zones have additional values such as subsidiary use as silvopasture. This multifunctionality associated with the margins will be discussed later.

It is clear that shelterbelts have been planted to reduce the damaging effects of strong winds in Hungary, mostly traditionally in lowland areas and mountain plateaus or wide valleys where a wind-tunnel effect is created. As a result of ownership changes after 1989, the farm structure diversified and nowadays shelterbelt-systems and the connecting forest areas allows some kind of multipurpose management on rural field and roadsides causing a review of the wood producing capacity of belts and rows.

Any piece of land can be divided into two parts – an outer and inner-belt. The function of the outer-belt is to permit the movement of livestock and machinery. This area should be sited to meet local conditions along the borderlines of the area, taking into account the prevailing wind direction and landscape.

The rows of trees that make up the inner-belt are perpendicular to the prevailing wind direction and the interrows are 20 H–25 H wide, where H is the average final height of trees. The main belts can be supplemented with perpendicular cross-belts.

Size and position should be according to the benefit that the agroforestry system can deliver. On hilly sites, forest belts should follow the valleys and additional belts planted around the sides of the hills. Shelterbelt systems would normally use 4–5% of the landscape on the plains and 8–10% on hilly sites to give the protection needed (Hegyi 1978).

Most shelterbelts were established in the past 40–50 years. In addition to the market value of their function, they also have non-market values such as conservation, landscape protection and retention of the ethnic significance of shelterbelts and farming methods. Some native shelterbelt tree species like *Pyrus pyraster* (L.) Baumg, recent invasive species such as *Prunus serotina* (Ehrh.) Borkh. and, for example, windbreak trees like sensitive *Populus alba* L. play an important role in this context.

Two representative windbreak systems were surveyed and studied between 2003 and 2006. The aim of this was to identify the changes over recent decades and analyse the future possibilities for regeneration, expansion, etc. The examples chosen were established after Soviet models and are representative of how the fields and forest strips complement each other.

The first example was a 17 ha windbreak system in Sopronhorpács (30 km south of Sopron), started in 1949 and finished in 1960. These belts protected 12 km^2 of land and crops (sugar beet, corn, etc.) against the wind. Some areas such as marginal hedgerows or in-row planted scrubs also functioned as snow-fences. Originally this system was called “experimental forest-belt system”, which served the local Agriculture Research Institute for 40 years. The main species planted are *Acer* sp., *Quercus* sp., *Fraxinus* sp., *Tilia* sp. and *Robinia pseudoacacia* L. The commonest shrubs are *Rosa* sp., *Lonicera* sp., *Ligustrum vulgare* L. and *Maclura pomifera* (Raf.) C. K. Schneid. Some relatively rarely used species like *Gleditsia triachantos* L. or some *Salix* and *Populus* species were included to see how they would perform. From records and their present function it can be concluded that the desired aims of these belts, i.e. soil-, crop- and snow protection, were very successfully achieved. After a complete structural and silvicultural analysis, management in the near future should include thinning, replacement, regeneration and possible expansion of the length of these windbreaks (Takács 2003).

The second example was at Sarród-Nyárliget (Fig. 21.2), an area with a spacious shelterbelt, windbreak-network planted to protect the organic, boggy meadow soils on the eastern side of Lake Fertö. There is an area of 10 km^2 protected by 13 ha of forest-belts. These belts are mainly made up of species of genus *Populus*, *Quercus*, *Acer*, *Tilia* and *Ulmus*. Similar to the Sopronhorpács example, the spacing of the trees is 2 (3) m interrow and the plant-to-plant distances are 1–4 m, depending on the number of rows and local conditions. There are 30 forest-belts which influence the local rural landscape and have the widespread function of soil protection (Pintér 2003).

The same silvicultural tasks as in the previous experiment, thinning and regeneration, were necessary and the same functions of soil, wildlife and crop protection were fulfilled. Such shelterbelt systems (or at least their remains) can be found all over Hungary. It is in everyone's interest to explore, conserve and regenerate, these forgotten or scarce shelterbelt systems.

