AGFORWARD
Agroforestry for Europe

Ecosystem services and profitability of agroforestry practices

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1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale,
4. and to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report comprises Deliverable 7.20 which contributes to the third objective as it uses bio-physical, economic and socio-cultural approaches to improve our evaluation of the ecosystem services and profitability of European agroforestry. The original aim of the deliverable was to investigate the ecosystem services and profitability of novel agroforestry practices in major European bio-geographical zone compared to the status quo. The systems examined in this report include the high stem cherry orchard agroforestry in Switzerland, the Dehesa system in Spain, and the wood pasture system in Romania. Although these systems are not novel, the Deliverable describes novel means of investigating the ecosystem services and the profitability of contrasting types of European agroforestry. **This version of the deliverable, uploaded to the website comprises the five published papers; the remaining paper will be made available when it is published.** The characteristics of study sites, agroforestry systems and related ecosystem services in the six pilot studies are described in Table 1.

The paper that is still in production is:

Kay S, Herzog F, Szerencsits E, Crous-Duran J, García de Jalón S. Landscape-scale modelling of agroforestry ecosystems services: A methodological approach.

The five papers that have been published and which are presented in this report are:

García de Jalón S, Graves A, Moreno G, Palma JHN, Crous-Duran J, Kay S, Burgess PJ. (2018).Forage-SAFE: a model for assessing the impact of tree cover on wood pasture profitability. Ecological Modelling 372, 24–32.

Torralba M, Oteros-Rozas E, Moreno G, Plieninger T. (2018). Exploring the role of farm management in the co-production of ecosystem services in wood pastures. Rangeland Ecology & Management. Article in Press. https://doi.org/10.1016/j.rama.2017.09.001

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Hartel T, Réti K-O, Craioveanu C (2016). Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe. Agriculture, Ecosystems & Environment 236, 304-311.http://dx.doi.org/10.1016/j.agee.2016.11.019

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Table 1. Characteristics of study sites, studied agroforestry systems and related ecosystem services in six pilot studies

Study	**Kay et al.**	**García de Jalón et al. (2018)**	**Torralba et al. (2018)**	**Fagerholm et al. (2016)**	**Hartel et al. (2016)**	**Garrido et al. (2017)**
Title	Landscape-scale modelling of agroforestry ecosystems services: A methodological approach	Forage-SAFE: a model for assessing the impact of tree cover on wood pasture profitability	Exploring the role of farm management in the co-production of ecosystem services in wood pastures	Assessing linkages between ecosystem services, land-use and wellbeing in an agroforestry landscape using public participation GIS	Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe	Stakeholder perspectives of wood-pasture ecosystem services: A case study from Iberian dehesas
Country	Switzerland	Spain	Spain	Spain	Romania	Spain
Agroforestry system	High-stem cherry orchards, silvoarable	Dehesa wood pastures, agrosilvopastoral	Dehesa wood pastures, agrosilvopastoral	Dehesa wood pastures, agrosilvopastoral	Wood pastures (oak, pear), silvopastoral	Dehesa wood pastures, silvopastoral
Study area	7 municipalities in NW Switzerland	SW Spain	4 municipalities in Llanos de Trujillo 940 km^2	4 municipalities in Llanos de Trujillo 940 km^2	area of 3600 km^2, where 8 villages were chosen	province of Cáceres (219 municipalities)
Typical agroforestry-related ecosystem services in study area (mentioned by authors)	Cherries for liquor, tinned food or direct consumption, grass as fodder (hay, silage, pasture), timber	Grazing, firewood, acorns, hunting, mushrooms, cork, honey	Fodder (acorns, tree fodder), firewood, charcoal, microclimate, birdwatching, hunting, cultural heritage	Food, water regulation, minimization of soil erosion, recreation	Biodiversity, acorn, shade, fruits, erosion control, aesthetics, cultural heritage	Acorns, fodder, browse, firewood, charcoal, cork, microclimate, shelter, biodiversity, birdwatching, hunting, cultural heritage

2 Description and synthesis of six papers

Agroforestry is the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal production systems to benefit from the resulting ecological and economic interactions (Mosquera-Losada et al., 2009; Burgess et al., 2015). The diversity of practices behind the term agroforestry is vast and includes land uses such as silvoarable systems, forest farming, riparian buffer strips, improved fallow, multipurpose trees and silvopasture systems (Mosquera-Losada et al. 2009, den Herder et al. 2015). These agroforestry systems have played an important role in Europe in the past, and many current traditional land-use systems involve agroforestry. Economic conditions and a drive to produce low cost food decreased the importance of these systems during the twentieth century, but in recent years agroforestry has regained attention in Europe as a means of maintaining food production and profitability whilst enhancing environmental sustainability.

Agroforestry systems provide multiple ecosystem services, ranging from the provision of food, feed and fibre to non-commodity outputs, such as climate, water and soil regulation and recreational, aesthetic and cultural heritage values (e.g. McAdam et al., 2009; Smith et al., 2013, Torralba et al., 2016). Assessment of these ecosystem services creates knowledge to understand the supply and demand of ecosystem services, to raise awareness, and to achieve priority on the political agenda in the European Union (Cowling et al., 2008; Crossman et al., 2013; Maes et al., 2012). Assessments of ecosystem functions and their potential provision of ecosystem services to people have been dominated by natural sciences and economics (Seppelt et al., 2011; Vihervaara et al., 2010; Fagerholm et al., 2015). The common approaches to assessment have been identified as bio-physical, socio-cultural and economic (Cowling et al., 2008; de Groot et al., 2010).

This deliverable aims to provide a synthesis of different ecosystem service assessment approaches tested in different agroforestry systems identified for work-package 7 of the AGFORWARD project. The outputs provide evidence of the opportunities and challenges of each ecosystem service assessment approach and give insight for further synthesizing work in work-package 7. Below, each approach is shortly described based on which a synthesis for ecosystem service assessment approaches is presented.

The paper prepared by Kay et al. presents a bio-physical approach to ecosystem service assessment. The manuscript presents a study to assess ecosystem services of agroforestry systems from a landscape perspective. The authors select relevant indicators of provisioning, regulating and maintenance services, which differ in performance between agroforestry, agricultural and forest systems. Algorithms for quantifying these ecosystem service indicators are examined, tested, adapted and applied to a silvoarable landscape conformed by high-stem cherry orchards in Switzerland.

The paper published by García de Jalón et al. assesses the economic impact of trees in wood pastures for farm profitability. A new economic model called Forage-SAFE is presented, which simulates the daily balance between the produced and demanded food for livestock with a large number of biophysical and financial parameters to estimate annual farm net margin. The model estimates optimal management decisions that maximize net farm income such as tree cover density, carrying capacity and composition of livestock species. Application of Forage-SAFE is exemplified in dehesa wood pastures in Spain.

The remaining four papers present socio-cultural assessment approaches for ecosystem service assessment.

The paper in press by Torralba et al. assesses the co-production of ecosystem services in the Spanish dehesas by exploring the relationship between biophysical and sociocultural factors and farm management practices based on interviews with farm managers (n = 42). Relationships are characterized applying multivariate techniques that relate different quantitative farm management indicators and biophysical and sociocultural factors.

The case study by Fagerholm et al. (2016) is presented in Section 3. Residents of four municipalities (n = 219) are invited to respond to a map-based survey (PPGIS survey) to identify and map a range of ecosystem services that originate in place-based, local knowledge and list landscape-related items that contribute to subjective well-being. Identified ecosystem services and their spatial patterns and relationship to land properties are characterized. Linkages between ecosystem service provision and subjective well-being are explored. This socio-cultural assessment approach is applied in a Spanish dehesa landscape.

The paper produced by Hartel et al. (2016) is presented in Section 4. The paper assesses farmers' multiple values of scattered trees (mature and old) from oak wood pastures in a traditional rural region of Romania. Values by farmers are captured through semi-structured interviews (n = 92) and inductively coded to assess the importance of different values.

In Section 5, Garrido et al. (2017) perform face-to-face semi-structured interviews (n = 34) to describe stakeholders' appreciation of ecosystem services from dehesa landscapes in Spain. Interviews of selected stakeholder categories at civil, public and private sectors and at local and regional levels of governance are held to understand the difference of perception of ecosystem services between local and regional levels and among sectors.

Most of these studies are made at a local spatial scale with exception of García de Jalón et al. manuscript which targets regional level (Table 2). Garrido et al. (2017) presents a comparison between local and regional levels. Socio-cultural approaches seem to target a wider range of ecosystem service categories compared to the bio-physical or the economic approaches. The latter two, however, are more specific in defining indicators for ecosystem service assessment while the socio-cultural approaches are in most cases targeting values identified by people through participatory research. Data handling process is commonly based on statistical and spatial analysis or model development with exception of Hartel et al. (2016) and Garrido et al. (2017) papers where qualitative analysis is applied. Only two studies, Kay et al. and Fagerholm et al. (2016), are taking a spatially explicit approach for mapping ecosystem services.

All six approaches to ecosystem service assessment require high degree of time resources due to data collection either at field (measurements or interviews) or from statistics/literature. Field measurement or interview facilitation also requires a medium degree of economic resources.

