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Abstract

Wood-pastures are complex social-ecological systems that host multiple values and provide a wide range of ecosystem services. However, their current management in Europe is shifting from traditional towards more intensive farm models while wood-pasture surface is declining throughout the continent. The thesis systematically reviews how the ecosystem service framework has been used to assess European wood-pastures and other agroforestry systems and the outcomes these assessments have achieved. Further, based on a specific wood-pasture dominated landscape in the Southwest of Spain, diverse biophysical and sociocultural approaches are employed to assess ecosystem service supply at the farm and landscape scales. All previous work is integrated into a cross-site social-ecological analysis of ecosystem services supply and trade-offs in four distinctive oak-based wood-pasture dominated landscapes across Europe (Östergötland in Sweden, Southern Transylvania in Romania, Llanos de Trujillo in Spain and La Serena in Spain).

The thesis provides an understanding of the dynamics and mechanisms interacting in the generation of ecosystem services in European wood-pastures, and the factors that govern this supply. The results show that wood-pastures offer a wide range of ecosystem services, which is due to, on the one hand, the high multifunctionality that characterizes them and, on the other hand, the multiple socio-cultural values they host. However, the specific interactions between the social and ecological components and their outcomes rely highly on the place-based and context-related properties of the social-ecological system. There is potential to design sustainability policies that foster and promote the values of wood-pastures in Europe. To do so, a holistic and transdisciplinary approach is needed that considers the complexity of the system and goes beyond simplistic win-win assumptions, while allowing flexible policies that can be adapted to the different and changing regional contexts.

Keywords: Ecosystem services; wood-pastures; ecosystem services trade-offs; social-ecological systems
English Summary

Wood-pastures are complex social-ecological systems, consequence of a long-term interaction between society and its surrounding landscape. In Europe, wood-pastures are considered as archetypes of multifunctional landscapes and high nature value farming systems due to the rich natural and cultural values they contain and the multiple ecosystem services they provide. However, current management is shifting from traditional towards more intensive farm models, while the total area of wood-pasture is declining throughout Europe.

This thesis explores and analyzes the mechanisms and processes driving ecosystem service supply in European wood-pastures. In the first part of the thesis (papers I and II), the scientific literature was systematically reviewed to assess how the ecosystem service framework has been applied to European agroforestry systems and to identify the outcomes of these assessments. The results were used to identify the generality of existing case-study findings and the presence of large scale patterns; to detect methodological, theoretical and knowledge gaps, and; to provide insights into future research on European agroforestry.

In the second part of the thesis (papers III and IV), the focus was on a specific wood-pasture dominated landscape in the Southwest of Spain, where diverse biophysical and sociocultural approaches were employed to assess ecosystem service supply and demand at the farm and landscape scales. First, through semi-structured interviews with wood-pasture owners and managers, the relationship between ecosystem service provision and wood-pasture management was explored, which identified trade-offs and bundles of ecosystem services. Special emphasis was put on the influence of farm size, land tenure, vegetation structure diversity and wood-pasture accessibility policy on landowners’ management decisions. Then, a public participation GIS approach was used to map the spatial distribution, patterns and intensities of ecosystem services perception by local inhabitants. These were used to explore the differences between different groups of inhabitants, as well as to identify the linkages between how landscape is used and perceived, and the influence of the former on subjective well-being.

In the last part of the thesis (paper V), all previous work was integrated into a cross-site social-ecological analysis of ecosystem services supply and trade-offs in four distinctive oak-based wood-pasture dominated landscapes (Östergötland in Sweden, Southern Transylvania in Romania, Llanos de Trujillo in Spain and La Serena in Spain). A differentiated pattern of ecosystem service supply was found in the four study areas, which is governed by four main wood-pasture management dimensions that generate trade-offs of ecosystem services. It was further demonstrated that decisions concerning these management dimensions are determined by complex interactions between the properties of the social-ecological system, which have a direct influence on managers’ perspectives and motivations.
Resumé (Danish summary)

træbevoksede grænssenge er komplekse social-økologiske systemer, som er et resultat af et langsigtet samspil mellem mennesket og det omgivende landskab. De træbevoksede grænssenge i Europa betragtes som arketyper af multifunktionelle landskaber: Det er landbrugssystemer af høj værdi på grund af det rige natur- og kulturindhold, som tilvejebringer en mangfoldighed af økosystemtjenester. Imidlertid er forvaltningen af træbevoksede grænssenge ved at skifte fra traditionelle til mere intensive dyrkningssystemer, samtidig med til at arealet af træbevoksede grænssenge er faldende i hele Europa.

Denne afhandling undersøger de mekanismer og processer som driver tilvejebringen af økosystemtjenester i de europæiske træbevoksede grænssenge. I den første del af afhandlingen (paper I og paper II), gennemgår aktuel litteratur systematisk for at vurdere, hvordan økosystemtjeneste-begrebsrammen er blevet anvendt i relation til europæiske skovlandbrugs-systemer (agroforestry systems). I denne del af afhandlingen samles fællestæk fra casestudier og generelle månster fremhæves. Desuden identificeres metodiske og teoretiske videnshuller inden for området, og giver på den baggrund indsigt i fremtidige forskningsindsatser.

I anden del af afhandlingen (paper III og paper IV) er fokus på et specifikt landskab i det sydvestlige Spanien domineret af træbevoksede grænssenge. Her er anvendt forskellige biofysiske og sociokulturelle fremgangsmåder, for at vurdere tilvejebringen af økosystemtjenester både på landbrugsskala og på landskabsskala. Dette er gjort gennem semistrukturerede interviews med græningsarealernes ejere og driftsledere, hvor sammenhængen mellem leveringen af økosystemtjenester og arealernes forvaltning blev udforsket, herunder identifikation af tjenesternes indbyrdes trade-offs og grupperinger af økosystemtjenester (ecosystem services bundles). Der er i analysen lagt særlig vægt på hvilken indflydelse ejendomsstørrelsen, ejendomsretslige forhold, vegetationsstruktures diversitet og adgangsforhold har på driftsledelsesbeslutningerne. Derefter er der anvendt en borgerinddragende GIS-metode (PPGIS) til at kortlægge den rumlige fordeling og månster af økosystemtjenester samt undersøge forskelle og ligheder i hvordan lokalbefolkningen opfatter de forskellige økosystemtjenester. Endelig er der identificeret, hvilke relationer der er mellem hvordan landskabet bruges og opfattes, og hvilken indflydelse det har på den individuelle trivsel.

I den sidste del af afhandlingen (paper V), er gennemført en integreret social-økologisk analyse af tilvejebringen af økosystemtjenester og trade-offs på tværs af i fire europæiske landskaber domineret af egetræbevoksede grænssenge (Östergötlands län i Sverige, det sydlige Transsylvanien i Rumænien, Llanos de Trujillo i Spanien og La Serena i Spanien). Der blev fundet et differentieret mønster af tilvejebringen af økosystemtjenester i de fire casestudieområder underlagt fire dimensioner af forvaltningsmål for træbevoksede grænssenge. Det blev endvidere påvist, at beslutninger relateret til disse forvaltningsmålsdimensioner bliver bestemt på baggrund af komplekse interaktioner mellem det social-økologisk systems egenskaber, hvilket har direkte indflydelse på driftsledernes perspektiver og motiver.
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Having finally finished this intense phase that has been my PhD, I find often myself thinking back to my first months in Copenhagen in the spring of 2014, and reviewing the plans and personal objectives I had at that time. The result is a huge attack of nostalgia together with a feeling of satisfaction over all the experiences I have had, all the people I have met and all the places I have visited. I am sure I will always treasure this period as one of the happiest of my life. There are many people to whom I am grateful for making it like this.

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My final words go to Juliane, without whom everything would have been much more difficult and much less fun.
List of scientific publications

This PhD thesis has been carried out as a compilation of five scientific papers, which are consolidated in this synthesis. Papers I, II, III and IV have been published in peer-reviewed journals, while paper V was recently submitted (Oct. 2017). All papers are included at the end of the thesis as an appendix (see Papers I – V).


The publications are referred to in the text by their Roman numerals.

Relevant additional publications conducted through the PhD

- Pleninger, T., Torralba, M., Hartel, T., Fagerholm, N., 2017. Ecosystem services synergies, trade-offs, and bundles in European high nature value farming landscapes. (Manuscript ready for submission).
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1. Introduction

European Wood-pastures

Rural landscapes have undergone severe transformations since the second half of the 20th century (Foley et al., 2005; Tilman et al., 2001). In Europe, the trend has been a general process of homogenization and fragmentation of the landscape (Jongman, 2002) due to, on the one hand, a general intensification of agricultural practices (Donald et al., 2001; Stoate et al., 2001) and, on the other hand, large scale abandonment of less productive agricultural areas (MacDonald et al., 2000; Stoate et al., 2009). As a consequence, the economic, socio-cultural and ecological sustainability of traditional agroecosystems is being challenged, which poses a major threat to the conservation of the rich farmland biodiversity they host (Halada et al., 2011; Oppermann and Beaufoy, 2012) and the multiple ecological processes these systems sustain (Kragt and Robertson, 2014).

Multifunctional agricultural land-use systems, such as agroforestry, which is defined as the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal production to benefit from the resulting ecological and economic interactions (Mosquera-Losada et al., 2009), have been proposed as a potential strategy to advance rural development and maintain production, while preventing the current trends of ecosystem services degradation (Jose, 2009; Primdahl et al., 2013; Rigueiro-Rodríguez et al., 2009). Agroforestry has been widely adopted in different regions of the world (McAdam et al., 2009) and has a long history of land-use in Europe, where it represents one of the most characteristic elements of European landscapes. There are many types of agroforestry systems in Europe including silvoarable systems, forest farming, riparian buffer strips, improved fallow, multipurpose trees and wood-pastures (Mosquera-Losada et al., 2009). Of these, wood-pasture is the most abundant agroforestry system in Europe (Nerlich et al., 2012; Plieninger et al., 2015) and likely the one with the longest history of land-use (Jørgensen and Quelch, 2014; Vera, 2000).

Wood-pasture is the practice of combining trees with forage and animal production. These systems have been part of European rural landscapes for a long time and as such, they are known regionally and sometimes locally by multiple names across Europe (e.g. dehesa in Spain, montado in Portugal, Streuobst in Germany, Lövängar in the Baltic countries) (Bergmeier et al., 2010). Throughout this thesis, the term wood-pasture is used as a unifying term to represent all types of European grazing systems on semi-open pastures. Despite this etymological diversity, these systems share several common characteristics. Wood-pasture management is traditionally extensive in terms of external inputs and it is highly multifunctional in that it combines animal production with small scale cereal production (mostly to produce animal fodder), the extraction of forest products (e.g. fruits, firewood, cork), honey production, the provision of habitat for game, and other recreational activities. The physiognomy of wood-pastures varies greatly across Europe, but commonly shared features include the existence of trees at various densities across a landscape that is managed mostly for livestock grazing (Bergmeier and Roellig, 2014). The specific composition of trees and grazing animals that form the wood-pasture is very diverse. For example, Bergmeier and Roellig (2014) identified a total of 21 different wood-pastures in Europe, which differ in terms of the dominant trees and animal species, the most common set of commodities produced and the natural vegetation accompanying the system. Of these 21 types, oak-based wood-pastures are the most common, with Quercus species occurring in 15 of the identified types. In North, Central and Eastern Europe the most common oaks are broadleaf
species such as pedunculated oak (*Quercus robur*) and sessile oak (*Quercus petrea*), while in the Mediterranean basin the dominant species are evergreen oaks such as holm oak (*Quercus ilex*) and cork oak (*Quercus suber*). Tree density also fluctuates in European wood-pastures, sometimes even within the same region (Roellig et al., 2016), usually as a result of the role the trees play in the system and the grazing intensity (Moreno et al., 2013). The density usually ranges from 20 to 100 trees per hectare (Moreno and Pulido, 2009), with a minimum of 4 trees per hectare (Hartel et al., 2013) and a maximum of more than 200 trees per hectare (Jakobsson and Lindborg, 2015; Roellig et al., 2016). Regions in Europe with increased interest in forestry resources will commonly present wood-pastures with lower grazing pressure and higher tree density. This is the case in, for example, the Portuguese montados or Fennoscandinavian wood-pastures, where cork and wood, respectively, play a relevant role in the farm economy. In contrast to this model, Spanish dehesas or Romanian wood-pastures maintain a lower density of trees, which maximizes pasture production (Moreno et al., 2013).