Windbreaks are beneficial in decreasing the speed of wind and in this way dissipate the active energy of soil- and snow-elements. When there are very strong winds from a typical direction, accompanied by a lot of snow, the effectiveness of the windbreaks is also reduced. Even one or two rows of a hedgerow can allow a considerable amount of an occasional 6–10 cm snow-fall when the wind-speed is 4–20 km h^{-1}.

The most complex a barrier to the wind's flow and direction, the better the expected result. The turbulence caused by the jointed structure will change the movement of the wind-vectors, the energy of transported snow and, deposit snow

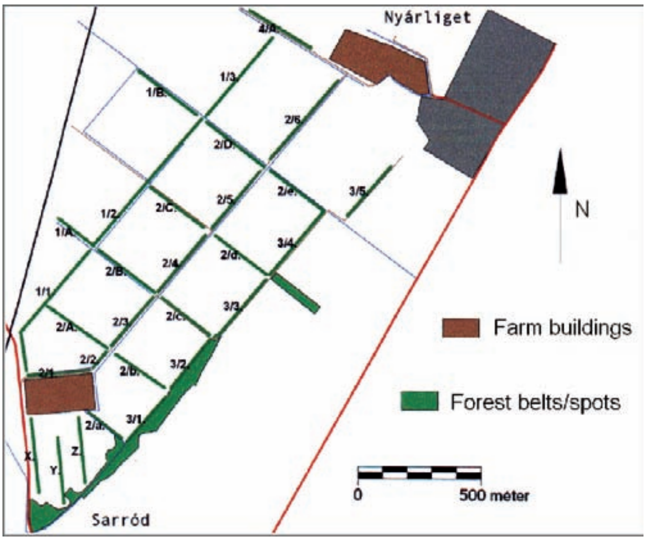

Fig. 21.2 Windbreak and shelterbelt network system at Sarród

on the lee side of the belt in the area between the windbreak and a row of trees or in a ditch between the row and the road (Ivelics and Takács 2006).

These windbreak-plantations can be combined with short-rotation linear tree energy plantations, which can be established on agricultural areas at adequate row- and stem-spacing. With fast-growing species such as hybrid poplars, osiers, black locust, plane or ailanthus planted on a 3-years rotation, yields of 15,000–20,000 kg ha^{-1} DM year^{-1} are possible on first class sites.

A suggested planting (T) and harvesting (B1, B2) model of a four row wide forested belt is shown in Fig. 21.3. The second two rows (B2) would be planted after 1 year, to strengthen the first two rows (B1). The first harvesting period is year 4–5 and regeneration will be needed after the second harvest, 7–8 years after the establishment of the belt.

It is recommended to plant and establish energy plantations for snow-shields with twin-rows. Due to the harvest-technology, the two twin-rows should be planted 1 year apart. This assures continuous coverage and more structural and three-dimensional variation in the levels and effectiveness of the windbreaks.

Replanting is only required after five to six harvesting periods, because the plantations maintain their capability to regrowth quickly for 15–20 years. Efficient and economic harvesting machines are available to harvest these short-rotation plantations. Such plantation-like-windbreaks could help the economic viability of agricultural areas and promote the development of the countryside. The energy crop material out of these belts should be a source of production based on renewable energy.

In addition, the windbreaks would not lose their original functions, as shortly after planting they will be providing protection against snow and wind in agricultural areas.