Bio-physical and economic approaches identify the beneficial effect of agroforestry on ecosystem service provision as easily interpretable measured figures. In these models however many methodological considerations are related to available and chosen indicators. The socio-cultural approaches stress the importance of cultural services. Many of the values attached to the land and the landscape by people are difficult to categorize within the ecosystem service framework as these are landscape values rather than values related to specific ecosystem services. The co-productive nature of ecosystem services, meaning that both the natural and humans factors affect the supply of these services is also highlighted.

As a summary, it can be concluded that as the different approaches place focus on different ecosystem services, either on their supply or demand, the results give very different insights of the importance of ecosystem services in agroforestry systems. In comprehensive ecosystem service assessment it would be an advantage to bring together various approaches and plan a transdisciplinary research bridging natural and social science and economic approaches. Based on the pilot studies presented here, AGFORWARD will perform comparative analyses of the performance of agroforestry systems in terms of ecosystem services across twelve sites that represent all major agroforestry systems in Europe. These results will be reported in Deliverable 7.21.

Table 2. Characteristics of ecosystems service assessment approaches applied in six pilot studies

Study	Kay et al.	García de Jalón et al. (2018)	Torralba et al. (2018)	Fagerholm et al. (2016)	Hartel et al. (2016)	Garrido et al. (2017)
Approach	Bio-physical	Bio-economic	Socio-cultural	Socio-cultural	Socio-cultural	Socio-cultural
Ecosystem service supply /demand	supply	supply, demand and their difference	supply	demand	demand	demand
Method	Field investigations combined with modelling, comparison of agroforestry to agriculture and forestry	Forage-SAFE bio-economic model to simulate daily balance between the produced and demanded fodder (grasses)	Structured face-to-face interviews of farm managers (n=42)	PPGIS, free listing in semi-structured interviews of residents (n=219)	Semi-structured interviews of farmers (n=92)	Semi-structured interviews of selected stakeholder categories at civil, public and private sectors and at local and regional levels of governance (n=34)
Spatial scale (site, local, regional)	Site (LTS), local (landscape)	Regional	Local	Local	Local	Local and regional
Ecosystem service category assessed	Provisioning, regulating and maintenance	Provisioning	Provisioning, regulating, cultural	Supporting, provisioning, regulating, cultural	Supporting, provisioning, regulating, cultural	Supporting, provisioning, regulating, cultural
Ecosystem service(s) assessed	8 different: nutrition, material, energy, water supply, regulation of biophysical environment, flow regulation, regulation of physiochemical environment, regulation of biotic environment	Production of fodder, browse, acorn, firewood	12 different: provision of products/activities, livestock production, cereal production, firewood production, pollination, regulating ecosystem disservices, habitat provision, recreation, hunting, outdoor activities, wild resources harvesting	10 different in PPGIS: farm and harvested products, outdoor recreation, social interaction, aesthetics, culture and heritage, inspirational, spiritual and religious values, existence value, biodiversity, environmental capacities + 28 different landscape values (as forms, practices and relationships)	Around 40 different: e.g. shadow for livestock, fruits, history, aesthetics, cultural identity, firewood + several other landscape values (as forms, practices and relationships)	36 different: e.g. biodiversity, food, fodder, firewood, charcoal, natural hazard regulation, cultural landscape, heritage, education and knowledge

Table 2 (continued). Characteristics of ecosystems service assessment approaches applied in six pilot studies

Study	**Kay et al.**	**García de Jalón et al. (2018)**	**Torralba et al. (2018)**	**Fagerholm et al. (2016)**	**Hartel et al. (2016)**	**Garrido et al. (2017)**
Ecosystem service indicators	Biomass production, groundwater recharge, nutrient retention, soil preservation (erosion), carbon sequestration, biodiversity (pollination, habitat richness)	Energy produced from the pasture (kcal/ha/d) and energy demanded by livestock (kcal/ha/d)	No. of commercialized products/activities, grazing intensity, cereal production, firewood production, number of beehives, mineral inputs, capital inputs proportion of stonewalls, intensity of hunting, housing facilities, visitor frequency, no. of non-wood forest products harvested	Places or areas representing landscape practices and values mapped by informants, landscape values mentioned in relation to study area	Values mentioned by informants	Products, services and values mentioned by informants
Data handling process (qualitative, quantitative)	Quantitative (statistical analysis on spatial database)	Quantitative (daily time-step dynamic model developed in MSExcel)	Quantitative (statistical multivariate analysis techniques)	Quantitative (statistical and GIS analysis)	Qualitative (inductive coding technique)	Qualitative (content analysis)
Mapping (y/n)	Yes	No	No	Yes	No	No
Time requirement (high, medium, low degree)	High (intensive field measurements)	High (collecting data for various data parameters)	High (interview process)	High (survey app. 20 min/respondent, resources needed for training facilitators)	High (interview process)	High (survey 20-118 min/respondent)
Economic requirement (high, medium, low degree)	Medium (field measurement facilitation)	Low (if no costs for input material)	Medium (requires facilitator)	Medium (requires facilitators)	Medium (requires facilitator)	Medium (requires facilitator)

Table 2 (continued). Characteristics of ecosystems service assessment approaches applied in six pilot studies

Study	**Kay et al.**	**García de Jalón et al. (2018)**	**Torralba et al. (2018)**	**Fagerholm et al. (2016)**	**Hartel et al. (2016)**	**Garrido et al. (2017)**
Key conclusion(s)/ insights	Higher supply of ecosystem services in agroforestry landscapes. Regulating ecosystem services perform better when agroforestry present but provisioning better with non-agroforestry. Several methodological considerations involved in defining indicators.	Trees have positive effects for profitability of the agrosilvopastoral system. Trees provide important supply of fodder in terms of forage resources and buffering the difficulties imposed by the strong seasonality of the pasture growth. In future work adding other ecosystem services to the model would be beneficial.	Biophysical and sociocultural factors co-produce ecosystem services. Different access to land and capital is related with different farm management styles, which has consequences on the supply of ecosystem services. Policy makers should be aware of these connections.	A mosaic of landscape types provides more ecosystem services, especially cultural and provisioning, to people compared with the individual land system of agroforestry. Land tenure and public access significantly guided the spatial practices and values beyond the preferred landscape types.	Provisioning services and shade associated more to mature trees while intangible values (age, beauty, cultural identity) are associated to old trees. Values are in change and provisioning services decreasing in importance. Several types of landscape values were identified beyond the typical ecosystem service classifications.	Wide range of ecosystem services out of which cultural services are the most important for people but many would not be captured in common ecosystem service assessments. Clear differences between local and regional stakeholders. Ecosystem services are co-generated.

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3 Annex A: Paper 1: Forage-SAFE: a model for assessing the impact of tree cover on wood pasture profitability

This is a pre-print version of the following paper:
García De Jalón S, Graves A, Moreno G, Palma Joao, Crous-Durán J, Kay S, Burgess P. (2018) Forage-SAFE: a model for assessing the impact of tree cover on wood pasture profitability. Manuscript submitted to Ecological Modelling. https://doi.org/10.1016/j.ecolmodel.2018.01.017

Abstract
Whilst numerous studies have examined the environmental benefits of introducing additional trees within wood pasture systems few studies have assessed the impact on farm profitability. This paper describes a model, called Forage-SAFE, which has been developed to improve understanding of the management and economics of wood pastures. The model simulates the daily balance between food production and the livestock demand for food to estimate annual farm net margins. Parameters in Forage-SAFE such as tree cover density, carrying capacity, and type of livestock can be modified to analyse their interactions on profitability and to identify optimal managerial decisions against a range of criteria. A modelled dehesa wood pasture in South-western Spain was used as a case study to demonstrate the applicability of the model. The results for the modelled dehesa showed that for a carrying capacity of 0.44 livestock units per hectare the maximum net margin was achieved at a tree cover of around 53% with a mixture of Iberian pigs (28% of the livestock units) and ruminants (72%). The results also showed that the higher the carrying capacity the more profitable the tree cover was. This was accentuated as the proportion of Iberian pigs increased.
Keywords: Wood pasture, Agroforestry, Tree cover, Dehesa, Model, Profitability

Introduction
Wood pastures are silvopastoral agroforestry systems with irreplaceable ecological, social, and cultural values. Wood pastures occupy around 20.3 million ha in the 27 EU member states which represents around 4.7% of the European land (Plieninger et al., 2015); the area of grazed wood pasture in the EU has been estimated to be 15.1 million ha (den Herder et al., 2017). During the twentieth century, the area of wood pastures in Europe has declined either through agricultural intensification or abandonment. However, an increasing appreciation of the socio-economic and biodiversity value of wood pastures has led to conservation organisations, national governments, and the EU promoting wood pasture conservation across Europe (Bergmeier et al., 2010).

Wood pastures are complex systems where trees and shrubs, grass fodder and livestock interact in ways that vary with location and time. This makes it difficult to determine the impact of specific farm-management decisions on farm profitability. For instance whilst studies like Moreno and Pulido (2009) and López-Díaz et al. (2015) indicate that increased tree cover has the potential to improve pasture production and profitability, it is difficult to determine the tree effect in monetary terms or to identify the tree cover density which maximises profitability. In addition, previous modelling analyses of agroforestry economics have often been undertaken at an annual time-step (e.g. Graves et al., 2011; García de Jalón et al., 2018) which is not suited to evaluation of the moderating effects of trees on seasonal pasture production. This paper therefore presents a bio-economic model, called Forage-SAFE, which has been developed to evaluate the management and economics of wood pastures. A key feature of the model is that it can simulate the daily balance between food production and the livestock demand for food in wood pasture systems. The objective in developing the model was to gain a better understanding of the effect of farm-management decisions regarding tree, pasture and livestock on farm profitability.