Most commonly, wood-pastures were formed by the process of clearing the natural vegetation and then maintained by introducing animals that prevent the regrowth of the natural vegetation (Bergmeier et al., 2010). At the same time, livestock help to reinvigorate nutrient cycles and improve the fertility of the soil (Moreno and Pulido, 2009). If the animal density increases above a certain threshold, the soils become degraded, tree recruitment is prevented and the nutrient cycles are altered. On the other hand, if the stocking density falls below a threshold, the natural vegetation will regrow and pastures may be encroached by shrubs. Therefore, the system depends on continuous human intervention (Bugalho et al., 2011). Trees, besides providing a range of subsidiary resources (e.g. firewood, cork, charcoal), are a key source of supplementary fodder. Moreover, trees generate a microclimate that provides shelter and reduces the impact of extreme temperatures (Fig. 1). In warm regions such as the Mediterranean, this microclimate also allows the pasture to remain productive for longer during the summer drought.

![Figure 1](image-url). A flock of sheep sheltering from high temperatures under an oak in Buneşti (Romania). Picture taken by Mario Torralba.
Wood-pastures are ecosystems that host high levels of biodiversity. These values are favored by the high spatial heterogeneity provided by the different vegetation types present in the system. In combination with the low-input and highly diverse management practices, this variability generates a variety of niches that provide habitat, which is exploited by numerous species (Bugalho et al., 2011; Moreno et al., 2016). Increased levels of biodiversity in European wood-pastures have been repeatedly found for numerous groups of species in multiple regions of Europe (Bergmeier et al., 2010; Buttler et al., 2009; Díaz et al., 2013; Dietz et al., 2013; Hartel et al., 2014; Hartel and Plieninger, 2014a; Jakobsson and Lindborg, 2017, 2015; Pereira et al., 2012). Biodiversity is further enhanced by some landscape elements which are commonly present in wood-pastures, such as large hollow or dead-standing trees (Manning et al., 2009). These trees are often not removed, making of them a suitable host for several species of lichens, fungi and insects (Grüebl et al., 2013; Manning et al., 2006). For example, this is the case for the hermit beetle (Osmotherma eremita), an endangered red-listed saproxylic beetle that maintains most of its population by dwelling in the large hollow oaks present in the declining wood-pastures and oak woodlands located in the southern part of the European Boreal region (Ek and Johansson, 2005).

Equally important are the socio-cultural values of wood-pastures. Many of the current elements present in wood-pastures are legacies of former management with high spiritual and cultural value (Fischer et al., 2010; Manning et al., 2006; Milcu et al., 2014). Wood-pastures also conserve important local-ecological knowledge as part of the traditional practices, which are often essential for the maintenance of the ecological processes of the ecosystem (Babai and Molnár, 2014; Dörrestréjn et al., 2013; Oteros-Rozas et al., 2013).

**Extent of wood-pastures in Europe**

Wood-pastures represent some of the most characteristic rural landscapes in Europe. Plieninger et al., (2015) recently used the European geo-referenced photo-interpreted database LUCAS to calculate the extensiveness of European wood-pastures. The authors found that wood-pastures cover approximately 203,000 km², which equates to around 4.7% of the total area of the EU27. However, wood-pastures are not equally distributed across Europe, with larger extensions along the Mediterranean basin and Eastern Europe and lower presence or absence in large parts of North and Central Europe (Fig. 2).

In former times wood-pastures were one of the most abundant types of woodland in Europe (Rotherham, 2013). Some authors, such as Vera (2000), trace the presence of these landscapes in Europe back to pre-Neolithic times, when grasslands would have alternated with broadleaf woodlands. As an agricultural system, it has been used for grazing for at least 6,000 to 7,500 years (Grove and Rackham, 2001), playing a key role in almost every European culture at some point (Alagona et al., 2013; Dirkx, 1998; Keyser, 2009; Luick, 2009), usually associated with subsistence economies reliant on a multifunctional land-use system (Jørgensen and Quelch, 2014).

Currently, having already disappeared in many areas, trends show that the total area of wood-pastures is in decline throughout Europe following a general trend of a reduction in woodland surface (Costa et al., 2011; Kouba and Alados, 2012). In particular, a decrease on the extensiveness of wood-pasture has been registered by several authors in multiple areas of Europe such as the Iberian Peninsula (Ales, Martin, Ortega, & Ales, 1992; Tobias Plieninger, 2006; Teixido, Quintanilla, Carreño, & Gutiérrez,
In the areas where the decline is not so significant, remaining wood-pastures are in a general process of transition from a complex agro-silvopastoral land-use towards a simplified livestock-raising system. In landscape terms, the former mosaic of arable land, tree crops, and pastures that characterizes European silvopastoral land is being replaced by more homogeneous grazed woodland (Pinto-Correia and Vos, 2004). For example, Schaich et al., (2015) detected that the extent of wood-pastures increased in Lesbos (Greece) over a period of 50 years. However, the arable land that is associated with these systems has almost disappeared. Therefore, management in wood-pastures is shifting towards a more intensive and high-input agricultural model, which is characterized by a decrease in the area devoted to crop production, a minor use of secondary subsidiary resources, a reduction in the number of products and the disappearance of traditional practices (Costa et al., 2011; Eriksson et al., 2002; Gaspar et al., 2009). In other cases, wood-pasture management has shifted towards an even more extensive model, close to semi-abandonment, where the role and predominance of animal production in the system as the main economic activity has been replaced by game or other recreational activities (Campos et al., 2003; Gaspar et al., 2009; Schaich and Plieninger, 2013), and where the spatial physiognomy is characterized by higher tree density (Roellig et al., 2016).

Figure 2. Distribution of wood-pastures in Europe. White background indicates the areas where data is not available. Extracted from Plieninger et al., (2015).
The reasons behind these declining trends are diverse and to a great degree associated with the past and undergoing changes in European societies and the role agricultural landscapes play in it. On the one hand, wood-pastures could not meet the increasing demand for agricultural products for a growing European population, and so they were replaced by more efficient and intensive land-use systems. On the other hand, the progressive switch to more globalized markets reduced the need for local multifunctional land-use systems (Fischer et al., 2012). As this process evolved, the local-ecological knowledge that traditionally maintained the system was forgotten or was replaced by technical knowledge (Hartel et al., 2013; Kirby and Potvin, 2007) and practices that were previously of great importance, such as transhumance, became relict (Oteros-Rozas et al., 2014).

**Wood-pastures and the European Common Agricultural Policy**

From a policy perspective, European wood-pastures have a long-history of difficulties in fitting their extensive and multifunctional character into contemporary policy schemes. In Europe, the most important policy framework is the *Common Agricultural Policy* (CAP), which economically supports European agricultural practices through two main pillars: pillar I provides economic support through direct payments, while pillar II is designed to economically compensate less profitable, but more environmentally friendly systems.

For a long time, CAP support was oriented towards promoting productivity in answer to the increasing demand for food as well as to maintain the competitiveness of European agricultural products on international trade markets. As such, CAP relied mostly on pillar I and economic support was linked to the productivity of systems. Therefore, more productive land-use systems were promoted, which meant a substantial reduction in the extension of wood-pastures in Europe (Beaufoy, 2014) and the acceleration of the area-decline processes described previously.

Due to the excess of agricultural land in Europe, towards the end of the 20th century productivity became gradually less important. CAP started to promote instead the modernization and specialization of European agricultural practices, while discouraging less productive and competitive land-use systems. In 2003, the CAP initiated a progressive process of de-coupling economic support from production and instead make it dependent on the area of the agricultural property (EC, 2003). In the new model, economic support for agriculture was granted regardless of the production as long as the agricultural property met some eligibility criteria.

However, the eligibility criteria on which economic support relied were not designed to take account of the multifunctionality of the landscapes. In the specific case of wood-pastures, the 2003 CAP reform included some criteria that made a great proportion of European wood-pastures ineligible for economic support by including a maximum of 50 trees/ha into the eligibility requirements (EC, 2003). Although this criterion was non-binding, it was applied to different degrees in the different countries and led to the removal of trees from pasture throughout Europe (Beaufoy, 2014). In 2014, the number of trees permitted per hectare was increased to 100 (EC, 2013a), which still did not match the average tree density of wood-pastures in some areas of Europe (Roellig et al., 2016; Wood et al., 2017). However, the CAP left it up to each country to decide the extent of tree density on grazed land by allowing "species such as shrub and/or trees which can be grazed". Still, besides the removal of criteria limiting the number of trees, in some European countries having trees is still penalized by reducing the the percentage of land that is eligible for support, depending on the extensiveness of tree cover.
(pasture under the trees is not considered productive land), and thereby perpetuating the discrimination of wood-pastures in a context where European farmland is still highly dependent on economic direct payments (EC, 2013a).

The de-coupling process of economic support was implemented gradually, and it is now in the 2014-2020 CAP period when it will be completed. The objective of de-coupling was to make European agricultural production more competitive in the global market, as more efficient and profitable land-uses (and thus, more competitive) would be promoted over less competitive ones. Other reforms were specifically oriented to discourage intensification. Some of the most important ones are the cross-compliance (CC) principles, first introduced in 2003, that introduce a set of basic rules that relate agricultural practices to the main public expectations on environment, public and animal health, as well as animal welfare (EC, 2014a). Among these rules, especially important for wood-pastures are the Good Agricultural and Environmental Condition (GAEC), that set a range of standards for soil protection, maintenance of soil organic matter and structure, and avoiding the deterioration of habitats (EC, 2014b). In 2013, the CAP reform made a step further and introduced Greening support actions, which are area-based payments dependant on various straightforward, non-contractual practices that benefit the environment (EC, 2013b). Some of these include crop diversification in arable land or the maintenance of permanent grasslands.

Pillar II is designed to economically support specific practices or activities. For wood-pastures, Pillar II can be very useful as it includes schemes that help enhance biodiversity in wood-pastures by, e.g., increasing the diversity and quality of the pasture, while it also addresses some current environmental challenges such as the lack of tree regeneration by encouraging grazing rotations (Beaufoy, 2014).
Theoretical framework

The Ecosystem service (ES) framework has become the most widely adopted framework for analyzing the relationship between ecosystems and people (Geijzendorffer et al., 2017). Defined as the benefits (and occasionally losses or detriments) that people obtain from ecosystems (MEA, 2005; Fig. 3), ecosystem services are categorized into provisioning services such as food and firewood; regulatory services such as pest and erosion control, and; cultural services such as recreation, aesthetics and sense of place. The success of the framework is in large part due to the fact that it directly links human well-being with the environment, incorporating aspects of the ecosystems that traditionally were not considered and emphasizing society’s dependence on ecosystems, while at the same time remaining an intuitive concept that is easy to communicate and use in decision making.