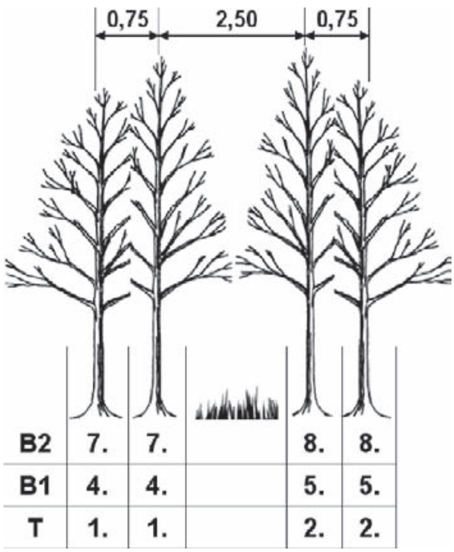

Fig. 21.3 Biomass production cycle in a forest-belt

The extraordinary snow-falls in recent years have taken road users and road maintainers by surprise. West-east snow-drifts mainly were reblown back into the road after they had been initially cleared. Features across and along the road such as ditches, traffic signs, trees, etc. consolidated the snow drift on the road in the absence of other snow-shield objects. For example, in Györ-Moson-Sopron county the officially recorded windbreaks are on 36 ha with 17 km of protected road-length (Takács and Ivelics 2005).

The road network of Györ-Moson-Sopron county is well distributed, mostly in a north-south orientation. The borders, the border crossing points and the two big cities (Györ and Sopron) influenced the radial and diagonal "distortions" and various road network directions. The main road network has 472.3 km of motorways and priority roads. Most of the roadside verges were planted with tree- or shrubs rows. As would be expected, there are several roads protected by old or newly planted forests, but unfortunately windbreak planting is infrequent in the county. Some of the major snow catching shelterbelts are at an age where they must be cut down and replanted to ensure continuity and traffic safety. In parallel with the development of the road network, it is necessary to integrate the landscape elements by connecting the man-made elements with those that have biological value.

A survey to estimate the tree species and windbreaks on roadside sites was carried out to investigate the old management system and give new guidelines on regeneration and planning of tree rows and other green belts along roads in collaboration with the road maintainers and the neighbouring farmers.

As well as being of aesthetic value, the traditional functions of roadside trees are to protect the outline of the road and lend structure to the area by delimiting land plots (fields) or other features, thereby naturally enhancing the landscape. They also improve traffic safety and protect the traffic against wind and snow.

To describe new structures and methods, it is necessary to define species suitability and the framework within which they will be planted. In recognition of the change in need and emphasis for shelterbelts more importance must be assigned, for example, to improved traffic and road safety. This can be done by comparing the actual conditions to the standards which were laid down some time ago. In light of all previous knowledge and experience roadside tree management (including regeneration) could be planned in a modern way involving decision support mechanisms and a systematic approach (Takács 2005).

Areas suitable for new afforestation are being reviewed to meet recent objectives. The potential areas for establishment of new plantings, windbreaks, shelterbelts and farm-forestations are the elements of the network. Potential sites for shelterbelt systems can be planned at a country level by setting down selection and designation criteria and by using geographical information systems (GIS), based on the digital maps, aerial photos, satellite pictures, State Forest Service and other databases. These territories should be areas of land which can be utilized for this aim and adequately meet the protective functions of the forests. On suitable sites the aim is to match conditions and expectations as much as possible.

In addition to the well-tried, traditional species there are some problematic, aggressive, spreading species such as black locust (*Robinia pseudoacacia* L.), black cherry (*Prunus serotina* Ehrh.) or Manitoba maple (*Acer negundo* L.). There is also the opportunity to plant other windbreak species such as *Populus nigra* 'Italica', replacing snow sensitive species currently growing on the road margins (ornamental or old trees, *Celtis occidentalis* L.). To minimise the ravages of diseases, like horse chestnut leaf miner (*Cameraria ohridella* Deschka & Dimic) or *Lymantria dispar* L. and risks from other potential problems mentioned above, a good structure and healthy conditions need to be ensured. Most of the roadside (alleys and windbreak) trees will reach their felling age (50–90 years) in 10–20 years, as shown in the poplar rows in Fig. 21.4. It is necessary to formulate special management protocols which would not disturb the traffic or agriculture. This will help preserve the existing natural habitats and the marginal semi-natural areas by ensuring continuous coverage with gradual regeneration.