A bio-economic model of wood pastures requires algorithms that explain the interactions between trees and pasture production. Numerous studies have measured the effect of trees on pasture production (Pardini et al., 2010; Moreno et al., 2007; Gea-Izquierdo et al., 2009). The net effect of trees on pasture production may be positive or negative depending on the soil fertility, light and water availability (Gea-Izquierdo et al., 2009; Rhoades, 1997). However, negative effects are more frequently reported (Pardini et al., 2010; Marañón and Bartolome, 1994; Barnes et al., 2011; Rivest et al 2013). Due to nutrient competition, Tian et al. (2017) found a reduction on productivity of grasses in the edge of tree-rows in alley cropping systems.

In a wood pasture in Central Italy Pardini et al. (2010) found that annual pasture biomass production at different distances from the tree trunk (at 2.11 m from the tree trunk, under the tree canopy; at 4.22 m on the limit of the tree canopy, and at 5 m, 10 m, and 20 m) was highest at the furthest distance from the tree. They also found that the annual pasture biomass under the tree canopy and at the limit of the tree canopy was 75% and 84% of the production at 20 m respectively.

In addition to affecting total grass production, trees also affect the composition of grass species which in turn, affects the nutritional characteristics of the pasture. Under trees in the dehesa, the presence of herbaceous perennials as well as the ratio of grasses (*Poaceae*) to legumes (*Fabaceae*) was higher than that in treeless areas (Puerto Martín et al., 1987; Montoya and Meson, 1982). Trees can also affect the seasonal distribution of pasture growth, and nutritional quality and this will also affect the quantity of pasture consumed by the livestock. Pasture that has not been grazed is available for livestock until the palatability and nutritional characteristics drop below a certain threshold (Pérez-Corona et al., 1998). Thus, extending the duration of suitable nutritional characteristics of the pasture more deeply into the summer and winter periods could potentially have beneficial effects on meeting the daily livestock demand for food. For example, in Spain, the shade provided by tree canopies during the hot summer months can reduce temperatures and evapotranspiration rates and hence the maturation rate of understorey grass. Thus, pasture under trees can be palatable for longer periods than in treeless areas. Furthermore, in cold winters the presence of trees can increase minimum temperatures that reduce the risk of ground frost and extends the growing season of pasture (Gea-Izquierdo et al., 2009; Moreno Marcos et al., 2007). However there are also locations and seasons where trees have a negative effect on pasture growth by increasing the competition for water and sunlight (Moreno et al. 2007; Pardini et al., 2010). This has been confirmed in alley cropping systems where the biomass yield of intercropped plants was limited by adjacent trees because of competition for water and light (Miller and Pallardy, 2001; Tian et al., 2015).

These effects of trees on the seasonal distribution of grass growth can vary with region. In Mediterranean pastures grass production is greatest in the spring and autumn-winter period whilst drought restricts growth during the summer. By contrast in wetter regions of North Europe, pasture production can be maintained during summer months whilst low temperatures restrict grass growth during the winter. When the food demand by livestock is greater than the immediate availability of pasture, farmers typically have to provide livestock with supplementary feed such as hay, silage or concentrates. In wood pastures trees can reduce fluctuations in pasture production and thus increase the number of days when pasture is available for livestock.

1) Trees can also contribute to the food demands of livestock by providing fruit and browse. Hence these components are included in the Forage-SAFE model which was developed to guide the decisions of researchers and advisors in relation to wood pasture management. This paper aims to describe the Forage-SAFE model and then to apply the model for a case study to assess the impact of tree cover density, carrying capacity, and composition of livestock species on wood pasture profitability.

Case study: a modelled dehesa in south-western Spain

A wood pasture dehesa in south-western Spain was selected as an example to show the applicability of the Forage-SAFE model. The major wood pasture system in South-western Spain is known as dehesa and the equivalent areas in Southern Portugal are known as montado. Dehesas are primarily used for grazing, but they also produce a wide variety of products including firewood, acorns, hunting, mushrooms, cork, and honey (Olea et al., 1990). The area of dehesa and montado in the Iberian Peninsula has been estimated to be around 3.04 million ha (Figure 1).

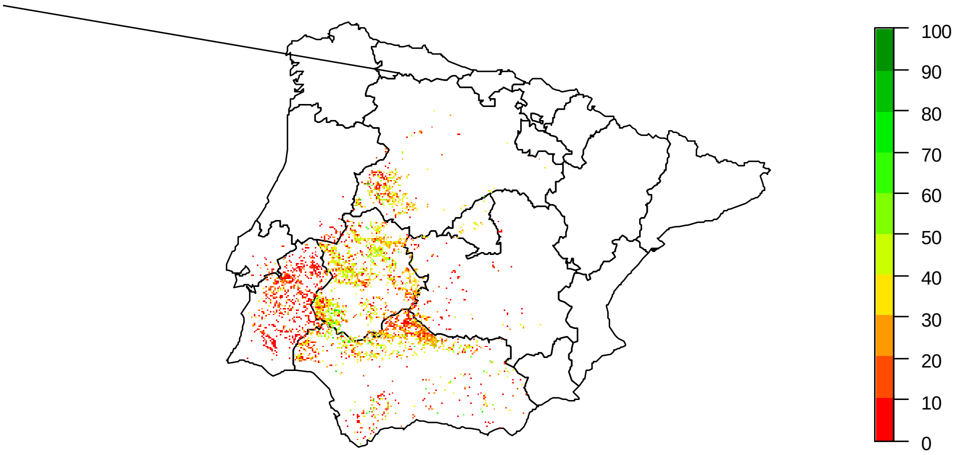

Figure 1. Location and tree cover of dehesa and montado in the Iberian Peninsula. Data used from CORINE Land Cover CLC 2012 and 2012 Tree Cover Density (http://land.copernicus.eu/).

In general, dehesa farms contain a mix of livestock and tree species, with the most common livestock species being ruminants (cattle, sheep and goats) and Iberian pigs. The main tree species is holm oak (*Quercus ilex* L. subsp. *ballota*), followed by cork oak (*Quercus suber* L.), and *Quercus pyrenaica* Willd. and *Quercus faginea* Lam. The average fraction of tree cover in the dehesa regions is around 24% (estimated in this study from CORINE Land Cover CLC 2012 and 2012 Tree Cover Density from the European Land Monitoring Service, http://land.copernicus.eu/). However, it is estimated that there are over 388,000 ha out of the 3.04 million ha mapped as dehesas that have no trees (over 10% of the total area of dehesa); the majority of the dehesa (around 93% of the area) has a tree cover lower than 50% (Figure 1). Treeless areas are still classified as dehesa, and not pasture, as the treeless areas belonged to dehesa farms in which the whole farm is considered as a dehesa system (Moreno et al 2016).

The typical carrying capacity of the dehesa, i.e. its capacity to support the energy needs of livestock, is relatively low with values between 0.2 and 0.7 Livestock Units (LU) ha^{-1}. Dehesas in Extremadura showed a mean carrying capacity of 0.37 LU ha^{-1} (Escribano et al. 2002). Daily grass production changes during the year and farmers often try to adapt the management system (e.g. the timing of calving or lambing) so that the demand of the livestock matches, as far as is possible, the seasonal food availability which is typically high during the spring and low in the dry summer months (Olea et al., 1990).

Methods

Methodological structure of the Forage-SAFE model

The Forage-SAFE model was developed to determine how the daily balance between food production and the demand for food by livestock affects the annual profitability of wood pastures. The model can be downloaded on the website of a EU FP7 project called "AGroFORestry that Will Advance Rural Development" (AGFORWARD, contract 613520, www.agforward.eu/index.php/es/1828.html). The model identifies food energy deficits and calculates when extra forage, concentrates, fruit or browse are required to meet livestock energy demands. Users can change a large number of parameters including farm structure and alternative forage sources to determine their effect on farm profitability. An optimisation module was developed to identify the combinations of tree cover, carrying capacity and livestock species that maximise production and profitability.

Forage-SAFE is a relatively simple daily time-step dynamic model developed in Microsoft Excel. It contains some macros written in Microsoft Visual Basic for Applications (VBA) to facilitate model use and to run optimization tools to identify locally optimal farm management practices that maximise profitability.

Over 300 variables and parameters can be set in Forage-SAFE to define the biophysical, managerial and economic characteristics of the wood pasture system. The biophysical characteristics include data on pasture, fruit, timber, firewood and browse production. The managerial characteristics include data related to livestock (species, type, age, calendar, weight and consumption), tree (planting, tree protection, pruning, thinning, cutting and browsing) and pasture and fodder crops (planting, fertilising, spraying, harvesting and baling). The economic variables include farm costs (variable, fixed, subcontracted labour and rented machinery, and unpaid labour) and revenue (sale of livestock and tree products, and other services).