![Diagram of Ecosystem Services and Constituents of Well-Being](image)

**Figure 3.** Theoretical framework as presented in the *Millennium Ecosystem Assessment* (2005) with the linkages between ecosystem services and the constituents of well-being.

However, the ecosystem services framework is not free from criticism. The vagueness of the concept and the lack of consensus regarding the definitions and ecosystem services classifications used have been frequently highlighted (see for example Nahlik et al., 2012). While it is true that many definitions and classifications exist (for a review of the multiple definitions, see Lamarque et al., 2011), this ambiguity in the definitions is in part because the concept and its application have largely evolved and still is under development since its creation (to see some reviews on the development of the ES concept and its application see Chaudhary et al., 2015 and Gómez-Baggethun et al., 2010). It has also...
been criticized the strong anthropocentric focus of the framework, which envisions human-environment relationships as merely exploitative and, thus, potentially leads to general commodification processes. However, the ecosystem service framework does not necessarily entail the commodification of ecosystems. Moreover, alternative non-monetary biophysical and socio-cultural approaches are focused on re-conceptualizing the relationships between society and nature and bridging the gap between them (Bennett et al., 2015). The debate is still ongoing and encompasses many other aspects of the framework. A summary of the ongoing discussion can be found in Schröter et al., (2014) who compile the most frequent critiques as well as the most common counter-arguments.

However, these debates have not reduced scientific interest (Fisher et al., 2008) or the implementation of the ecosystem service framework in diverse sustainable development initiatives that followed the path started by the Millennium Ecosystem Assessment in 2005 (Chaudhary et al., 2015). Current examples of such initiatives that specifically target the economic and the policy arenas are The Economics of Ecosystems and Biodiversity (TEEB), which is a global initiative that focuses on introducing biodiversity and ecosystem service values into decision-making at all levels (de Groot et al., 2010), and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the objective of which is to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development (Díaz et al., 2015). At the European level, as part of the EU 2020 Biodiversity Strategy (E.C., 2011), the European Commission required its member states to map and assess the state of their ecosystems and the associated services (Maes et al., 2013). To this end, several assessments have already been conducted in the last decade at the regional scale, such as the Flanders Regional Assessment (NARA, 2014), and at the national scale, such as the Millennium Ecosystem Assessment of Spain (EME, 2011) or the UK National Ecosystem Assessment (NEA, 2011).

The approaches to ecosystem service assessment can be classified as biophysical, socio-cultural and economic (de Groot et al., 2010). Assessments have traditionally been dominated by natural and economic sciences (Seppelt et al., 2011; Vihervaara et al., 2010), which has meant that cultural services lag behind provisioning and regulatory service categories (Martínez-Harms and Balvanera, 2012; Nieto-Romero et al., 2014). This is in part because cultural services are the most challenging category to elicit and measure by using biophysical and monetary economic approaches (Chan et al., 2012; Milcu et al., 2013). Martín-López et al., (2014) describe how no approach can in fact fully assess the provision of ecosystem services independently, as each tackles a different value-domain of the process, providing different but complementary information, which can only be properly interpreted when analyzed holistically.

Recently, there has been an increasing interest in determining how ecosystem services interact and associate (Mouchet et al., 2014). Typically, the provision of one service will positively or negatively affect the provision of other services. When the provision of one service is enhanced at the cost of another, it is referred to as an ecosystem service trade-off. In contrast, the simultaneous enhancement of multiple ecosystem services is known as synergy (Bennett et al., 2009; Lavorel and Grigulis, 2012). These co-variations are rather complex, behave differently at diverse spatial and temporal scales (Felipe-Lucía et al., 2014; Rodríguez et al., 2006) and are affected by both socio-cultural and environmental factors (Maes et al., 2012b; Martín-López et al., 2012). In European agroecosystems, ecosystem service trade-offs have been assessed on multiple occasions, with trade-offs being
repeatedly identified between provisioning services and regulatory and cultural service categories (for example see Andersson et al., 2015; Power, 2010). When a set of ecosystem services appears together consistently, they are referred to as a bundle of ecosystem services (Raudsepp-Hearne et al., 2010). Identifying these bundles has been receiving increased attention recently as they can potentially give a powerful message to managers and policy makers when working with complex landscapes (see, for example, Ament et al., 2017; Baró et al., 2017; Queiroz et al., 2015; Renard et al., 2015).

In social-ecological systems such as wood-pastures, ecosystem services are jointly produced by the interaction between biophysical and sociocultural processes (Huntsinger and Oviedo, 2014). Therefore, when assessing anthropic landscapes, it is necessary to account not only for the natural, but also the social elements of the system (Bennett et al., 2015; Reyers et al., 2013). Recently, Palomo et al. (2016) and Fischer and Eastwood (2016) have proposed integrative theoretical frameworks to explain how ecosystem services are co-produced by natural and social components in human-modified systems (Fig. 4). By acknowledging the social component of the process of ecosystem service supply, the concept of co-production accounts for the artificial inputs (fertilizers, machinery, etc.) that contribute to the ongoing ecological processes in the generation of ecosystem services.

![Figure 4](image.png)

**Figure 4.** Conceptual framework for the integration of co-production into ecosystem service assessments. Extracted from Palomo et al., (2016).
Social-ecological research approach

As discussed earlier, in Europe, wood-pastures are emblematic agricultural landscapes that have been shaped by the people living in them. They are human-made systems in which the ecological processes that underpin them are driven by human management, without which they would quickly disappear (Bugalho et al., 2011). Wood-pastures are, therefore, widely considered to be social-ecological systems (Hartel and Plieninger, 2014b; Huber et al., 2013; Huntsinger and Oviedo, 2014). As such, the configuration and use of wood-pastures answers the needs of the community living in them. In turn, the society has simultaneously been shaped by the surrounding landscape, assimilating its values and incorporating them into their lifestyle, thereby becoming part of their cultural identity.

The origin of wood-pastures has always been associated with the needs of a semi-subistence society that required multifunctional landscapes able to provide multiple products and services. In the past, the way in which the values associated with these landscapes were perceived was very different from the way they are perceived today, just as current society's needs and the role of agricultural landscapes differ from former times. Today, the sustainability of wood-pastures is under threat. To a certain extent, this is due to the fact that the multiple services they provide and values they host are not included in current formal valuation systems. Therefore, when assessing systems such as wood-pastures, it is necessary to use a social-ecological approach that incorporates both the natural and social values.

Wood-pastures share some common biophysical characteristics, but differ greatly in their composition, spatial configuration and system outcomes. These differences are, to a certain extent, the expression of different biogeographic and geomorphologic differences across Europe, but equally important are the sociocultural differences among them. The social-ecological trajectories of the various European regions have not been parallel. Due to different historical processes, these trajectories have diverged often resulting in legacy effects on the current context (Bennett et al., 2015; Reyers et al., 2013). Therefore, on top of their diverse physiognomies, wood-pastures in Europe also differ greatly in terms of their underlying social structure. For example, in some areas of Europe, such Spain or the Saxon cultural region of Romania, the communal use of pastoral areas was widespread in the past (Guzmán Álvarez, 2016; Sutcliffe et al., 2014), which is still reflected in the current management structure and practices (Dorrestein et al., 2013; Oteros-Rozas et al., 2014). The distribution of land and the size of the properties also have historic roots, such as Greek wood-pastures (Papanastasis et al., 2009) where properties are rather small compared to the big “latifundios” of the Southern Iberian Peninsula (Oviedo et al., 2013).

In this complex system, there are tight feedbacks between the social and natural elements (Fischer et al., 2012), in which the wood-pasture owners and/or managers have a central role in deciding what practices to promote and what processes to enhance (Fig. 5). Their decisions are often primarily driven by economic considerations (Burton and Schwarz, 2013; Siebert et al., 2006), although other sociocultural considerations often play an almost equally important role (Ahnström et al., 2009; Birge and Herzon, 2014; Burton, 2004; Siebert et al., 2006). Therefore, in order to conduct a proper assessment of the dynamics of the social-ecological system, it is necessary to determine how all these elements affect the way wood-pasture managers perceive the landscape, the values it contains and how they influence their management decisions. Our analytical framework departs from the general framework for analyzing social-ecological systems developed by Ostrom (2009). By categorizing the
social-ecological system into different sub-systems, Ostrom’s framework facilitates the identification and characterization of the key factors and variables that interact in the system.

![Diagram](image)

**Figure 5.** General overview of the management activities and interactions that regulate the provision of social-ecological services in wood-pastures. Modified from Hartel and Plieninger (2014).

Nowadays, agricultural landscapes in the European Union are mostly governed by the same policy framework, which is one of the most influencing drivers of agricultural change (Stoate et al., 2009). However, these policies are designed at the European level and are often too simplistic as they do not consider the dissimilar sociocultural dynamics and socioeconomic status of the landscapes they address, which may result in their failure. Therefore, there is a need to adopt a holistic view that acknowledges the different social-ecological characteristics that affect the system in order to design flexible policy instruments that can be adapted to the different rural contexts and that go beyond simplistic win-win solutions.
2. Objectives and structure of the thesis

The main aims of this thesis are to assess the supply of ecosystem services in European wood-pastures and to identify the underlying processes and mechanisms that drive this supply. Wood-pastures are complex landscapes where ecosystem services are jointly produced by the biophysical landscape and society. Therefore, this thesis uses an integrated social-ecological approach to account for the multiple dimensions that interact in the provision of services. These general aims will be achieved by addressing the following interrelated sub-objectives:

1. To assess the current state of research on European wood-pastures and other agroforestry systems, the way the ecosystem service framework has been applied to these systems and the outcomes of this research (Papers I and II).

2. To explore how management practices influence the co-production of ecosystem services and the establishment of synergies and tradeoffs between ecosystem services, and to determine the influence that biophysical and sociocultural factors have on these ecosystem service associations (Paper III).

3. To quantify and map the spatial distribution, pattern and intensity of ecosystem services as perceived by local people in a wood-pasture dominated landscape with an emphasis on the differences between local actors; and to explore the relationships between the demanded ecosystem services and the self-identified landscape values that are attached to subjective well-being (Paper IV).

4. To assess, compare and relate the supply of and trade-offs between ecosystem services, the properties of the social-ecological system and farmers' perceived landscape values and threats; and to propose a social-ecological conceptual framework to integrate such information (Paper V).

This PhD study is structured as a compilation of five scientific papers (see papers I-V at the end of the thesis) and this synthesis. Papers I and II apply an explorative perspective at the European scale and use systematic review and meta-analytical techniques to answer the research questions. Papers III and IV are both based on a specific case of a dehesa dominated landscape in Spain and combine biophysical and sociocultural approaches to answer the research questions. Finally, paper V integrates all the previous findings in a cross-site social-ecological analysis that compares four distinct European oak wood-pasture dominated regions.