Those responsible for the management of the road trees and forest belts should be aware of their responsibilities and road maintainers must be give the necessary up-to-date technical training to maintain and manage regeneration and planting of new rows. The integration of forestry and other contractors, into roadside management should be considered.

There is plenty of literature on forest regeneration in Hungary, but little relevant to roadside trees and forest belts. It is not known how these green rows of trees and silvopastoral sites will be regenerated. To reach the strategic forestry goal, i.e. increasing forest cover to 25–27% by planting 15,000–18,000 ha year^{-1} these issues will need to be addressed over the next 5–10 years.

Fig. 21.4 Roadside poplar rows in GYMS-county

The present agriculture and forest policy must comply with EU directives and there must be redefinition of EU classifications to accommodate the unique forestry and agriculture land use types found in Hungary.

Alley Crops and Silvopasture

In the past, agroforestry systems were managed without the use of fertilizers, just using the high nutritional values of forest soils and decades of continuous grazing and animals returning to the sites. Despite their efforts, the fertility of these areas was reduced, they lost nutrients, the composition of plants was affected, mainly the sensitive plants in the undergrowth, and weak trees were shadedout by unmanaged forestry development.

Intertilled crops were grown in forests and used for cropping and seedlings. In the first year buckwheat (*Fagopyrum esculentum* Moench) was planted, followed by spice-producing plants, potato and corn in the second year, and when in the third year canopy growth was too dense to permit agricultural use.

In an area designated for forestry, after 2 or 3 years, tree seedlings started to appear. If saplings are extensively planted in the clearcut areas of seedling-forests, agricultural crops could continue to be grown in rows beneath the trees until the 5th–8th year when the seedlings had grown enough to shade them. This leads to a so-called “woody agriculture”, a form of agroforestry.

Because of the paucity of countryside pastures or this unfavourable use, it was common to graze the undergrowth and clearings in forests. These areas derived from fallows, stubbles or meadows after harvesting, and primary grazing fields (forest-grasslands). Forest grazing must always be carefully managed because if it is not at the right time (e.g. avoiding bud sprouting) and place, it can cause serious damage.

Forest grazing was a common practice in the 19th century, opening up closed forests, and allowing grass to grow under the canopy and in clearing. The main tree types in such forests were vörösfenyö (higher regions), oaks, chestnut, wild fruit-trees. The fodder value of forest grazing was approximately one quarter of that from meadows.

Currently people realize the need for official control and regulation of the relative potentials of grazing land both in forests and meadows. They are aware of the reduction in nutritional value of swards, the slowing-down of the humus producing process, erosion, deflation, compaction of soil, forest renewal, declining water supply to households and problems with the abiotic components of the landscape. Cattle created less problems than goats, sheep and horses.

Pannage is the grazing of beech mast and oak acorns with pigs from the end of September until the new year or later. Scarifying the forest cover leads to a rich and balanced acorn-crop. However, regeneration from acorns is almost impossible, not because of the lack of acorns; it is just because of the compaction and digging of animals searching for acorn, roots, snails and other edible material (Benkovits 1956).

However, traditional forest grazing has nowadays almost disappeared. There are no more shepherds or competent people and the area of grassland has declined. The role of pastures has declined against the use of stock-yards. Meadow and grassland management is localized into small scale areas for producing quality green forage. There does, however, seem to be hope for renewing old traditions under the newer type of ecological management which is becoming more common in Hungary. There is now the possibility of re-discovering the facilities of forested grasslands and developing them into agroforestry systems.

Grassland Afforestation

Afforestation on grasslands with forested plots and regular plantations can add additional value to the grassland ecosystem. In some cases this is the only way to maintain a meadow on which species like negundo (*Acer negundo* L.) or black locust (*Robinia pseudoacacia* L.) can spread. At the same time, trees on grassland will help soil protection, prevent waterlogging, desiccation from wind and sunshine and protect grazing animals against the harmful effects of the weather. Figure 21.5shows fenced pastures in the Fertö-Hanság and Örségi National Park area near Sarród.