Forage-SAFE is separated in seven spreadsheets:

1) Biophysical input data: this is the principal spreadsheet where end-users can set biophysical and managerial variables. The annual results are also shown in this sheet. It is divided in three different parts: *i)* biophysical and managerial input data, *ii)* the main annual results with links to graphical results, and *iii)* estimation of 'locally' optimal values of tree cover, carrying capacity and distribution of livestock species to maximise production and profitability.
2) Financial input data: input data on the monetary value of the various components of wood pastures.
3) Graphs: main graphical results including those with a daily time-step.
4) Livestock demand: calculations of daily food and energy demanded from each livestock species (e.g. cows, sheep and pigs) and type (e.g. suckler cow, growing cow and male adult cow).
5) Production NO TREE: calculations of the daily production of pasture and duration of energy content in areas beyond the tree canopy.
6) Production TREE: calculations of the daily production of pasture and duration of energy content in areas under the tree canopy. It also calculates browse and acorn production.
7) Biophysical analysis: calculations of the daily balance between produced and demanded food and resources in the wood pasture.

Produced food and resources

The model is designed so that the primary source of food energy to satisfy livestock demand is the energy contained in pasture, tree browse and fruits. As the available energy changes over time a daily basis framework was needed to assess the balance between produced and demanded food.

Produced energy from the pasture

The model calculated the energy produced from the pasture (MJ ha^{-1} d^{-1}) as the product of pasture produced in time *t* (kg dry matter (DM) ha^{-1} d^{-1}) and the energy content of the pasture (MJ kg DM^{-1}). The daily balance between pasture production and pasture consumption was calculated for each day, and unconsumed pasture was assumed to be available in subsequent time periods with an updated energy content. The potential change of available energy from pasture (*AEP;* units: MJ ha^{-1} d^{-1}) for day *t* was calculated using Equation 1:

$$\frac{dAEP_t}{dt} = PP_t * ECP + SEP_t \qquad \text{Eq. (1)}$$

where PP_t is the dry weight of pasture production on day t (kg DM ha^{-1} d^{-1}), *ECP* is the energy content in the pasture (MJ kg DM^{-1}), and SEP_t indicates the surplus of energy from accumulated pasture (MJ ha^{-1} d^{-1}), i.e. pasture previously produced that had not been consumed.
The value of SEP_t was calculated daily as the difference between pasture production and consumption using Equation 2 where:

$$\begin{gathered} SEP_t = \\ SP_{t-1} * ECP * D_{t-1} + \\ SP_{t-2} * ECP * D_{t-2} * D_{t-1} + \\ SP_{t-3} * ECP * D_{t-3} * D_{t-2} * D_{t-1} + \\ \ldots + \\ SP_{t-n} * ECP * D_{t-n} * D_{t-(n-1)} * D_{t-(n-2)} * D_{t-(n-3)} * \ldots * D_{t-(n-(n-1))} \end{gathered} \qquad \text{Eq. (2)}$$

and *SP* is the surplus from pasture produced in instant t (kg DM ha^{-1} d^{-1}) and D is the pasture senescence coefficient which indicates the retention of energy content over time. The value of D is affected by weather conditions: for example under extreme heat the retention of energy is greater at low temperatures than at high temperatures, e.g. in the summer, and these temperatures can be moderated by the shading effect of the trees.

The model separately calculates the available energy from pasture in treeless areas and areas under tree canopy. Building on Equation 1, which calculates the available energy from pasture in treeless areas, the available energy in areas under a tree canopy ($AEPwt_t$) is similarly calculated but with the inclusion of a tree density effect (Equation 3) using a Gompertz equation.

$$\frac{dAEPwt_t}{dt} = (PPwt_t * (1 - e^{\left(-e^{-b*(\delta - C)}\right)})) * ECPwt + SEPwt_t \qquad \text{Eq. (3)}$$

where $PPwt_t$ is the dry weight of produced pasture, *ECPwt* is the energy content and $SEPwt_t$ is the surplus of energy from accumulated pasture. Pasture production under tree canopy is multiplied by the Gompertz equation where δ is the proportion of tree cover (between 0 and 1) and b and C are constants.

Finally, the available energy from pasture in the system combining treeless areas and areas under tree canopies is calculated as follows:

$$AEP_t = (1 - \delta) * AEPwot_t + \delta * AEPwt_t \qquad \text{Eq. (4)}$$

where δ is the proportional tree cover, AEP_{wot} is the available energy from pasture in treeless areas and AEP_{wt} is the available energy from pasture in areas under tree canopy. In the modelled dehesa, 3.5% of the tree cover area was considered to be unproductive in terms of pasture production due to the area occupied by the tree trunks, and the fenced-off or protected areas safeguarding the regeneration of trees.

To derive the daily grass production needed as an input in Forage-SAFE, real data or the output of agroforestry models (e.g. Yield-SAFE (van der Werf et al., 2007; Palma et al., 2016; 2017), Modelo Dehesa (Hernández Díaz-Hambrona et al., 2008; Iglesias et al., 2016) and SPUR2 (Hanson et al., 1994)) can be used. In the dehesa case study, we used data from Daza (1999) in which daily pasture production and energy content in a dehesa in South-western Spain was measured for each month of the year.

Fruit and browse production by the tree

Fruit and browse were included in the model as sources of food to feed the livestock. A normal probability distribution was used to simulate daily production of fruit within the year comprising three terms: the level of maximum production, the day of the year of highest production, and the standard deviation in terms of number of days. In the modelled dehesa, the fruit was the holm oak acorn. The modelled average acorn production at 40% tree cover was 354.6 kg ha^{-1} between October and February. The assumed maximum value of production was 500 kg ha^{-1} yr^{-1}, the day of maximum occurrence was on 10 November and the standard deviation was 25 days. Rodríguez-Estévez (2007) stated that mean acorn yield in dehesas in Extremadura range from 300 to 700 kg ha^{-1} with a production equivalent to 8-14 kg tree^{-1}.

Typically in dehesas, Iberian pigs are preferred to ruminants as they are able to benefit from the foraging of the acorns (Rodríguez-Estevez et al., 2009) and the resulting high value added of Iberian pig products. This was included in the model by calculating two energy balances on each day. When acorn availability was greater than demanded by the pigs, the model assumed that ruminants could meet up to 10% of their daily food demand from the remaining acorns.

Browse from the tree was considered a food source when pasture production did not meet ruminants demand. In the modelled dehesa, browse was assumed to be available when pruning takes place in early February; this is to minimise the impact on acorn production. Pruning costs associated with browsing were considered after the acorns ripened and fell to the ground.

Forage-SAFE also includes other products that can contribute to farm revenues such as timber, firewood, cork, wool and milk. However for the modelled dehesa, it was assumed that all of the farm revenues came from the sale of animals and firewood.

Livestock demand for food

The livestock demand for food at each time increment (*DE;* units: MJ ha^{-1} d^{-1}) was separately calculated for each species (cattle, sheep and Iberian pigs) and individual according to gender/age category (growing, suckler and male adults) (Equation 5):

$$DE_t = \sum_{s=1}^{3}\sum_{y=1}^{3}(n_{t,s,y} * de_{t,s,y}) \qquad \text{Eq. (5)}$$

where $n_{t,s,y}$ indicated the number of animals in the field and $de_{t,s,y}$ the energy demand of each animal in the field (MJ animal^{-1}) at time *t*, for species *s* and type *y*. Forage-SAFE included two distinct ways to calculate the demanded energy from pasture of each animal. One way was to set the consumption of each animal (DM kg animal^{-1}) according to specific characteristics such as species, type, weight and physiological state (gestation, lactation and maintenance). The other way was to calculate the demanded energy from pasture using utilised metabolisable energy (*UME*; units: MJ LU^{-1} d^{-1}) (see Hodgson, 1990). Hodgson (1990) calculated the UME of a “reference animal” defined as a lactating dairy cow with a live weight (*W*) of 500 kg and milk yield (*Y*) of 10 kg d^{-1} as:

$$UME_t = 8.3 + 0.091 * W_t + 4.94 * Y_t \qquad \text{Eq. (6)}$$

where W_t and Y_t indicated the weight and milk yield respectively in instant *t*.

For Iberian pigs, it was assumed that they would consume between 6.5 and 7.6 kg of fresh acorns per day (3.1-3.6 kg DM kernel d^{-1}) and between 0.38 and 0.49 kg DM of pasture depending on the animal’s weight (Rodríguez-Estévez et al. 2009).

In the modelled dehesa, the selected carrying capacity was 0.37 LU ha^{-1} including cattle, sheep and Iberian pigs. It was considered that 38.5% of the total LU were cattle (0.122 growing cows, 0.148 suckler cows and 0.005 male adults per hectare), 39.9% sheep (1.287 growing sheep, 1.261 suckler sheep and 0.048 male adults per hectare) and 21.6% Iberian pigs (0.444 growing pigs per hectare). In the case of the Iberian pig, it was assumed that only growing pigs would be in the field. It was assumed that the new calves and lambs were born in December and February respectively to match the period of maximum pasture production with maximum demand.