This thesis has been designed and executed under the umbrella of work package 7 of the European FP7 project AGFORWARD, the overall objective of which is to assess European agroforestry systems at the landscape scale. As such, the work within this thesis complements and has been complemented by some of the scientific results of the AGFORWARD project, which are summarized in Table 1.
Table 1. Schematic display of the scientific outcomes of this thesis. The arrows indicate information and/or data flow between scientific outcomes. The grey shading indicates a review approach; the blue shading indicates a biophysical approach; the red shading indicates a sociocultural approach, and the purple shading indicates a mixed approach.

<table>
<thead>
<tr>
<th>Obj. 1</th>
<th>European scale</th>
<th>Landscape scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plieninger, T., Torralba, M., Hartel, T., Fagerholm, N. (2017) Ecosystem services synergies, trade-offs, and bundles in European high nature value farming landscapes (Manuscript ready for submission)</td>
<td></td>
</tr>
<tr>
<td>Obj. 4</td>
<td><strong>Paper V</strong>: Torralba, M., Fagerholm, N., Hartel, T., Moreno, G., Plieninger, T. A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures. (Submitted)</td>
<td></td>
</tr>
</tbody>
</table>
3. Methods and data

This thesis combines different approaches and methods at various scales with the aim of generalizing the results to wood-pastures across Europe. The objective of the thesis is not to solely assign specific values of supply to specific ecosystem services. Instead, its main purpose is to draw attention to the processes and elements that interact in the provision of ecosystem services in European wood-pastures. As such, most of its findings can be generalized to wood-pastures in Europe despite being derived from specific examples of wood-pasture dominated regions. This decision is based on the view that wood-pastures are social-ecological systems in which the ecosystem service supply is the manifestation of the interaction between the biophysical and social contexts, which are place-specific. Table 2 provides an overview of the methods applied, the statistical approaches used and the main variables considered in each analysis.

Systematic literature review

The first objective of the thesis, which is addressed in papers I and II, is to review the existing literature on agroforestry systems using the ecosystem service framework in order to identify the results of this research and how it has been conducted. These research questions were addressed through a systematic literature review approach. Systematic review methodologies were initiated in the field of medicine and health science. Its prime objective is to synthesize the available scientific information, while maximizing the transparency of the data and minimizing biases (Pullin and Stewart, 2006). By gathering all the scientific research that addresses the same question or uses a similar methodology, it is possible to upscale the results to a more general level by using different statistical methods such as ordination analysis or meta-analysis.

Within environmental sciences, these approaches are becoming increasingly popular. Although research in these fields is inherently variable and is often not replicable, systematic methods facilitate the examination of the relationship between studies with increased power, even with a low number of replications. Moreover, through the use of systematic methods, it is possible to determine the effect of the heterogeneous local or regional conditions of the studies, such as different biogeographic regions, different types of system or the use of diverse methods (Haddaway, 2015).

To apply these methods, a similar review protocol was developed and applied for papers I and II, which was based on established guidelines (Bilotta et al., 2014; Pullin and Knight, 2009) and informed by previous systematic reviews (García-Nieto et al., 2013; Milcu et al., 2013) and meta-analyses (Felton et al., 2010; Paillet et al., 2010; Pleninger et al., 2014).
Table 2. Overview of the methods and main variables used

<table>
<thead>
<tr>
<th>Paper</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific research question</strong></td>
<td>What are the outcomes of available research on European agroforestry systems?</td>
<td>What is the current status of research on European agroforestry systems?</td>
<td>How do management decisions affect the supply of ES? What factors influence these decisions?</td>
<td>How do people use and perceive the landscape? What are the linkages between these perceptions and well-being?</td>
<td>What ES tradeoffs are present in European wood-pastures? How do the properties of the SES affect farmers’ management and perceptions?</td>
</tr>
<tr>
<td><strong>Methods of data elicitation and data analysis</strong></td>
<td>Systematic literature review</td>
<td>Systematic literature review</td>
<td>Semi-structured interviews</td>
<td>Internet-based Public Participation GIS Mapping (PPGIS)</td>
<td>Semi-structured interviews</td>
</tr>
<tr>
<td></td>
<td>Descriptive and meta-analytical techniques</td>
<td>Descriptive and structural multivariate techniques</td>
<td>Structural multivariate techniques</td>
<td>Spatial analysis Ordination multivariate techniques</td>
<td>Structural and functional multivariate techniques</td>
</tr>
<tr>
<td><strong>Key variables</strong></td>
<td>Timber production Food production Soil fertility Erosion control Biodiversity levels</td>
<td>Geographical distribution Type of agroforestry system ES analyzed</td>
<td>Management indicators (12) Landscape values</td>
<td>Spatial distribution of ES (10) Landscape values</td>
<td>Management indicators (13) Landscape values Perceived threats</td>
</tr>
<tr>
<td></td>
<td>Biogeographical region Type of agroforestry system Scale of the assessment</td>
<td>Approach of ES assessment Methods used Number of ES assessed Data source</td>
<td>Farm size Vegetation structure Land tenure Farm access policy</td>
<td></td>
<td>Geographical location Properties of the SES (environmental, social, governance, technological and economic)</td>
</tr>
</tbody>
</table>

**Semi-structured interviews**

In wood-pastures, the ecosystem processes from which ecosystem services are derived are regulated and controlled through management. Therefore, wood-pasture owners and/or managers have a central role in the generation of services. Their management decisions will, on the one hand, regulate the amount of artificial inputs (machinery, fertilizers, additional animal fodder) that contribute to the supply or harness of some ecosystem services and, on the other hand, engineer the ecosystem both structurally (by altering the physical structure of the wood-pasture, e.g. controlling the tree-density, deciding the crop composition, etc.) and functionally (by altering the intensity of the activities that
take place in the wood-pasture, e.g. regulatory the grazing intensity, controlling access to the wood-pastures, etc.).

These dynamics were explored in papers III and V, where the role of management decisions on ecosystem service supply was assessed, as well as the biophysical and sociocultural factors influencing these decisions. To address these topics, the methodological approach selected was to conduct semi-structured interviews. These were carried out, with some exceptions, on the properties managed by the interviewees to obtain direct information as well as a direct assessment of the information gathered. Following the interviews, on-foot inspections were conducted on the land, part of the time accompanied by the managers, in order to contextualize the information they provided.

Land-owners and managers were identified using snowball sampling techniques (Bryman, 2016), by which a few initial contacts in each study area were used to recruit additional landowners. The data collection for paper III took place simultaneously or soon after the data collection for paper IV and for Fagerholm et al. (unpublished data) and Plieninger et al. (unpublished data), which helped to create synergies in terms of the recruitment of managers and gain the trust and cooperation of the inhabitants of each study area.

The interviews were designed to gather different types of information. First, to infer the provision of ecosystem services, a set of management indicators was selected to characterize the management of the properties. The selection of the indicators was based on previous research that linked management practices and service supply (Andersson et al., 2015; Herzog et al., 2012; Lüscher et al., 2014; Maes et al., 2012a; Malinga et al., 2016; Stubkjaer Andersen et al., 2013); on the outcomes obtained from papers I and II, and; on previous assessments of the most relevant ecosystem services in European wood-pastures and grazing systems (Hartel et al., 2017a; Modernel et al., 2016; Nieto-Romero et al., 2014; Plieninger et al., 2015). Second, to assess the factors influencing management, a set of questions were selected to gather general socioeconomic information; land tenure, history and personal relationship with the farm and the reasons why different management decisions were made.

The statistical analysis of the data combined different multivariate analysis methods, which mainly used ordination (Principal component analysis, Multiple correspondence analysis, Multiple factor analysis) and clustering techniques (Hierarchical clustering analysis). These methods answered to the nature of the research questions addressed and the data collected. The objectives of papers III and V were to identify the structures underlying the social-ecological processes, rather than to infer the influence of specific response variables. Thus, structural statistical methods were used to identify the latent effects of the multiple categorical and continuous variables considered, in line with existing methodological guidelines (Greenacre and Primicerio, 2014; Mouchet et al., 2014) and previous successful examples of social-ecological analyses (Maes et al., 2012a; Martín-López et al., 2012; Queiroz et al., 2015; Raudsepp-Hearne et al., 2010).

Public participation GIS mapping

While in paper III the focus was on analyzing the effect of management on the provision of ecosystem services in a wood-pasture dominated region, paper IV centered on mapping the spatial distribution of ecosystem service provision as perceived by the local inhabitants of the same region. To this end, the method selected included a public participation GIS mapping approach (Brown and Fagerholm, 2015), the aim of which was to capture the sociocultural dimension of the landscape by including both the
tangible and abstract benefits of ecosystem services in relation to the different local stakeholders’ everyday lives. The sampling approach addressed multiple actors, including landowners as well as local residents, and balanced the respondents’ characteristics through a stratified sampling by gender and age.

The analysis of the data included the visual exploration and spatial analysis of the distribution, patterns and intensity of mapped ecosystem services through the generation of density surfaces. The spatial distribution was then linked to the self-reported contribution of landscape to personal wellbeing (Bieling et al., 2014). The linkages between all these elements were explored by using multivariate statistical techniques (Redundancy analysis).
4. Study areas

While papers I and II are based on an evaluation of published sources, papers III to V are based on elicited primary data. The results are derived from four study areas in three countries: Llanos de Trujillo and La Serena in Spain; Östergötland in Sweden; and Southern Transylvania in Romania (Fig. 6). Each of the four sites hosts a consistent social-ecological system with internal social and biophysical coherence and a common identity among the inhabitants. The study areas were chosen in order to balance the different types of European oak wood-pastures in terms of structure (from dense wood-pastures in Sweden to sparse wood-pastures in Romania); function (cattle in Sweden, sheep in Romania and cattle and pigs in Spain); management style (trees intercropped with cereal in La Serena, highly mechanized management in Sweden, solely-focused on grazing in Llanos de Trujillo); geomorphology (poor soils in Llanos de Trujillo, rich soils in La Serena), and climate (Mediterranean, Continental and Boreal). It was also decisive for the selection of the study area the presence of local facilitators, who could assist with the preliminary phases of the fieldwork and in contextualizing the results.

The four study areas are dominated by agricultural landscapes, oak-based wood-pasture being the most characteristic element of the landscape. On the other hand, the four study areas differ greatly in terms of their socioeconomic characteristics and some large-scale operating factors such as climate and geomorphology (Table 3). Furthermore, the four study areas mirror some of the diverse changes in the relationship between people and wood-pastures in Europe. As a consequence, the challenges they face are caused by different environmental, social and political drivers. In this sense, the four study areas are a good representation of the diversity of wood-pastures across Europe and an informative choice for cross-site comparison.

![Image of Europe with biogeographical regions and the study areas.](image)

**Figure 6.** Map of Europe with biogeographical regions and the study areas. A: Llanos de Trujillo; B: La Serena; C: Östergötland; D: Southern Transylvania
By focusing on the current status of four study areas, this thesis takes a “snapshot” of the status and functioning of European wood-pastures. However, wood-pastures have been the subject of human influence for centuries and the ecosystems we see nowadays are the legacy of this long-term human intervention. These interactions did not have a linear trajectory and the relationship between wood-pastures and the society managing them has shifted over time as the local social and ecological context evolved. Historical dynamics and large-scale decisions made at different points triggered some of the current social and ecological trajectories we can observe today and will continue to have an influence in the future. Therefore, the aim of this section is to describe the study areas used in the thesis and their main differentiating traits, but also to provide an insight into their social-ecological trajectories with a special emphasis on the changes that took place in the second half of the twentieth century and the more recent influence of European policies.