Tree species for grassland afforestation should be grown rapidly under the site conditions and complementary species would be wind-proof deciduous and

Fig. 21.5 Trees protecting pasture near Sopron

coniferous species. Scrub and low-growing species could also form edges. Physical protection is best obtained from spiny, pickly species like honey-locust (*Gleditsia triacanthos* L.) and blackthorn (*Crataegus monogyna* Jacq.).

Stock-farming or plant-growing with supplementary trees, forest plots or shelterbelt can give enhanced yields due to the protection offered by the trees, a good example of multi-functionality. When agriculture activities are introduced into forests, every effort should be made to have minimal effect on the ecology of the forest. When planting trees such as birch, poplar, maple or pines into grasslands the correct grazing density of livestock must be chosen.

From experience, multifunctional forest management or agriculture is needed where the natural resources are so reduced, that the farmers have no other choice. If areas that need similar management are integrated, all the potential benefits can be obtained from the interaction of forestry and agricultural species.

Future Perspectives of Agroforestry Systems in Hungary

Tree species which are native (*Quercus* spp., etc.), tall, shading (*Tilia* spp., *Acer* spp., etc.) and/or fruit-producing (*Pyrus* spp., *Prunus* spp., etc.) have a key role to play in the development of agroforestry systems in Hungary. Treatment, management plans and directives need to be specified to: (a) remove windbreak-sensitive species (*Populus* spp., etc.) (b) suppress aggressively spreading introduced species (*Prunus* spp., etc.). However, some introduced species could be useful as natural barriers and for fencing (*Maclura* spp., *Gleditsia* spp., etc.). From currently available information, the most appropriate, shelterbelt types and pasture or crop tree planting patterns should be chosen to suit the particular site conditions and end use.

Shelterbelts containing the slower-growing species (these are usually not classified as forest area), are suitable for grazing if they are thinned to a wider-spaced structure which benefits the pasture. They can be located on agricultural lands, mostly close to livestock-farms, and animals can graze the herbaceous layer, the main ground cover vegetation. The tree spacing (2–3 m interrow and trunk spacing) facilitates cultivation and grazing.

The issues are how silvopastoral systems can contribute to the expansion of the Hungarian forest area and how can silvopastoral systems be integrated into the restructuring of existing shelterbelts or the establishment of new shelterbelt systems.

To address these issues the available resource must be quantified.

Combining forestry use and grazing on the same land base (silvopastoralism), allows a range of objectives such as multipurpose use of forest, timber and forage processing, landscape protection, protection from wind, revitalization of traditions or rehabilitation of individual farms to be achieved (Takács and Frank 2005).

Since accession to the EU the present agricultural policy has had to adapt to a certain set of common standards. One of its main policy elements is the utilization of particular agricultural areas for afforestation. It is proposed that about 700,000 ha of land currently in arable crops could potentially be converted to agroforestry.

Planting new forests with grasslands are a potential alternative way to use land in areas of poor productivity and arable lands with unfavourable site conditions. Based on research by the Hungarian State Forest Service, the potential area recommended for change of land use is 683,900 ha of arable land, 56,100 ha of pasture and 38,300 ha of meadow. From this area it is suggested that an area of 174,000 of afforestation be earmarked for the 2001–2010 period. It is necessary to study how the establishment of silvopastoral systems fits this concept.

These areas should have a tradition of farming, should be suitable for tree growing, should be suited to this type of land use and adequately perform the necessary soil protection and other ecosystem functions. Suitable sites will meet as many of these conditions as possible. Our research is at the stage of defining categories and conditions by studying a chosen sample area in the northeast of Hungary where data and information are available from the past 60 years both in agriculture (livestock, forage, weather) and forestry (forest, shelterbelts). To help draw up a viable proposal, a land owner can apply to different forums like the government, ministries and others funds for agricultural development and forestry (afforestation) grants to help develop the proposal.