Assessing the profitability of the wood pasture
The daily comparison of the energy available in the pasture, browse and fruits and the demand by livestock was used to estimate the requirement for supplementary food as forage, concentrates or acorns to meet the livestock demand. In the modelled dehesa, economic data from the EU Farm Account Data Network (FADN) database (http://ec.europa.eu/agriculture/rica/) and data from personal communication with farmers and experts were used.

Forage-SAFE used three different indicators to assess the profitability of the wood pasture and were calculated as follows:

1) **Gross margin**: revenue from any product and/or service of the wood pasture (e.g. animal sale, wool, milk, firewood and hunting) plus farming subsidies minus variable costs. Variable costs were separately measured for the livestock (animal purchase, forage and concentrates, veterinary and medicines, bedding and miscellaneous), the crop (seed and plants, fertiliser, crop protection, baling and other costs), and the tree (planting, tree protection, pruning, thinning, cutting and other costs) components. The annual gross margin of the wood pasture was denominated in euros (as of 2016) and expressed per hectare (see Equation 7).

2) **Net margin**: gross margin minus fixed costs (installation and repairs of infrastructure, fuel and energy, machinery, interest on working capital, and other costs) and paid labour and rented machinery costs (see Equation 8).

3) **Net margin including unpaid labour**: net margin minus unpaid labour rate times the estimated labour cost (see Equation 9). In the modelled dehesa, the estimated unpaid labour cost was 4.5 € h^{-1}. It could be argued that this cost was too low. However, considering that the opportunity cost of farmers in rural South-western Spain to work off-farm is very low the assumed cost seemed to be reasonable.

Estimating optimal managerial decisions in wood pastures
An important function within Forage-SAFE was the estimation of optimal managerial decisions to maximise gross margin, net margin and net margin including unpaid labour. Thus Forage-SAFE could suggest optimal tree cover, carrying capacity and livestock species composition, assuming that other parameters remained constant. Forage-SAFE used the Generalized Reduced Gradient (GRG) algorithm of the nonlinear Solving method in Microsoft Excel as not all the equations of the model were linear. The GRG algorithm estimated a 'locally' rather than 'globally' optimal solution. This indicated that there was no other set of values for the decision variables close to the current values that yielded a better value for the objective function (maximise production or gross and net margin). Equations 7-9 show the objective function used in Forage-SAFE to maximise annual gross margin (*GM*), net margin (*NM*) and net margin including unpaid labour ($NM_{unpaid\ labour}$), respectively:

$$Max.GM = \sum_{t=1}^{365}\sum_{c=1}^{3} PI_{t,c} + \sum_{t=1}^{365}\sum_{c=1}^{3} SI_{t,c} - \sum_{t=1}^{365}\sum_{c=1}^{3} VC_{t,c} \qquad \text{Eq. (7)}$$

$$Max.NM = GM - \sum_{t=1}^{365}\sum_{c=1}^{3} FC_{t,c} - \sum_{t=1}^{365}\sum_{c=1}^{3} SC_{t,c} \qquad \text{Eq. (8)}$$

$$Max.NM_{unpaid\ labour} = NM - \sum_{t=1}^{365}\sum_{c=1}^{3} UC_{t,c} \qquad \text{Eq. (9)}$$

where $PI_{t,c}$ is the income from sale products of the component *c* (livestock, tree and crop) at time *t*. *SI* is the income from subsidies, *VC* is the variables cost, *FC* is the fixed cost, *SC* is the subcontracted labour and rented machinery cost, and *UC* is the unpaid labour cost.

Results

Livestock demand for food

The results for the daily energy demanded for each animal species and type from pasture in the modelled dehesa shows the highest demand for pasture in the dehesa in the spring occurred at the same time as maximum pasture production (Figure 2). On dehesa farms, farmers try to maximise the number of ruminants in the spring and the number of Iberian pigs in late autumn and early winter to coincide with the production of holm oak acorn (Olea et al., 1990).

In the case of cattle and sheep (Figures 2.a and 2.b), the greatest demand for pasture occurred between late February and June, and the growing animals were assumed to be sold before pasture production falls in the summer. For cattle (Figure 2.a), calving was assumed to occur in December, and hence the energy demand of the suckler cows, which started increasing at the end of the gestation stage in November increases when lactation starts. Growing cows and sheep were assumed to be in the field until the age of 6.5 and 3.5 months respectively. In the case of Iberian pigs (Figure 2.c), it was assumed that only growing pigs would be in the field. The figure only shows the demanded energy from pasture. Iberian pigs were in the field for 100 days (90 days is the minimum period that Iberian pigs need to be in the field to obtain the premium value of acorn Iberian pork). Finally the total demand for pasture per day in the modelled dehesa was calculated as the sum of the demands of each animal (red line in Figure 2.d, see Equation 5).

Food supply for livestock

The seasonal distribution of the daily energy balance for the pasture and browse (Figure 3a) shows that maximal production occurred between February and early June and to a lesser extent between October and December. The largest surplus of pasture occurred between March and July. Overall, from early August to October and from late November to late January the provision of food energy of the system did not meet livestock demand. Thus farmers would need to use concentrates to satisfy the livestock demand or, as is common practice in the Spanish dehesas, allocate alternative land for producing forage for storage.

From early June to late September pasture production was almost negligible. However, ruminants in this period did not need extra forage or concentrates until August due to the surplus of pasture that was not consumed in the spring. During the spring, pasture production in treeless areas was higher than in areas under tree canopies. However, in early summer the duration of energy content in the surplus of pasture decreased faster in treeless areas than in areas under tree cover. Thus when the pasture was dry with very low energy content in treeless areas, under the tree canopy the accumulated pasture was still fresh and provided a source of food for the livestock. This allowed the extension of the period when external feed was not required. In a similar way but to a lesser extent, this also occurred in the winter where the tree canopy protected the pasture from frosts and thereby the pasture retained its energy content for longer.

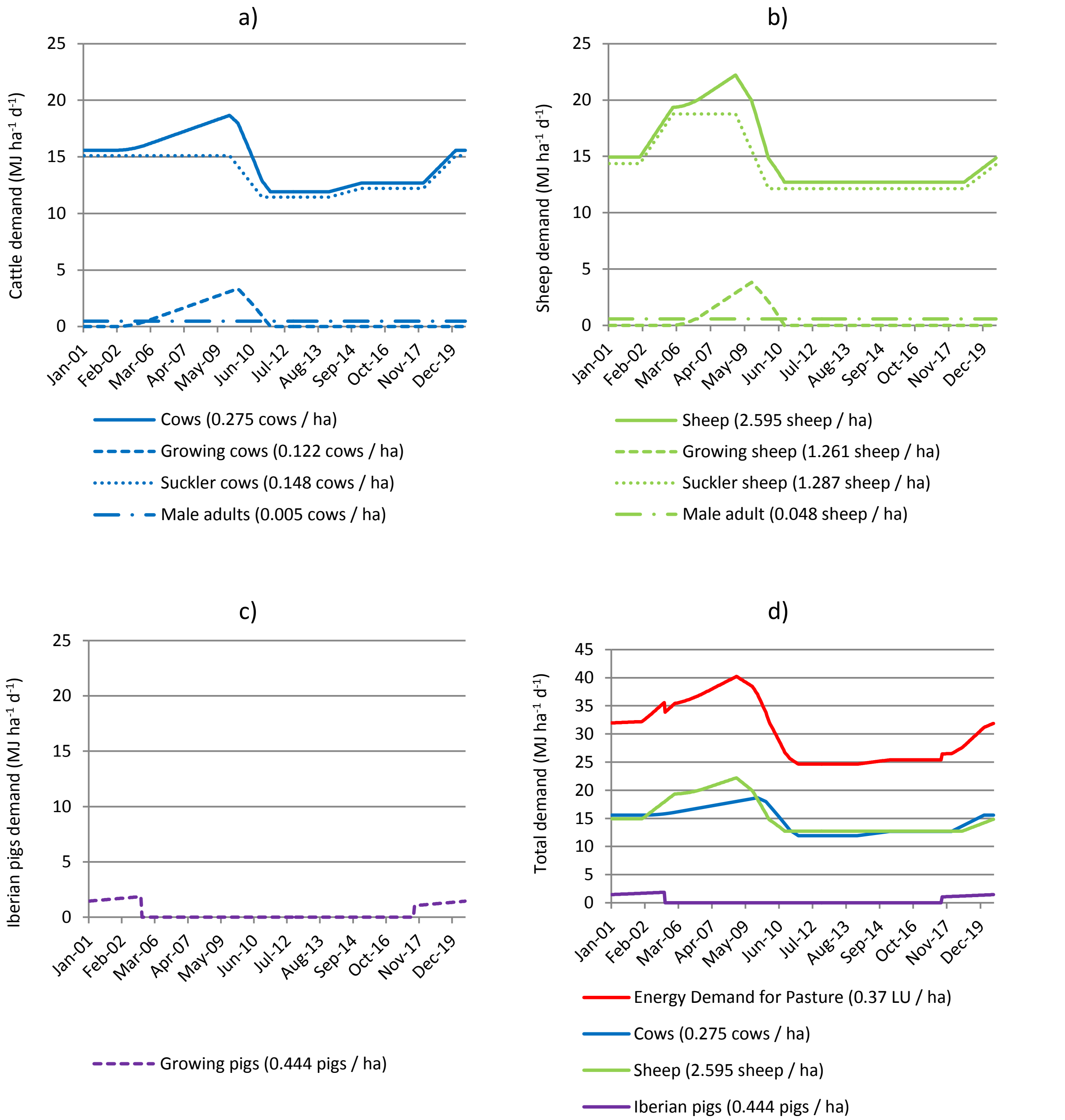

Figure 2. Seasonal (January to December) energy demand from pasture in the dehesa for 2.a) cattle, b) sheep, c) growing pigs, and d) the combination of each of the above.