<table>
<thead>
<tr>
<th>Study area</th>
<th>Mean annual rainfall (mm)</th>
<th>Mean annual temperature (°C)</th>
<th>Mean altitude and range (m)</th>
<th>Population density (inh./km²)</th>
<th>Wealth level (gross domestic product/capita in €)</th>
<th>Soil type⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Transylvania</td>
<td>627</td>
<td>9.4</td>
<td>574 (440 - 761)</td>
<td>26</td>
<td>4,600</td>
<td>Stagnic luvisol</td>
</tr>
<tr>
<td>Östergötland</td>
<td>641</td>
<td>5.2</td>
<td>142 (0 - 243)</td>
<td>27</td>
<td>33,440</td>
<td>Eutric cambisol</td>
</tr>
<tr>
<td>La Serena</td>
<td>594</td>
<td>19.1</td>
<td>519 (354 - 840)</td>
<td>11</td>
<td>15,600</td>
<td>Gleyic acrisol</td>
</tr>
<tr>
<td>Llanos de Trujillo</td>
<td>569</td>
<td>19.2</td>
<td>424 (209 - 781)</td>
<td>13</td>
<td>15,700</td>
<td>Dystric regosol</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study area</th>
<th>Surface (ha)</th>
<th>Agricultural land (%)⁴</th>
<th>Arable land (%)⁴</th>
<th>Forest and semi-natural areas (%)⁴</th>
<th>Mean slope (%)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Transylvania</td>
<td>23,773</td>
<td>63.1</td>
<td>17.7</td>
<td>34.0</td>
<td>11.9</td>
</tr>
<tr>
<td>Östergötland</td>
<td>116,696</td>
<td>32.8</td>
<td>27.5</td>
<td>57.7</td>
<td>4.8</td>
</tr>
<tr>
<td>La Serena</td>
<td>63,768</td>
<td>73.4</td>
<td>27.9</td>
<td>20.3</td>
<td>7.4</td>
</tr>
<tr>
<td>Llanos de Trujillo</td>
<td>94,048</td>
<td>83.3</td>
<td>5.9</td>
<td>16.2</td>
<td>5.7</td>
</tr>
</tbody>
</table>

¹ Extracted from Metz et al. 2014: Surface temperatures at the continental scale: Tracking changes with remote sensing in unprecedented detail. Remote Sensing, 6, 3822-3840 (http://gis.cri.fmach.it/euroslst-bioclim/).
² Calculated from the Digital Elevation Map of GMES RDA project (www.eea.europa.eu/data-and-maps/data/eu-dem)
⁴ According to CORINE Land Use 2006. Agricultural land includes arable and grazing land (including natural grasslands).
Wood-pastures in Spain: the cases of Llanos de Trujillo and La Serena

The study area of Llanos de Trujillo and La Serena are located in the region of Extremadura, in South Western Spain (Fig. 6A and 6B). Both study areas are formed by four municipalities (Trujillo, Aldea del Obispo, La Cumbre and Torrecilla de la Tiesa in Llanos de Trujillo; and Campillo de la Serena, Retamal de la Serena, Higuera de la Serena and Zalamea de la Serena in La Serena). Llanos de Trujillo covers 940 km², while La Serena covers 634 km². Both study areas are sparsely inhabited by an aging population, which is mostly concentrated in compact villages. They suffer from high unemployment, and their economies rely on a diversified agricultural sector and a tertiary sector, which targets the following three main types of tourists: those who are attracted by the high biodiversity of the agricultural landscapes (especially birdwatchers), those who are interested in game (especially deer and wild boar hunting), and those who are attracted by the rich historical and cultural heritage of the region.

![Figure 7. Landscape in Llanos de Trujillo. Picture taken by Tobias Pleninger.](image)

The dominant landscape is the holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) wood-pastures, named dehesas. Dehesas originally appeared as a way to maintain a productive land in the typically poor soils and harsh summer drought conditions of Extremadura (Joffre et al., 1999; Moreno and Pulido, 2009). The dehesa was originated through the simplification of the natural evergreen Mediterranean woodlands, where the natural vegetation was thinned actively selecting the holm oak to support cattle and sheep husbandry and to provide a source of food for the Iberian pig. Trees were intensively pruned to encourage acorn production to supplement the natural pasture and to remove foliage to allow light to reach the understory. Animal production was combined with cereal cultivation
(often intercropped between the oaks in long rotational cycles of 4 to 10 years as is the case in La Serena), firewood and charcoal production, hunting and other recreational activities such as the harvesting of mushrooms, berries and asparagus. In the Southern areas of Extremadura, the more humid conditions often favored the selection of cork oak instead of holm oak as the tree element, gaining relative importance forestry activities to produce cork (instead of acorns) and therefore increasing the tree density of the dehesas, which created a similar landscape to the Portuguese wood-pastures, called *montados* (Pinto-Correia and Vos, 2004).

In Extremadura, land tenure is very stable and new access to land is difficult as most of the productive land is concentrated on a few large properties. These properties, called *latifundios*, have often belonged to the same families for several generations. In fact, Extremadura has the highest GINI index (index of concentration of land) in Spain with 0.81 (Soler and Fernández, 2015) and with 69% of the area belonging to 8.71 % of the properties (Fig. 8). In the past, traditionally managed dehesas supported several worker households who often lived on the property. These traditional systems were rather stable and were based on multifunctional management that was heavily reliant on poorly paid labor (Costa et al., 2014). During the 1960s and 1970s, the Spanish society and economy developed and these traditional systems collapsed as a significant proportion of the rural population migrated to cities and abroad. In the subsequent decades, the management of the dehesas substantially shifted towards intensification and it became characterized by activities that required less labor (e.g. use of cattle breeding instead of sheep breeding; use of meat breeds instead of milk breeds) and by less diverse production activities (Alagona et al., 2013; Plieninger, 2006).

![Figure 8](image-url) Farm area and number of farms across size classes in the region of Extremadura (Soler and Fernández, 2015).
Spain's accession to the European Union in 1986 introduced a new phase to dehesa management. Although the CAP triggered an increase in grazing intensity during some periods (Moreno and Pulido, 2009; Plieninger, 2007), the biggest change resulting from joining the EU was the acknowledgement of the environmental values of the dehesas. For example, dehesas became a priority habitat in the EU Natura 2000 network, while the quality of their traditional local products (especially pig-derived products) was recognized, as was their potential for recreation (with the development of the tourism industry).

**Wood-pastures in Sweden: the case of Östergötland**

The Östergötland study area is located in the Southeast of Sweden (Fig. 6C). It is formed by the municipality of Linköping and covers an area of 1,568 km². Östergötland currently contains the largest remnant area of wood-pastures in Sweden with around 180,000 ha distributed in scattered small patches (Ek and Johannesson, 2005) (Fig. 9). The population of 155,817 inhabitants is mostly concentrated in the city of Linköping, while the rest of the territory is scarcely inhabited. The regional economy is highly diversified, combining the agricultural sector with a growing technology manufacturing industry.

![Figure 9. Distribution of oaks in Östergötland. Large or hollow oak stands of high nature value are highlighted in black and core areas for oak conservation and restoration are in grey. Modified from Ek and Johannesson (2005).](image)

In the past, in Central and Southern Sweden, broadleaf wood-pastures, mainly composed of pedunculated (*Quercus robur*) and sessile oaks (*Quercus petraea*), were much more widespread (Eliasson and Nilsson, 2002). The cold and snowy winters created a need for oak wooded meadows
that provided fodder during the winter when the animals were kept indoors. In the 15th century, oaks started to be intensely thinned due to an increasing demand for timber from the growing Swedish population. Therefore, oaks became a highly strategic resource. In order to protect oaks, in 1558, they were declared the property of the Crown (Eliasson and Nilsson, 2002), which meant that they could not be felled. This had an adverse effect on how the oak was perceived in the future as it was considered an impediment to agriculture. In 1830, oaks ceased to be the property of the Crown, which led to a reduction in the number of oaks (Eliasson and Nilsson, 2002). Not all wood-pastures disappeared, especially in Östergötland, where they were kept as a key management resource. However, the traditional management of wooded meadows and grazed wood-pastures has gradually disappeared. Today, the remaining wood-pastures are integrated with farms and they are maintained as important cultural and historical elements of the landscape, where several recreational activities take place such as outdoor sports, orienteering competitions or hunting (Garrido, 2014; Garrido et al., 2017).

Currently, regional and county administrations are implementing different restoration and management programs to recover existing and establish new wood-pastures and oak habitats, which is motivated by their historical, cultural and environmental values. For example, the County Administrative Board has implemented programs to introduce grazing animals to wood-pastures that are being abandoned in order to maintain them and conserve the oaks in selected areas (Ek and Johannesson, 2005) (Fig 6D). At the same time, different local and regional marketing campaigns are ongoing in order to promote high quality local products that are associated with oak habitats (for example, the ice cream producers Stafsäter Gårdsglass. Fig. 10).

![Image](image_url)

**Figure 10.** Local dairy farm Stafsäter Gårdsglass produces a variety of products (e.g. ice cream) that are branded as oak landscape products. Left picture taken by Jesús Calanques.

**Wood-pastures in Romania: the case of Southern Transylvania**

The study area of Southern Transylvania is located in the Saxon cultural region (Fig. 11) and is formed by the municipalities of Rupea, Viscri, Bunesti and Messendorf. Oak wood-pastures (mainly formed by *Quercus robur*) have a long history in the region. They were established in the region as a common
land resource within the Saxon communities in the Middle Ages (Gündisch & Beer, 1998). Transylvanian Saxons practiced a rather multifunctional management and valued oak trees not only for timber production, but also for their acorns, which were used as a supplementary nutritional resource for pigs (Hartel et al., 2013). Forests and pastures were managed in a communal way with strict rules, where each individual in the community had rights and obligations regarding their use, which turned out to be a very stable governance structure that lasted for a long time (Sutcliffe et al., 2014).

Saxons institutions disappeared after 1947 during the communist regime as the agricultural land became property of the state. The traditional communal management of wood-pastures mostly disappeared as the Saxon social structure was decimated in a period that was characterized by a general reduction in multifunctional management. When the communist period ended in 1989, the remnant Saxon influence in the region virtually disappeared overnight due to large-scale migration, mainly to Germany, leaving only around 10% of the Saxons who were originally in Romania in 1945 (Sutcliffe et al., 2014). Therefore, a period of extensive abandonment started with the land slowly being repopulated by newcomers.

With the accession of Romania to the European Union in 2007, economic interest in the region has increased due to its natural and cultural heritage, but also because of its agricultural landscape and potential for economic intensification. Thus, the farming model is slowly transitioning from one that is based on semi-subistence farming to one that is larger and more profitable. The future consequences of the current socioeconomic changes in the area are unknown (Hartel and Plieninger, 2014a). A recent study has explored how local farmers perceive wood-pastures in the region, and has identified several tangible and intangible values that are associated with oaks, which indicates that when managed, oak trees become a very valuable resource for local ranchers (Hartel et al., 2017b).

![Image](image-url)

**Figure 11.** Wood-pasture in Southern Transylvania. Picture taken by Tobias Plieninger
5. Results and Discussion

Knowledge landscape on ecosystem services assessments in European agroforestry systems

Paper I and paper II of this thesis review the state-of-the-art in research on European agroforestry systems. The two systematic reviews considered a total of 117 scientific publications, revealing a substantial and rapid growth in the number of studies on agroforestry and ecosystem services in Europe in the last 20 years. Together, the two papers summarize the approaches and methods applied in this field and the outcomes of the research.