Proposed structural changes in Hungary's agricultural policy, as a result of EU membership, will increase the economic objectives of afforestation and take into account wind-farming, landscape- and settlement-protecting functions of forests. The range and importance of these alternative land use options will expand. After the survey, long term planning must occur with a goal of increasing the rate of forest protection. The full potential of the land structures should be exploited based on past experience. Further research and involvement of all interested parties will be essential for optimal land use.

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Future Directions of Agroforestry in Europe

M.R. Mosquera-Losada[1], J.H. McAdam[2], and A. Rigueiro-Rodríguez[1]

The main direction of current research on Agroforestry systems in Europe has been summarised in this book. These have included general descriptions of the different areas where there are good examples of how agroforestry practices are currently being implemented or could be implemented from farm to landscape level and, as a land use option, at a local level. The book has four sections, each providing a synthesis of the information for each of the four biogeographic regions. This structure was chosen because temperature and precipitation (quantity and distribution) will determine the opportunities for agroforestry systems in the different regions of Europe. Most of the recommendations from the Orlando Declaration (2004) on agroforestry following the 1st World Congress of Agroforestry and the Declaration published in the Silvopastoralism for Sustainable Land Management Conference (Mosquera-Losada et al. 2005) are valid within the European context. However, there are several aspects that need improvement at a research, education and policy level.

In the **research** context, this book summarizes production, environmental and social aspects of research on agroforestry systems. Government-funded trials have been carried out over the past 20 years in different countries. Recently, SAFE (Silvoarable Agroforestry for Europe), a European Union (EU) funded project (Dupraz et al. 2005) has given an integrated European dimension to the study of some types of agroforestry systems. Results of research in Europe into agroforestry have been published in the proceedings of numerous European Congresses concerning agroforestry. These have been organized by: (1) INRA (Institute National de la Recherche Agronomique, France) and coordinated by M. Etienne (1996) (2) A major EU-wide silvopastoral network was funded by the EU (AIR CT92-0134 contract) and, a congress was held in Montpellier, France in 1997 (Auclair and Dupraz 1999). (3) the European Grassland Society and Coordinated by V. Papanastasis

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A. Rigueiro-Rodríguez et al. (eds.), *Agroforestry in Europe: Current Status and Future Prospects*.

et al. (1999) (4) organized by the EU in collaboration with FAO (Food and Agriculture Organization) and EFI (European Forest Institute) and coordinated by M.R. Mosquera-Losada, J. McAdam and A. Rigueiro-Rodríguez (2005). At these meetings partners participated from all over Europe and this facilitated the interchange of ideas and research findings from different countries of Europe. United Kingdom, France, Greece and Spain have created agroforestry research networks at country levels. The first of these was the UK Agroforestry Research Forum (now the Farm Woodland Forum), from which grew two multi-site co-ordinated silvopastoral and silvoarable research trials. The results from these have helped to persuade policy makers of the value of such systems at a broad scale in Europe, and the Council Regulation to support rural development by the European Agricultural Fund for Rural Development (EAFRD) (EC 2005) included a specific direct payment for the establishment of this kind of systems at a European scale.

However, agroforestry practices are more complex land use systems than exclusively forestry or agriculture (Nair et al. 2008). As with forestry, long term studies are very important and must be implemented to develop systems to encourage both tree growth and to promote synergies with the agricultural component. These synergies and interactions help such systems deliver environmental and social benefits. Some networks have been established, but more coordination within and between different European countries and at a European scale is needed. The interactions of trees and crop production in the different biogeographic regions should be widely evaluated across a range of land types. The overall aim should be to develop models which allow farmers to make decisions on the real options for cropping, and to underpin the development of policy to encourage appropriate support measures. More specifically, field and laboratory studies should be carried out to understand the synergy between the components of agroforestry systems from productive and environmental perspectives. Aspects related to environmental benefits (mainly nutrient cycling, carbon sequestration, biodiversity and landscape enhancement) should be evaluated on a broad scale, taking into account the different biogeographic regions in Europe.