Browse was used to feed ruminants in late January and this met some of the demand for pasture. The timing of Iberian pigs in the field from November to February coincided with the period of maximal acorn production (Figure 3b). It was assumed that pigs would have priority to eat acorns over ruminants, i.e. the ruminants would only eat acorns if pigs had previously satisfied their demand for acorns. Thus most acorns were used to feed the Iberian pigs.

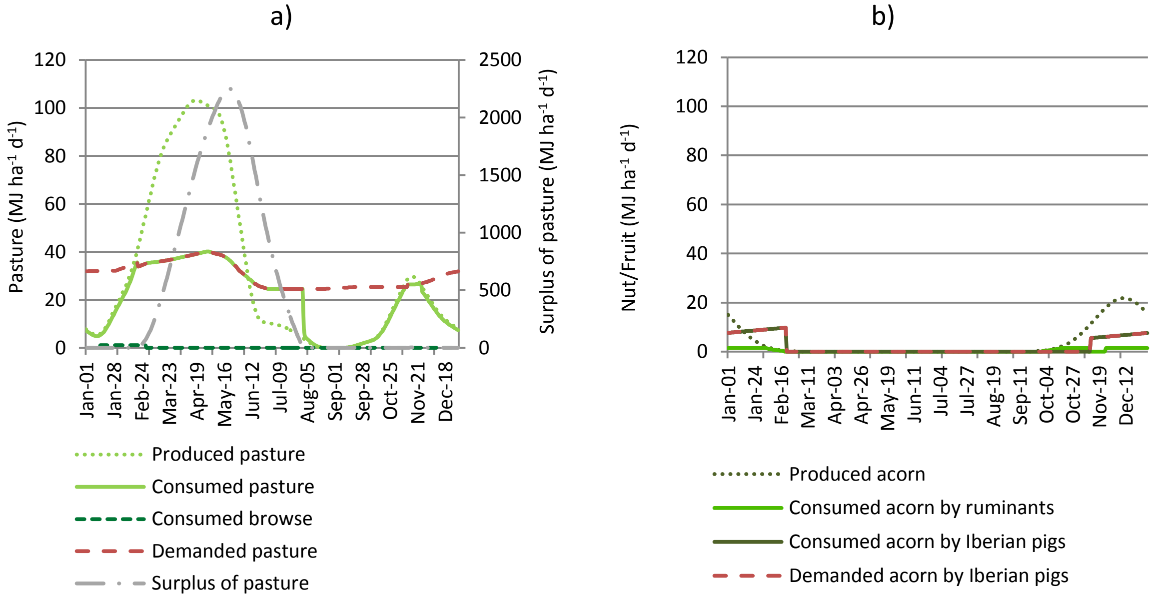

Figure 3. Produced (dotted lines), consumed (continuous lines), surplus (dashed and dotted line) and demanded (dashed lines) energy from a) pasture, browse and b) acorn in the dehesa case study at 0.37 LU ha^{-1} (39.9% sheep, 38.5% cattle and 21.6% Iberian pigs).

An analysis of the annual food production, consumption and extra requirements of the modelled dehesa at a carrying capacity 0.37 LU ha^{-1} (under different tree cover densities) showed that maximum annual pasture production was obtained at 0% tree cover (1465 kg DM ha^{-1}) (Table 1). Annual pasture production decreased as tree cover increased. By contrast acorn production increased as tree cover increased up to 70% tree cover beyond which point tree competition reduced acorn production.

The lower half of Table 1 shows annual consumption and extra requirements for a dehesa: i) with and ii) without Iberian pigs. Pasture consumption reached the maximum value at 30% tree cover in both situations reaching 876 kg DM ha^{-1} in the case of Iberian pigs and 1007 kg DM ha^{-1} without Iberian pigs. Browse consumption also increased as tree cover increased. Acorn consumption was maximal at 80% with Iberian pigs (285 kg ha^{-1}) and at 70% without Iberian pigs (103 kg ha^{-1}).

The annual quantity of extra forage and acorn needed to meet the livestock demand was also estimated. The lowest requirement for forage was 375 kg DM ha^{-1} in a dehesa with Iberian pigs at 50% tree cover and 559 kg DM ha^{-1} without Iberian pigs at 40% tree cover. Compared to the maximum value, in a treeless dehesa the forage needed increased by around 9% with and without Iberian pigs. In regards to acorn needs, from a 40% tree cover onwards there was no need to meet the Iberian pigs demand for acorns.

Table 1. Annual generated products and supplementary needs to satisfy livestock demand (0.37 LU ha^{-1}) in dehesa under different tree cover densities. Bold and underlined figures indicate the best and worst values from a financial perspective, respectively.

Indicator	**Tree cover (%)**										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Production											
Pasture (kg DM ha^{-1})	**1465**	1431	1397	1364	1328	1279	1181	1010	781	529	<u>281</u>
Acorns (kg ha^{-1})	<u>0</u>	90	179	269	352	424	475	**499**	495	466	424
With Iberian pigs (cattle = 0.14 LU ha^{-1}, sheep = 0.15 LU ha^{-1}, Iberian pigs = 0.08 LU ha^{-1})											
Consumption											
Pasture (kg DM ha^{-1})	874	875	876	**876**	875	870	848	799	705	502	<u>267</u>
Browse (kg DM ha^{-1})	<u>0</u>	3	5	8	10	13	15	18	21	23	**26**
Acorns (kg ha^{-1})	<u>0</u>	63	126	188	241	276	284	285	**285**	284	277
Extra supplementary needs											
Forage needed (kg DM ha^{-1})	408	406	405	403	385	**375**	390	436	528	730	<u>967</u>
Acorns needed (kg ha^{-1})	<u>201</u>	138	75	13	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Without Iberian pigs (cattle = 0.18 LU ha^{-1}, sheep = 0.19 LU ha^{-1})											
Consumption											
Pasture (kg DM ha^{-1})	1005	1006	1007	**1008**	1007	1001	972	901	742	502	<u>267</u>
Browse (kg DM ha^{-1})	<u>0</u>	3	5	8	10	13	15	18	21	23	**26**
Acorns (kg ha^{-1})	<u>0</u>	41	79	91	96	100	102	**103**	103	102	100
Extra supplementary needs											
Forage needed (kg DM ha^{-1})	610	589	570	563	**559**	562	588	657	815	1053	<u>1288</u>
Acorns needed (kg ha^{-1})	0	0	0	0	0	0	0	0	0	0	0

Tree cover impact on profitability

Forage-SAFE was designed to allow the assessment of the impact of different tree cover densities on the profitability of the wood pasture. Table 2 shows the gross margin, net margin and net margin including unpaid labour in the modelled dehesa, and the percentages show the relative change compared to the maximum value. With Iberian pigs, the highest profitability was achieved at 40% tree cover (*GM* = 179 € ha^{-1}, *NM* = 72 € ha^{-1} and $NM_{\text{including unpaid labour}}$ = 35 € ha^{-1}). Without Iberian pigs, the highest profitability was achieved at 20% tree cover (*GM* = 128 € ha^{-1}, *NM* = 43 € ha^{-1} and $NM_{\text{including unpaid labour}}$ = 28 € ha^{-1}). It is worth highlighting that the net margin including unpaid labour in a treeless dehesa without Iberian pigs was 8% lower than at 20% tree cover.

Table 2. Profitability of dehesa under different tree cover densities. Percentage values show the relative reduction compared to the maximum value in each indicator. Bold and underlined figures indicate the best and worst values from a financial perspective within each scenario, respectively.