Paper II performs a meta-analysis, which allowed the upscaling of individual studies assessing biodiversity and ecosystem service supply from agroforestry compared to conventional land-use systems. The results reveal an overall positive effect of agroforestry on biodiversity and ecosystem service provision. These results confirm the Central agroforestry hypothesis, put forward by Cannell (1996), which states that the structural and functional diversity of agroforestry systems results in more efficient ecological processes and efficient use of available resources. Therefore, agroforestry will ultimately boost soil fertility, reduce erosion, improve water quality, and enhance biodiversity without compromising productivity. In particular, the meta-analysis shows a significant positive effect of agroforestry on biodiversity and soil-related ecosystem services such as erosion control and soil fertility (Paper II, Fig. 2), while the effects on provisioning services (timber and food provision) are not significant, providing higher or lower yields depending on the regional context. For the specific case of wood-pastures, the outcomes of the comparative analysis show a clear positive effect of wood-pastures on erosion control, biodiversity and soil fertility, while the results for food and timber provision are not significant and biomass provision shows a negative effect (paper II, Fig. 4).

As expected, the results of the meta-analysis fluctuate depending on the geographical location, tree-component and land-use types used for comparison in the assessment. The substantial variation in the effect of agroforestry on ecosystem service generation highlights how the responses are fundamentally dependent on the context-specific biophysical and land-use conditions. However, based on the evidence, some generalizations can be made for particular situations. This is the case, for example, for olive and vineyard monoculture plantations which are widespread in the Mediterranean. In these systems, it is common practice to mechanically or chemically remove all natural herbaceous vegetation to leave bare soil in order to reduce water resource competition (Chiti et al., 2011; Durán Zuazo et al., 2014). However, the results show that leaving the natural vegetation and introducing grazing animals to the system improves soil fertility and biodiversity and helps to prevent soil erosion, while maintaining and sometimes enhancing provisioning services.

The results for provisioning services should be interpreted with caution as most of the assessments only consider one of the productive elements of the agroforestry system. As such, when compared with conventional monofunctional land-use systems, most of the studies only considered the arable or pasture yields if the comparison was between monoculture/grassland vs. silvoarable/wood-pasture; or the fruit or timber yields if the comparison was between tree plantations vs. silvoarable/wood-pasture. Multifunctional production is one of the main traits of agroforestry (Rigueiro-Rodríguez et al., 2009). Therefore, by considering only one of the productive elements of the system, results lead to
uneven comparisons. Moreover, in paper V, the results from the cross-site comparison of the supply of ecosystem services in wood-pasture dominated regions show that, to a varying extent, wood-pastures in Europe exhibit a rather multifunctional production, which provides a wide range of provisioning services (Paper V, fig. 3). We could, therefore, infer that in many cases, when summing up the commodity production of each of the productive elements in the system, the overall generation of provisioning services has the potential to be superior in the agroforestry system when compared under the same conditions.

However, despite this evidence and the growing research effort, current trends show a continued decrease in the total area of agroforestry (Den Herder et al., 2017). Farmers still tend to associate agroforestry with a loss in farm income and reduced system productivity (García de Jalón et al., 2017; Graves et al., 2009). This negative perception is realistic to a certain degree. Agroforestry, in general, and wood-pastures, in particular, are generally associated with traditional land-use systems that require extensive management in terms of external inputs and reduced mechanization (Gaspar et al., 2009). The conversion of traditional agroforestry systems to more simple and homogeneous land-uses was motivated by a desire to increase production yields and associated with the transformation of agriculture to models characterized by increased use of fertilizers, pesticides and specialized field machinery. Therefore, the farmers’ dilemma about whether to implement agroforestry practices is often more a question of whether to increase the intensiveness of the management practices rather than incorporating/removing trees from the system; while the effects on the latter are typically a consequence of the decisions regarding the former.

Traditional agroforestry systems are often less profitable than comparable conventional land uses as they are less intensively managed. This is simply part of their character. Lower productivity does not mean a lower supply of ecosystem services. In fact, the meta-analysis conclusively shows that agroforestry significantly boosts biodiversity levels and increases the provision of regulatory services. In paper III, the analysis of the influence of farm management shows that an increased focus on single-commodity production results in turn, in a reduction in multifunctionality and some regulatory services supplied by dehesas (Paper III, Fig. 4). These dynamics are normal in agro-ecosystems where ecosystem service trade-offs usually appear between provisioning and regulatory services (Power, 2010). To ensure that ecosystem services in agroforestry systems are valued correctly, it is necessary to account for all ecosystem services as well as their interactions. However, the systematic mapping of ecosystem services associated with agroforestry performed in paper I reveals that ecosystem service trade-offs are rarely accounted for (only in 6% of assessments). In fact, the results show that assessments often consider few ecosystem services (58% of the assessments considered only one), which leaves some of the most beneficial characteristics of agroforestry systems for society out of the assessments. This pattern is not only present in agroforestry research. Ring et al. (2010) found that most valuation studies of ecosystem services have only focused on one or a few services without considering the interdependence and highly non-linear relationships among them.

The initial aim of the meta-analysis performed in paper II was to analyze the effect of agroforestry on the provision of all ecosystem service categories present in the Millennium Ecosystem Assessment. However, it soon became apparent that this scope would have to be reduced. The requirement of at least three primary studies targeting the same ecosystem service reduced the scope, which initially included a wider range of ecosystem services (including air and water purification, pollination, pest regulation and multiple cultural ecosystem services) to a smaller final selection, which did not include
any cultural ecosystem services. This lack of primary studies covering a wider range of ecosystem services is also reflected in paper I, where the results reveal a methodological bias towards biophysical approaches (used in 79% of the assessments). This exposed a need of more comprehensive metrics that also account for more regulatory and cultural services. In fact, although a very similar set of keywords was used to elicit the publications to be analyzed in paper I and paper II (the main difference is that the keywords used for the meta-analysis also included terms related to biodiversity), the final dataset shared only 7 publications (Fontana et al., 2014; Hussain et al., 2009; Lozano-García and Parras-Alcántara, 2013; Moreno Marcos et al., 2007; Rollin et al., 2013; Shvaleva et al., 2013). On the one hand, formal ecosystem service assessments rarely included a comparative site (70% did not) and when they did, they often did not meet the requirements for inclusion in the meta-analysis in terms of data quality and availability. On the other hand, and despite the growing importance of new socio-cultural approaches to ecosystem service science, agroforestry science is still dominated by biophysical and economic approaches. Methodologies within these fields commonly measure the efficiency of agroforestry through “land equivalent ratios” (Graves et al., 2010; Palma et al., 2007), which are generally based on a small number of productivity indicators and often do not use an ecosystem service framework.

![Figure 12. Geographical distribution of the study sites in regards to the distribution of wood-pastures in Europe (based on Plieninger et al., 2015). The red dots indicate the study sites included Paper I; in green are the study sites included in Paper II; blue for study sites included in both publications.](image-url)
These types of approach based on productivity and economic profitability indicators are very useful, especially for the implementation of innovative agroforestry systems. Such agroforestry systems, for example, intercropped silvoarable systems (Brownlow et al., 2005; Dupraz et al., 2005; Eichhorn et al., 2006), have the potential to improve economic performance and to become a sustainable alternative to intensive agricultural systems. However, these approaches are not designed to capture the diverse social-ecological values that characterize traditional systems such as wood-pastures. Despite the rich socio-cultural values that wood-pastures host, the results in paper I show that the social side of these ecosystems is largely ignored and that stakeholders are rarely involved in assessments of their ecosystem services (Paper I, Fig. 6).

Altogether, papers I and II identified the existence of geographical knowledge gaps. The extension of wood-pastures in Europe is not homogeneous, displaying hot-spots in the Mediterranean and Eastern Europe. However, although the Mediterranean was intensely researched, large wood-pasture regions of Europe remain almost unexplored, in particular those in Central and Eastern Europe (Fig. 12). Given the large differences between wood-pastures in Europe, more research is required on those under-represented areas in order to holistically evaluate the status of wood-pastures in Europe. For regions where research is already broad, such as the Iberian Peninsula, such assessments on biodiversity and ecosystem services may be advanced towards long-term monitoring programs.

**Ecosystem service supply and trade-offs**

This thesis assesses the supply of ecosystem services at the farm-level in four landscapes that are illustrative of oak wood-pastures in Europe. The results reveal that wood-pastures in Europe provide, beyond single commodity production, a wide variety of ecosystem services spanning all categories (paper III, Fig. 3; paper V, Fig. 3). However, the assessment also shows that the individual values of provision for each ecosystem service change across wood-pastures, ranging from systems single-focused on a reduced number of services, to wood-pastures providing a rather diverse set of ecosystem services. These heterogeneous patterns occur at various scales. Within regions, different types of wood-pasture exist in terms of service supply (as seen in the assessment of the Spanish dehesas in Llanos de Trujillo in paper III). At a larger scale, each region exhibits different patterns of ecosystem service supply, while the variability observed at the local scale is shadowed by the larger and specific patterns and characteristics that each study area shares (as seen in cross-site assessment in paper V).

Wood-pastures are human-maintained ecosystems and, thus, the ecosystem processes from which ecosystem services are derived are not solely natural. Instead, ecosystem services are jointly produced by the interaction between biophysical and sociocultural processes (paper III, Fig. 1). Management decisions will promote specific social-ecological processes that will enhance specific ecosystem services depending on the personal interests and motivations of the manager or land owner of the wood-pasture. Due to the long history of land-use in Europe, the structure, composition and physiognomy of wood-pastures have diverged in line with the different social-ecological trajectories in each region. Therefore, the diverse pattern of ecosystem service supply in wood-pastures mirrors their multiplicity across Europe, where their management, purpose and social role in the landscape are different depending on their location.
Wood-pasture managers and landowners, therefore, play a central role in the process of ecosystem service supply as their decisions to promote specific practices boosts some social-ecological processes at the expense of others, which generates trade-offs in ecosystem services. The current focus in ecosystem services trade-off analysis is mainly on the differences between land-use types, while little attention has been given to the mechanisms by which trade-offs appear within these land-uses (Cord et al., 2017; Deng et al., 2016; Ryffel et al., 2014). Given the wide variety and complexity of wood-pasture physiognomies and management models across Europe, the single-focus on land-use types appears too simplistic. Although the four study areas considered in this thesis are dominated by wood-pastures, the provision of ecosystem services varies greatly within and between them, which implies there are inherent trade-offs related to the different management styles. By focusing on the role of management, this thesis both characterizes the diverse provision of ecosystem services in European wood-pastures and identifies the social-ecological mechanisms through which these ecosystem service trade-offs appear. The assessments performed in papers III and V detect four main dimensions of management that control these ecosystem service associations:

1. Multifunctionality: the degree of diversification in production is one of the main factors driving ecosystem associations in wood-pastures. Increased multifunctionality will enhance regulatory ecosystem services at the expense of reducing the supply of single-provisioning services. By diversifying production, more diverse habitat is generated, while reliance on external inputs is reduced, which boosts regulatory services. Multifunctionality is also the management dimension that generates more synergistic associations (Paper III, Table 2; Paper V, Table 1).