Studies on traditional management should be carried out to preserve traditional knowledge of historic and culturally significant practices and to improve and sustain these through the implementation of new agroforestry techniques. An evaluation of biofuel production and bioenergy generation as valid components of agroforestry systems should also be carried out. There is a clear need for knowledge of forest farming practice, and research is urgently needed on sustainable cultivation techniques for farmers to increase rural farm profitability. Agroforestry practices such as silvoarable, riparian buffer strips, improved fallow and multipurpose trees should be evaluated as whole agroecosystems, studying the agricultural and forestry components as well as their interactions and the ecosystem services they deliver.

To facilitate the implementation of agroforestry **policy**, the common message from this book is that no reliable and easily generated statistics exist on agroforestry systems. Cultural, social and regional differences in the collection of statistics on land use make it impossible to extract data on agroforestry systems in all European countries. Land use systems depend on climate and data should be collected at a European scale that enables different datasets to be aggregated for distinct climatic regions. It is accepted that data is usually given on a national scale, without taking into account the fact that most important European countries have their lands allocated in different biogeographic regions, and this makes it even more difficult to compare. The historic perspective is even more difficult to follow. As the list of countries which make up the European Union has changed over time, comparative statistics on the main forestry and agricultural land uses are even more difficult to obtain. Finally, statistics related to forest or agrarian land use is usually collected separately, making it impossible to deduce information on the degree of the interaction between these two major land-use types. These should be the basis for statistics on agroforestry practices and the best way to understand landscape management. An effort should be made to correct this to have more accurate figures on the implementation of agroforestry in Europe, especially to act as a baseline to assess the impact of European Rural Development Measures on agroforestry. The inclusion of a common climatic classification would facilitate extraction of data from climatic zones and across national boundaries.

Researchers should evaluate policy instruments and test agroforestry systems based on the new Rural Development Regulation, to improve them and underpin the recommendations to policy makers at a regional scale with sound, systems-based science. To help advance this position, the Farm Woodland Forum in the UK, is currently evaluating, the specific policy measures extant in different regions of Europe derived from the new regulation on Rural Development policy.

It is also very important to develop agroforestry **education** at different levels. Farmers should be given sufficient information on systems to help them make informed decisions on the best and most sustainable land use options for their farms. This is best done through a technology transfer process involving demonstration plots, publications, leaflets or web–driven "toolboxes" to help the farmer decide on the best option, taking into account individual circumstances, profitability and best practice. Agroforestry should be included as part of forestry and agricultural degree courses at third level education. The synergy between these two components (tree and crop) is not usually studied by the future foresters and agriculturalists. This lack of integration and broad knowledge-base will make it difficult to develop the expertise necessary to disseminate information on these systems to potential growers in the future.

It is important also that this information is delivered in a truly informed, authoritative and enthusiastic fashion to help agroforestry be considered as a viable land use option alongside the more conventional areas of farming and forestry. An agroforestry international course funded by the European Union (within an ERASMUS project) has recently been approved to be held in Spain, where agroforestry systems dealing with the Atlantic and other biogeographic regions will be taught. The course will be held in 2008 and teachers and students from different countries of Europe will participate.

Throughout this book, the implications of agroforestry systems on land management in Europe have been evaluated and found to address some of the key issues affecting rural prosperity. These include farm profitability, rural abandonment, recreation, security of products, animal welfare, the environment, ecosystem service delivery, fire control, nitrate leaching, carbon sequestration, biodiversity, land conservation social aspects, landscape management. The clear message emanating from this book is that more work needs to be done to promote the realisation of benefits of agroforestry at a broader European level in the fields of research, policy and education.

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