Profitability indicator	**Tree cover (%)**										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
With Iberian pigs (cattle = 0.14 LU ha^{-1}, sheep = 0.15 LU ha^{-1}, Iberian pigs = 0.08 LU ha^{-1})											
Gross margin (€ ha^{-1})	106	129	153	175	**179**	177	175	173	159	120	<u>74</u>
	-41%	-28%	-15%	-2%	**0%**	-1%	-2%	-3%	-11%	-33%	<u>-58%</u>
Net margin (€ ha^{-1})	-1	23	46	69	**72**	70	68	66	52	13	<u>-33</u>
	-101%	-69%	-36%	-4%	**0%**	-3%	-6%	-8%	-27%	-82%	<u>-146%</u>
Net margin including unpaid labour (€ ha^{-1})	-35	-12	10	33	**35**	33	30	28	14	-26	<u>-72</u>
	-198%	-134%	-70%	-7%	**0%**	-7%	-14%	-22%	-61%	-174%	<u>-305%</u>
Without Iberian pigs (cattle = 0.18 LU ha^{-1}, sheep = 0.19 LU ha^{-1})											
Gross margin (€ ha^{-1})	124	126	**128**	127	126	123	117	102	71	24	<u>-21</u>
	-3%	-1%	**0%**	-1%	-2%	-4%	-9%	-20%	-45%	-81%	<u>-116%</u>
Net margin (€ ha^{-1})	39	41	**43**	42	41	38	31	16	-15	-61	<u>-106</u>
	-8%	-4%	**0%**	-2%	-5%	-11%	-27%	-61%	-135%	-243%	<u>-350%</u>
Net margin including unpaid labour (€ ha^{-1})	25	26	**28**	26	24	21	14	-1	-33	-80	<u>-126</u>
	-8%	-4%	**0%**	-4%	-11%	-23%	-49%	-105%	-220%	-390%	<u>-556%</u>

Lastly the locally optimal tree cover, carrying capacity and livestock species composition that maximised the gross margin, net margin and net margin including unpaid labour costs in the modelled dehesa were calculated (Table 3). These values were locally optimal for the parameter values in the modelled dehesa which had a tree cover of 40% and a carrying capacity of 0.37 LU ha^{-1} from which 38.5% corresponded to cattle, 39.9% to sheep, and 21.6% to Iberian pigs. The results showed that, keeping all other parameters constant, profitability was maximised at about 32% tree cover. The carrying capacity values that maximised profitability ranged between 0.40 LU ha^{-1} and 0.46 LU ha^{-1}. The gross and net margins were maximised when Iberian pigs comprised between 9.8% and 26.7% of the overall livestock units.

The last three rows of the table showed the optimal simultaneous combination of tree cover, carrying capacity, and livestock species composition. The estimated gross and net margins were higher than those estimated when only one variable was changed in the optimisation problem. This reflects the economic effect of combining these managerial decisions. The optimal combination that maximised the net margin including unpaid labour had a tree cover of 53.1% and a carrying capacity of 0.44 LU ha^{-1} of which 71.9% were ruminants and 28.1% Iberian pigs. The maximum net margin including unpaid labour in the modelled dehesa was 52 Euros ha^{-1}.

Table 3. Locally optimal values of tree cover, carrying capacity and livestock species composition that maximise farm gross margin (*GM*), net margin (*NM*) and net margin including unpaid labour costs (*NM* unpaid labour). The default values of the modelled dehesa were a tree cover density 28% and a carrying capacity 0.37 LU ha^{-1} from which 78.4% were ruminants (0.28 cows and 2.60 sheep ha^{-1}) and 21.6% Iberian pigs (0.44 pigs ha^{-1}).

Objective function	**Tree cover (%)**	**Carrying capacity (LU ha^{-1})**	**Livestock species composition**		**Margin (€ ha^{-1})**
			Ruminants (% LU ha^{-1})	**Iberian pigs (% LU ha^{-1})**	
Optimal tree cover					
Max. *GM*	32.1	-	-	-	180
Max. N*M*	32.1	-	-	-	73
Max. *NM* *unpaid labour*	32.1	-	-	-	37
Optimal carrying capacity					
Max. *GM*	-	0.46	-	-	196
Max. N*M*	-	0.41	-	-	86
Max. *NM* *unpaid labour*	-	0.41	-	-	48
Optimal livestock species composition					
Max. *GM*	-	-	26.7	73.3	189
Max. N*M*	-	-	26.7	73.3	77
Max. *NM* *unpaid labour*	-	-	9.8	90.2	40
Optimal combination of tree cover, carrying capacity and livestock species composition					
Max. *GM*	61.8	0.44	30.6	69.4	225
Max. N*M*	55.9	0.44	29.2	70.8	103
Max. *NM* *unpaid labour*	53.1	0.44	28.1	71.9	53

Discussion

Forage-SAFE has some limitations that should be taken into account. Firstly, some of the input parameters could not be easily obtained or varied substantially throughout time, and the calculation of the farm net margin can be very sensitive to these parameters. For example, the price of the live weight of the animals affects the estimation of optimal carrying capacity and livestock species composition. Since livestock prices can be volatile, the results can vary greatly between years. Secondly, the rate of decrease of the energy content in pasture can be difficult to model and validate with real data. In Forage-SAFE, the value of the pasture senescence coefficient (*D*) varied with daily weather data and considered microclimatic effects determined by the interaction between the tree and the pasture. In the Mediterranean dehesa, the coefficient should have lower values in summer when the nutritional value of the pasture decreases quickly as a result of drought. Thirdly, within the model it is assumed that the farm administrative costs are independent of the tree cover. However in practice a farmer may need to spend time categorising the different levels of tree cover across a farm when claiming support from the European Union Common Agricultural Policy. Fourthly, the model assumed a steady state in terms of the maturity and density of the trees and did not simulate a whole tree rotation. Thus there were some revenues and costs that were not considered in the economic analysis. However, the rotation of wood pastures is often very long which makes it difficult to model all the costs and benefits incurred in the past. In the case of the dehesa, the rotation of holm oak is often around 180-250 years (Montoya, 1989; Olea and San Miguel-Ayanz, 2006) and sometimes the origin of the dehesa is associated with clearing of the trees in holm oak forests (San Miguel, 1994). In order to solve these issues, Forage-SAFE calculates costs that are not annually undertaken (e.g., planting, pruning and thinning costs) by using the frequency of the operation during the rotation. Despite these challenges, Forage-SAFE provides a systematic means of quantifying the effect of trees on pasture production and the impact of managerial decisions on the economics of wood pasture systems.

The results in the modelled dehesa showed that trees could provide an important supply of food in terms of forage resources and buffer the challenges created by the strong seasonality of pasture growth. In terms of forage resources, the results showed that for the modelled dehesa farm, 40% tree cover provided the maximum metabolisable energy. This metabolisable energy was provided by the pasture, browse and acorns. Although at this tree cover, neither the production of pasture, browse, or acorns was maximised, the combined metabolisable energy production of all three together, was greater than at any other tree cover density. In terms of buffering the strong seasonality of pasture growth, the results showed that despite lowering annual pasture production, the presence of trees can increase pasture consumption. Annual pasture production was maximised at 0% tree cover. However, despite producing 9% less grass than at 0% tree cover, the maximum pasture consumption was reached at a tree cover of around 30% both with Iberian pigs (an increase of 0.2% in comparison with 0% tree cover) and without Iberian pigs (an increase of 0.3% in comparison with 0% tree cover). This was because the trees helped to maintain the nutritional characteristics of the pasture for longer periods of time, particularly in summer and winter. These results indicate that even if there are no Iberian pigs in the dehesa, trees will still have a positive effect on the profitability of the system. It is worth highlighting that over 10% of the total area of dehesa and montado in the Iberian Peninsula has a tree cover density lower than 10% (Figure 1). Thus our results suggest that profitability of Iberian dehesas and montados could be increased by increasing tree cover density, since higher levels of metabolisable energy would be produced and consumed at higher tree cover densities.

Pasture production under the tree canopy was calculated to be around 77% of the production in treeless areas. Approximately 3.5% of the tree cover area was considered unproductive due to the area occupied by the trunk and any fenced off or protected areas protecting the regeneration of trees. Several studies have shown that annual grass production under tree canopies is usually lower than in areas without trees (e.g. Marañón and Bartolome, 1994, Pardini et al., 2010 and Barnes et al., 2011). These studies have found an annual reduction of pasture production under tree canopies of 75-100% compared to treeless areas. The extent of the variation depends on a number of factors such as climate, slope, orientation, and tree and grass species. Some studies have highlighted that higher latitudes and colder climates can lead to a lower relative yield (Silva-Pando et al., 2002; Pardini et al., 2010) than in Iberian dehesas (Moreno et al., 2007; Gea-Izquierdo et al., 2009). Moreover, extrapolating a reliable estimation of pasture production in scattered trees wood pastures is difficult and Rivest et al. (2013) and Mazía et al. (2016) show that, on average, the net effect of the trees on pasture understory is almost neutral although there is high spatio-temporal variability. The meta-analysis in Rivest et al. (2013) shows that the net effect depends on tree traits (e.g. deciduous vs evergreen; legumes vs non-legumes), climate, temporal distribution of rainfall and soil fertility. Recent advances in agroforestry modelling (e.g. van der Werf et al., 2007 and Iglesias et al., 2016) could help provide more robust data to use with the Forage-SAFE model. The increasing reliability of satellite data for estimating pasture productivity also provides opportunities to use such data for individual farms (e.g. Ali et al., 2016).

Only provisioning ecosystem services (production of pasture, browse, acorn and firewood) were included as sources of revenue in this assessment. A wider economic analysis, from a societal perspective, could also include a range of non-marketed ecosystem services and this is likely to increase the estimates of optimal tree cover density. For example, including the value of regulating and cultural services such as carbon sequestration, biodiversity, recreation and landscape values, would increase the value of the trees, and in turn the optimal tree density in the landscape. Some studies have measured the beneficial effect of trees in increasing soil organic carbon (Howlett et al., 2011) and described benefits to biodiversity (Moreno et al., 2016), and cultural services such as recreation and landscape aesthetic (Fagerholm et al., 2016). The RECAMAN project has recently evaluated the monetary value of provisioning, regulating and cultural services of Iberian dehesas

(Campos et al., 2014; Ovando et al., 2015). The profitability of trees in dehesas could also be increased by including agri-environment subsidies that can be available for afforestation of agricultural land (since 1992) or the establishment and maintenance of agroforestry (since 2007) (European Commission, 2013).