These results are in line with previous studies that found similar synergistic associations at landscape scales associated with multifunctional landscapes. For example, Branca et al. (2013) associated areas with increased agroforestry (as opposed to mono-cultures) to poverty alleviation and climate change mitigation in Brazil. Similarly, Queiroz et al. (2015) positively associated the provision of multiple ecosystem services with an increase in landscape multifunctionality in Sweden. Multifunctionality is one of the main characteristics of traditional wood-pastures management. Current trends show a reduction in the multifunctional character of wood-pastures (Plieninger et al., 2015), which is linked to the low profitability of secondary (not animal derived) wood-pasture products. However, lower profitability does not necessarily imply a reduced supply of provisioning services. The results show that the diversified management of wood-pastures is a strategy that allows the maintenance of animal production and recreational uses, while reducing the costs of external inputs.

2. The intensity of management: trade-offs associated with landscape intensification have been the most commonly assessed and identified trade-offs in agricultural landscapes (Cord et al., 2017; Power, 2010). Intensive land-use change has been recognized as one of the major drivers influencing ecosystem services provision (Bryan, 2013; Sheng et al., 2011). In contrast to the multifunctionality management dimension (multifunctional landscapes tend to be less intensively managed and vice versa), an increase in the intensity of management practices (increased mechanization, external inputs) increases single-commodity production at the expense of regulatory and cultural ecosystem services. Similar trade-off dynamics have been previously found, for example, in Badgley et al., (2007) who associated extensive management practices such as conservation tillage and crop diversification with mitigated trade-offs of ecosystem services.
3. Crop production: in many biogeographic regions of Europe, such as the Mediterranean or the Boreal region, pasture is not available for the whole year. Thus, natural pasture needs to be complemented and often fully replaced by supplementary fodder during specific periods. This nutritional supplement was traditionally provided through tree fodder and small-scale cereal production. Nowadays, the relative importance of these activities has been reduced, especially in areas with poor soil quality, where farmers import almost all the cereal grain (Alagona et al., 2013). This is the case for Llanos de Trujillo, where today devoting part of the wood-pasture to cereal production is unusual as it is cheaper to import it. The results show that while increased crop production improves the resource sovereignty of the wood-pasture (control over the mechanisms of food production and distribution), it usually leads to a reduction in the generation of regulatory services and the potential for some recreational activities. These results are in line with the findings in Potschin and Haines-Young (2012) who found similar trade-offs between provisioning and regulatory services associated with croplands.

4. Accessibility policy: through management, landowners and managers not only enhance different social-ecological processes, but also control and regulate the general public’s access to the land. Restricted access to wood-pastures is often a side-effect of management practices such as fencing the property. Fencing is a way of controlling the movements of livestock and/or game animals which involves lower costs than traditional herding. It is, therefore, being increasingly introduced in European wood-pastures. The results show that the most significant factor for the supply of cultural ecosystem services is the degree of accessibility to the land. Similarly, the results in paper IV, where local inhabitants mapped how they used and perceived their surrounding landscape, show that accessibility was the best predictor of ecosystem services provision above any land-use type.

The results in paper III revealed that large wood-pastures were often the most multifunctional and provided the highest values for provisioning and regulatory services (Paper III, Fig. 3). However, they were largely inaccessible and, thus, were used and valued by fewer people. The situation was reversed in wood-pastures with open access to the general public. These hold the highest values for cultural ecosystem services, regardless of how multifunctional/monofunctional, intensive/extensive or crop-focused was the remainder of the management. This was also reflected in paper IV. Although many respondents allocated multiple cultural ecosystem services within wood-pastures, the intensity was not higher than for the surrounding agricultural areas (paper IV, table 3). This is in part because people do not usually have access to them and, thus, cannot value them. Paper IV further reveals the importance of access for the valuation of wood-pastures as those who had relatively easy access to wood-pastures (such as agricultural workers and people who stated an excellent knowledge of the area and its surroundings) showed a higher appreciation of wood-pastures than people who did not have easy access (paper IV, Fig. 4).

Howe et al. (2014) found that while trade-offs were the most common types of ecosystem service associations, synergies between different ecosystem services are rare and only appear when managers or land-owners manage to avoid or overcome economic pressures. This conclusion appears to be correct for the case of European wood-pastures. The four management dimensions resulting in trade-offs in ecosystem services are ultimately driven by economic motivations to increase profitability, either by specializing in single commodities (multifunctionality trade-offs, crop production trade-offs),
by increasing net production (intensity of management trade-offs) or by reducing the costs of labor (accessibility policy trade-offs).

The decisions of managers and land-owners in regard to these four main management dimensions determine ecosystem service supply. At the landscape scale, wood-pastures form a mosaic in which the different farm management models can potentially complement each other. For example, a wood-pasture might not achieve the required cereal production to maintain its livestock. This demand can be met by nearby wood-pastures with a more intense focus on crop production. In turn, this “crop-oriented” wood-pasture could benefit from the former by using its surplus animal manure as natural fertilizer and reducing dependence on imported fertilizers. Based on an ecosystem service trade-off assessment in Hawaii, Goldstein et al. (2012) found that diversified agriculture and forestry was the best scenario for meeting the policy goals of climate change mitigation, food security, and diversifying rural economic opportunities.

Together, paper III and paper IV provide complementary information on the ecosystem service flow in the study area of Llanos de Trujillo as they assess and reflect different value domains of ecosystem services (Martín-López et al., 2014). In paper III, when assessing ecosystem services by measuring management-related indicators, the assessment is, in fact, being made of the supply-side of the ecosystem services and the performance of ecosystem service delivery. Instead, in paper IV, by using a socio-cultural approach to the assessment of ecosystem services, what is being assessed is the demand-side of ecosystem services and how the general public uses and values this delivery. The combination of the two assessments highlights the role of landowners as key stakeholders who control and maintain the flow of ecosystem services. In the specific case of Llanos de Trujillo, a significant proportion of the territory is privately-owned agricultural land (83.3%), especially grazing land (70.68%), which leads to a monopolization of ecosystem services, where a single group of stakeholders uses and manages more than two-thirds of the land. In a flood-plain assessment conducted in North-Eastern Spain, Felipe-Lucía et al. (2015) found that such unbalanced power-relationships between stakeholders can lead to positive feedback processes, whereby one service can be depleted by unregulated use, which reduces the capacity of the system to generate services in the long term.

**A social-ecological approach**

Wood-pastures represent an arena where coupled interactions between natural and social systems occur for which managers play a central role as ultimate decision makers. His/her decisions in relation to the management style will have decisive effects on ecosystem service supply. Therefore, it is important to understand the mechanisms through which ecosystem services are jointly produced in order to understand the factors and dynamics that drive these processes.

The results in paper V contribute to the understanding of these factors by assessing the relationship between the emerging ecosystem services trade-offs and the properties of the social-ecological system in four wood-pasture regions (Fig. 13). Using the social-ecological framework (Ostrom, 2009) as a theoretical foundation, this thesis proposes that the provision of ecosystem services is determined by the interactions between the different subsystems that compose the social-ecological system. These subsystems include the resource system, governance system, resource units and users.
Figure 13. Framework for analyzing the co-production of ecosystem services in woodland pastures as social-ecological systems. Solid line arrows indicate a direct relationship; dashed arrows indicate an indirect relationship. Extracted from paper V.

The resource system encompasses the whole silvopastoral landscape, including all the factors and processes that maintain its composition and structure. The resource system directly influences the resource units, which include all the biophysical components and landscape features present in the woodland pasture (such as the tree elements, the pastures and arable lands). Together, the resource system and resource units limit and constrain the range of management decisions that can be made. This was clear in paper III, where the size of the property was a decisive factor for the implementation of arable land. Smaller properties would not devote part of the limited available space to crop production so easily. These dynamics are complex and are often affected by more than one factor. For example, in the study area of La Serena, not far located from Llanos de Trujillo, the size of the properties had a reduced influence on the relative importance of crop production. In fact, most of the woodland pastures in La Serena, regardless of property size, holm oaks are periodically intercropped with cereals and, to a minor extent, legumes. This is due to the fact that the soil is more fertile in La Serena (Moreno et al., unpublished data), which leads to higher cereal yields than in Llanos de Trujillo, which increases the range of management decisions in regards to crop production.

The governance system includes all the processes and factors that, to a certain extent, determine the management of woodland pastures and regulate their use. It has a direct influence on the users, who are all
those who directly benefit from wood-pastures either productively (such as farmers and product consumers) or through non-material means (visitors and tourists). Sometimes these rules are formally expressed in legislation such as the regulation of public paths and drove roads in Spain. This was clear in paper IV, where common land was found to be a hotspot of ecosystem services, especially outdoor recreation, the supply of farm products and social interaction activities (Paper IV, Table 3). Sometimes these rules are informal, e.g. the case of game hunting in wood-pastures in Romania, where there is no formal legislation that regulates hunting, but instead a common agreement to keep such activities out of wood-pastures.

Often, different strategies that address the same problem can have a similar effect on the use of the landscape. For example, as previously mentioned, fencing is the most commonly used strategy for controlling the movements of animals in wood-pastures, while reducing labor costs. This is the case for most wood-pastures in Spain where fencing, to a great extent, discourages the general public from accessing the wood-pastures. In contrast, in Romania, fencing is rather uncommon. In the past, pastures were a common resource, which continues today as many shepherds combine their flocks to graze on large surfaces across properties (Sutcliffe et al., 2014). Therefore, fencing is often perceived as an odd and inconvenient practice. Instead, the most common way of spatially controlling large herds of animals is to use packs of herding dogs, which also protect the animals from predators. However, these dogs may also be a threat to humans and, therefore, many people avoid entering wood-pastures. Therefore, although there is no physical barrier in the form of fencing in wood-pastures in Romania, the management practice of using herding dogs has a similar effect in terms of discouraging public access.

All these subsystems are embedded within larger environmental, economic, political and social settings that operate across diverse spatial and temporal scales (Felipe-Lucia et al., 2014; Renard et al., 2015; Rodríguez et al., 2006). Different regions are locked into different social-ecological trajectories, whereby decisions made in the past have created path dependency that is often very costly to reverse (Farley, 2012). Such events are especially important for wood-pastures as their maintenance relies on continuous human intervention. Historical dynamics, such as the large-scale removal of trees from the agricultural landscape, as occurred in Swedish wood-pastures in the 16th Century (Eliasson and Nilsson, 2002), or drastic specific decisions, like the ban on grazing in forests in Romania in 1879 (Saláta et al., 2009), can result in long-lasting legacy effects that are still felt today.

The interaction of all these elements determines the environmental, social, governance, technological and economic properties of the social-ecological system. The results in paper V reveal that these properties, to a great extent, determine the final supply of ecosystem services. Their characteristics direct the wood-pasture manager’s decisions in particular directions regarding the four main management related ES trade-off dimensions (paper V, Fig. 4). The analysis revealed that the intensity of management is related to the socio-economic status of the social-ecological system. Wood-pastures with higher economic power, technologically more developed and with a more market-oriented production will tend to intensify the management practices favoring provisioning over regulatory services. Multifunctionality of production, on the other hand, tends to appear when the local product distribution chains are denser. Increased focus on crop production, which usually involves a high initial economic investment and long term-planning, tends to occur on privately owned wood-pastures. Finally, the supply of cultural ecosystem services appears to be mostly related to the degree of accessibility of the wood-pasture.
Cavender-Bares et al. (2015) presented a sustainability framework for landscape planning that characterizes ecosystem service trade-offs in terms of two dimensions: biophysical constraints, and; stakeholders’ different preferences and values. The results in paper III and V confirm these dynamics. At the farm scale, the wood-pasture manager’s or landowner’s values and perspectives are determined by the environmental, social, governance, technological and economic properties of the system, which shape the management model that ultimately determines the provision of ecosystem services.

Altogether, the papers in this thesis show how the diversity of wood-pastures in Europe mirrors the different roles wood-pastures play across Europe. They all share a similar spatial configuration, which combines trees at different densities with pasture, and a main principal objective of raising animals. However, the social-ecological state of wood-pastures varies greatly across Europe, which results in significant differences in ecosystem service supply depending on the diverse needs, values and motivations of the people working on them. In Östergötland, in general, agricultural landscapes are rather intensive. Food production is highly delocalized and, thus, the need for landscapes to produce multiple products is almost non-existent. In this context, wood-pastures are a relict landscape, perceived as a container of cultural values and which is, thus, primarily used for recreational purposes. In Spain, the dehesa is one of its most emblematic and recognizable landscapes and animal-derived products from dehesas are widely recognized. When dehesa enterprises are large, their management can be very profitable. Therefore, dehesas are increasingly being oriented towards provisioning services. In Southern Transylvania, wood-pastures are often semi-subsistence systems, where local households still rely heavily on multifunctional and extensive management. In conclusion, the social-ecological status of wood-pastures has a decisive influence on the supply or harnessing of ecosystem services. In order to efficiently address the multiple challenges currently faced by wood-pastures, there is a need to go beyond generalizations and acknowledge the multiple and diverse realities that exist within the same land-use system type.

Limitations of the study and perspectives for future research

Due to practical reasons, the scope of this thesis had to be narrowed to some core questions. This led to desirable, but also undesirable limitations with regards to the applied methods and the thematic scope. Moreover, the same way some planning and management decisions generate path-dependence effects that are often very costly to reverse, some decisions made at different points in the thesis limited the range of options to explore as research progressed. For example, the elicitation of the data in Southern Transylvania, Östergötland and La Serena was only achieved after fieldwork had been conducted in Llanos de Trujillo. Some elements that were considered decisive there were irrelevant later when fieldwork was conducted in La Serena, while new important elements arose in La Serena that had not been intensely explored previously. This situation recurred throughout the subsequent fieldwork in Östergötland and Southern Transylvania. It was possible to correct some of these elements by revisiting landowners and managers who had been previously interviewed, although this was not always possible. However, these limitations highlight once again the case-sensitivity and particularities of the different wood-pastures and regions.

One of the main limitations concerns the generalization of the results. The thesis applied a case study approach. The selection of the cases was guided by two main criteria. First, the selection aimed to choose paradigmatic and at the same time illustrative examples of different types of oak-based wood-pastures in Europe. The second criteria answered to pragmatic reasons. Given the nature of the
approach and the lack of previous experience working outside Spain, the presence of local facilitators was one of the prerequisites. Therefore, the cases were selected from the research network of the AGFORWARD project. Therefore, transferring the results as well as the implications to other contexts should be done with caution. In this sense, the aim of this thesis is to understand the underlying social-ecological processes that drive ecosystem service supply in wood-pastures, not to extrapolate the specific assessment results of, for example, Southern Transylvania to all Eastern European wood-pastures.

In this direction, more research is needed to fully understand the social-ecological dynamics of wood-pastures. Wood-pastures are integrated in larger agricultural landscapes that include other agricultural land-uses, urban and natural areas. The interaction between them has only been superficially explored in paper IV of this thesis. Moreover, the interactions between ecosystem services and the properties of the social-ecological system change across different spatial and temporal scales. As explained in the introductory section, this thesis takes a "snapshot" of the status of wood-pastures. Therefore, more social-ecological analyses in other regions over different periods of time are required to refine the results of this thesis and to obtain more knowledge on the role of path-dependency and legacy effects. Furthermore, although wood-pasture managers and landowners play a central role, they are part of a larger community. Therefore, the integration of the different stakeholders’ needs, values and perspectives along with the interaction between them and their positioning in the community is crucial for a full understanding of the undergoing dynamics of wood-pastures.
6. Conclusions

The overarching aim of this thesis was to assess the supply of ecosystem services in European wood-pastures and to identify the underlying mechanisms that drive this supply. It did so by using a holistic social-ecological approach:

1. First, the state-of-the-art in research on European wood-pastures was evaluated by assessing the methods and approaches employed in previous studies (paper I) and their main outcomes (paper II). The thesis reveals a rapid growth in interest in agroforestry, which, in general, has a positive effect on the provision of ecosystem services and biodiversity. However, several knowledge gaps, geographical and methodological biases were identified, which require further attention.

Current research on wood-pastures strongly relies on biophysical and economic approaches. There is a need for more research covering both a wider set of valuation approaches and a wider set of ecosystem services based on empirical quantitative primary data. In this direction, greater effort is required to develop formal metrics that can assess and value cultural and regulatory ecosystem services. Furthermore, wood-pastures and other agroforestry systems differ greatly across Europe and even within regions. This diversity is not represented in current research agenda. While the Mediterranean and Atlantic Europe are well-covered, Central and Eastern Europe remain largely unexplored. This geographical bias needs to be addressed.

Place-based assessments should subsequently be integrated in upscaling exercises to identify large-scale patterns across diverse social-ecological gradients. To do so, the outcomes of place-based research should be made available, possibly through open-source networks of primary data. Successful initiatives could be used as inspiration, such as the TRY database (Kattge et al., 2011), which provides a comprehensive archive of the functional biodiversity plants traits based on individual measurements. Similarly, individual assessments that only consider a few ecosystem services could be complemented or scaled up with research from other disciplines and other regions.

There is a widespread acknowledgement of the integrated social-ecological character of wood-pastures. However, the social side has been rarely considered. In order to efficiently address current sustainability challenges, it is necessary to integrate local stakeholders’ views and values in the assessments. In the same direction, there is a need to move beyond simplistic causal interpretations in the provision of ecosystem services to consider the interactions between multiple ecosystem processes. Finally, when assessing social-ecological systems, it is necessary to take the impact of present management into account as it may be creating pathway effects, as well as consider the past social-ecological trajectory and remaining legacy effects.

2. By focusing on the management practices carried out in the wood-pastures, this thesis links the supply of ecosystem services with diverse management styles that are present in a wood-pasture dominated landscape in South West Spain (paper III). This thesis demonstrates that ecosystem services in wood-pastures are co-produced by social-ecological processes. Wood-pasture
managers and landowners have a central role in this process as their management decisions will ultimately promote some ecological processes over others.

The focus of this study was then on exploring the role wood-pastures and other land-uses play at the landscape scale for the local inhabitants of the same region. This was achieved by using a socio-cultural approach to map place-based ecosystem services as perceived by the local community (paper IV). It was concluded that a mosaic of landscape types provided more ecosystem services to people compared with wood-pastures alone. It was also demonstrated that common land was perceived as a hot spot of ecosystem services. Finally, it was established that accessibility was a better predictor of ecosystem services provision than any land cover type.

This thesis draws a big part of its results from the Spanish dehesas. This is in part because the dehesa is the most extended wood-pasture type in Europe and its values are widely recognized by local stakeholders, consumers, policy makers and the research community. However, the results confirm previous assessments which state that current management is shifting towards more intensive models, while its social-ecological values are only accessible by a few people. To reverse some of these trends, some measures that should be explored are: (1) the facilitation of land access for small landowners or new ranchers to reverse the current dynamics of management intensification on small properties and land-use abandonment on large properties; (2) the promotion of integrated arable land in wood-pastures to reduce the high reliance on external supplementary fodder; (3) the stimulation of the commercialization of dehesa secondary products such as honey or wool, and alternative tertiary activities such as birdwatching-related tourism in order to enhance the multifunctionality of the dehesa and conserve its ecological values; and; (4) the recovery, maintenance and restoration of public paths and drove roads to make the landscape more accessible to the general public. The implementation of these four suggestions would require substantial interventions, such as a collectively planned land reform, where land tenure and management are discussed in a participatory manner and which considers a diverse representation of all stakeholders, including big and small, as well as both land-owners and tenants.

3. Finally, all previous finding were integrated in a cross-site comparison of four illustrative wood-pasture dominated regions to identify the inter-related social-ecological dynamics that ultimately drive ecosystem service supply in European wood-pastures (paper V). A different pattern of ecosystem service provision was identified in each of the four regions, which was governed by the decisions of wood-pasture managers and landowners in response to the following four main management dimensions: (1) the intensity of management; (2) the role played by crop production; (3) the degree of multifunctionality of the management, and; (4) the accessibility of the wood-pasture to the general public. These decisions are influenced by the environmental, social, technological, governance and economic properties of the systems, which have a direct influence on managers’ perspectives and motivations.

At the European level, it is demonstrated that beyond the similarities in the landscape between the wood-pastures in different regions, there is great variation in the social-ecological processes, the underlying dynamics, and the main challenges faced. Decision makers should, therefore, be cautious when designing large-scale policies as measures that could work for German *Streuobsts*
may overlook key elements for Portuguese montados. Hence, agroforestry systems embody the challenge of similar land-use systems that require different policy approaches. On the one hand, promoters of innovative agroforestry systems seek to increase their area and become a profitable alternative to monocultures in intensive agricultural landscapes. On the other hand, promoters of traditional agroforestry systems, such as wood-pastures, seek to prevent a decrease in the area while maintaining their cultural and ecological values. Given the context-specificity of the dynamics in agroforestry systems in general, and wood-pastures in particular, policies should, therefore, aim to fulfil their objectives on a smaller scale. One strategy would be to go beyond simplistic land-use type categorizations and strengthen the role of management in the Common Agricultural Policy. This could be achieved by further strengthening the role of payment schemes based on management practices that benefit the environment in pillar I of the CAP; while using the pillar II to influence on the place-based properties of the system driving management styles. In the case of wood-pastures, this thesis contributes to this recommendation by identifying the four main management dimensions that control the trade-offs and synergies between ecosystem services in wood-pastures and the key properties of the social-ecological system that drive management decisions.
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Paper I

A systematic map of ecosystem services assessments around European agroforestry

By Nora Fagerholm, Mario Torralba, Paul J. Burgess and Tobias Plieninger

Published in *Ecological Indicators, 62, 47–65. 2016*

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Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis

By Mario Torralba, Nora Fagerholm, Paul J. Burgess, Gerardo Moreno and Tobias Plieninger
Published in *Agriculture, Ecosystems & Environment, 230, 150–161. 2016*

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Paper III

Exploring the role of management in the co-production of ecosystem services from Spanish wooded rangelands

By Mario Torralba, Elisa Oteros-Rozas, Gerardo Moreno and Tobias Plieninger

Published in *Rangeland Ecology & Management*, in press. 2017

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Paper IV

Assessing linkages between ecosystem services, land-use and well-being in an agroforestry landscape using public participation GIS.

By Nora Fagerholm, Elisa Oteros-Rozas, Christopher M. Raymond, Mario Torralba, Gerardo Moreno and Tobias Plieninger

Published in *Applied Geography*, 74, 30–46. 2016

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Paper V

A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures

By Mario Torralba, Nora Fagerholm, Tibor Hartel, Gerardo Moreno and Tobias Plieninger

Submitted in October 2017 (under review)

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