Conclusions

This paper describes a bio-economic model, Forage-SAFE, and its application to determine the impact of tree cover on the management and economics of wood pasture systems using a dehesa case study. The model quantified the energy demanded by livestock and the energy provided by the system using a daily time-step. Using the model, we calculated how much extra forage was needed to satisfy the livestock feeding requirements and included this cost in the profitability assessments. Using current costs and benefits, the results demonstrate that the trees in dehesas provide a net financial benefit and it is possible to identify an optimal tree cover density. The results showed that the highest annual pasture production was achieved at 0% tree cover. However, considering pasture, browse, and acorns together the production of metabolisable energy was maximised at a tree cover density of around 40%. At a typical stocking density of 0.37 LU ha^{-1}, the maximum net margin, including unpaid labour as a cost to the farmer, was obtained at a tree cover density of around 32%. This increased as carrying capacity and the proportion of Iberian pigs was increased. These results suggest that a daily time-step modelling approach based on the practical challenges of managing varying livestock demand for metabolisable energy and varying pasture production is needed for quantifying the economic impact that trees have on buffering the strong seasonality of pasture growth.

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4 Annex B: Paper 2: Exploring the role of farm management in the coproduction of ecosystem services in wood pastures

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Abstract
The wood pastures or hardwood rangelands of the southwestern Iberian Peninsula are complex social-ecological systems created from the long-term interaction of society and the landscape. *Dehesa*, oak woodlands managed for grazing, cropping, and other forms of production, is the most common rangeland system and one of the most distinctive landscapes. Traditionally characterized by multifunctional low-intensity management that enhances a wide range of ecosystem services, current management has shifted from the traditional towards more intensified models. This paper assesses the co-production of ecosystem services on dehesa properties by exploring the relationship between biophysical and sociocultural factors and dehesa management practices. Based on 42 surveys we analyze 16 quantitative indicators using multivariate techniques. The results indicate that there are four main dehesa types as defined by their characteristics and management: large heterogeneous operations with diverse products; small and homogeneous operations focused on a reduced number of products; medium-large properties focused on crop production; and mid-sized properties with easy public access. Management is the result of the dynamics of interacting biophysical and sociocultural factors that influence manager priorities and investments. Management decisions group around the degree of multifunctionality of the operation, the relative importance of crop production, the degree of grazing pressure in the system, and how restrictive public access policy is. We find that in the study area, interactions between all the above-mentioned elements covary consistently, generating bundles of ecosystem services associated with each of three management models based in the intensity of management.

Keywords: social-ecological system, tradeoffs, synergies, bundles, multifunctionality

Introduction
In Europe, wood pasture is a historical land management system in which open woodland provides shelter and forage for grazing animals, as well as providing for the production of a variety of woodland products. These rangelands, with their scattered trees and shrubs (Bergmeier et al., 2010), have an important role in European rural landscapes (Jørgensen and Quelch, 2014). Wood pastures are especially abundant in Mediterranean countries and Eastern Europe, and in total they cover an area of 203,000 km^2, approximately 4.7% of the 27 countries of the European Union (EU) (Plieninger et al., 2015). In the South-West of the Iberian Peninsula wood pastures are most often oak woodlands, hardwood rangelands managed for diverse products including livestock and game, generally referred to as *dehesa* (Huntsinger et al. 2013).

The long-term interaction between these wooded rangelands and the people living among them is an archetype of coupled social-ecological systems (SES), where ecosystems and society have shaped one another (Huntsinger and Oviedo, 2014). As such, they are an important part of European cultural heritage and host rich local ecological knowledge (Plieninger et al., 2015). The traditional management of wood pastures, typically characterized by low intensity management practices (Halada et al., 2011) and multifunctionality (understood as the ability to generate multiple products and diverse activities in the same management unit), in combination with high temporal and spatial heterogeneity, enhances biodiversity and ecosystem service provision (Díaz et al., 2013; Torralba et al., 2016). Therefore, dehesa and other wooded rangelands are considered prime examples of high nature value farming systems by European policy makers and scholars (Oppermann and Beaufoy, 2012), as they enhance biodiversity through low-intensity management (Fischer et al., 2010; Mountford and Peterken, 2003) and habitat diversity (Moreno et al., 2016).

In Spain, holm oak (*Quercus ilex*) dehesas are the main rangeland type. Livestock graze the abundant understory grasses, and the oaks are a supplementary source of feed, providing acorns and tree fodder to a range of livestock including beef cattle, Iberian pigs, sheeps, and goats and supporting a secondary industry in firewood and charcoal. Tree density is managed to create a microclimate that allows pasture vegetation, mostly annual grasses, to survive for a longer period into the hot summer drought (López-Sánchez et al., 2016; Moreno et al., 2013), and to provide shelter for livestock (Ruiz and Gonzalez-Bernaldez, 1983). Dehesas traditionally incorporate crop production (mainly cereals for fodder production) and game habitat management within rangelands dominated by livestock grazing, creating an integrated and diverse agroecosystem.

Many dehesas have been affected by processes common to other European wood pastures, as a consequence of two antagonistic trends: land abandonment and agricultural intensification (Roellig et al., In revision; Stoate et al., 2009). Both processes reduce the multifunctional character of management and the heterogeneity of the landscape, and typically lead to a loss of biodiversity (Bugalho et al., 2011; Plieninger et al., 2014; Queiroz et al., 2015). The drivers behind these processes are complex, but the consequences are that the land is abandoned to the dense shrubs that take over unmanaged dehesas, or under intensification, management tends to become more mono-functional, focused on meat production. As the secondary products of wood pastures (such as charcoal or cork) have low profitability (Bugalho et al., 2011), production tends to become less diverse. In particular, there is an increasing tendency to import animal fodder instead of relying on local resources, further exacerbating the disappearance of traditional practices such as transhumance (Oteros-Rozas et al., 2014), or the use of trees as for fodder (Moreno and Pulido, 2009).

The challenges that wood pastures currently face may be threatening their capacity to provide ecosystem services (ES). The ES framework has proved to be a useful tool for understanding the functioning of social-ecological systems in general (Reyers et al., 2013), and of the multifunctional role of wood pastures in enhancing biodiversity and ES provision in particular (Huntsinger and Oviedo, 2014; Torralba et al., 2016). However, as it has been pointed out in different literature reviews of ES provision in agroecosystems, biophysical and monetary valuation of ES is to date the main area of research, which means that the socio-cultural dimension of ES provision is often neglected (Fagerholm et al., 2016b; Nieto-Romero et al., 2014). In addition, there is a need for a more thorough understanding of the complex relationships between ES, in particular their interactions in term of tradeoffs, synergies and bundles (Mouchet et al., 2014) and the relation between management practices and ES provision (Andersson et al., 2015).

Current understanding of the linkages between the biophysical and sociocultural components involved in ES provision is limited (Bennett et al., 2015). Recently, Palomo et al. (2016) and Fischer & Eastwood (2016) offered theoretical frameworks explaining how ES are coproduced in social-ecological systems through the interaction between an ecosystem component and a social component. Here, we propose that the co-production of ES is based on feedback processes in which a social system actively shapes and modifies an ecosystem through farm management (Fig. 1). At the same time, the ecosystem provides the physical framework and limits or increases the range of management options based on the ecosystem structure and the ecological processes underlying it.

On the one hand, management decisions are based on the natural resources involved in co-production, and their potential and limitations, while, on the other hand, they are also shaped by sociocultural factors, often external to the individual operation, such as the governance context or markets. Typically, the perception and appreciation of ES varies across stakeholder groups (Fagerholm et al., 2016a; Garrido et al., 2017; Oteros-Rozas et al., 2014; Villamor et al., 2014). Sociocultural and biophysical factors, such as land tenure and property size, influence management decisions, perceptions, and perspectives (Hausner et al., 2015; Huntsinger and Oviedo, 2014; Malinga et al., 2016).

The main objective of this paper is to explore how management influences the co-production of ES. In particular, we identify and characterize dehesas in relation to their management. We explore the synergies and tradeoffs associated with management, analyzing how biophysical and sociocultural factors influence the range of management models. Finally, we identify how different management styles foster and promote different management outcomes that result in the provision of different bundles of ES.

We not only analyze how different management models affect the social-ecological system, but also explore whether there are links between management and biophysical and sociocultural conditions. Property size and land tenure have been previously identified as key features for management (Hausner et al., 2015; Malinga et al., 2016; Schaich and Plieninger, 2013; Stubkjaer Andersen et al., 2013). Accessibility has also been identified as a decisive factor (even more than land use) in people's perceptions of ES provision, and has a determinant key role in regulating people's ability to explore and experience the landscape (Brown et al., 2014; Fagerholm et al., 2016a; Garrido et al., 2017), so we also explore how ranch access affects the creation of ES tradeoffs and synergies. Finally, we also examine how vegetation cover type diversity affects ES co-production. It is expected that greater diversity will deliver a broader range of ES, as has previously been observed in other studies (Andersson et al., 2015; Lüscher et al., 2014; Raudsepp-Hearne et al., 2010).

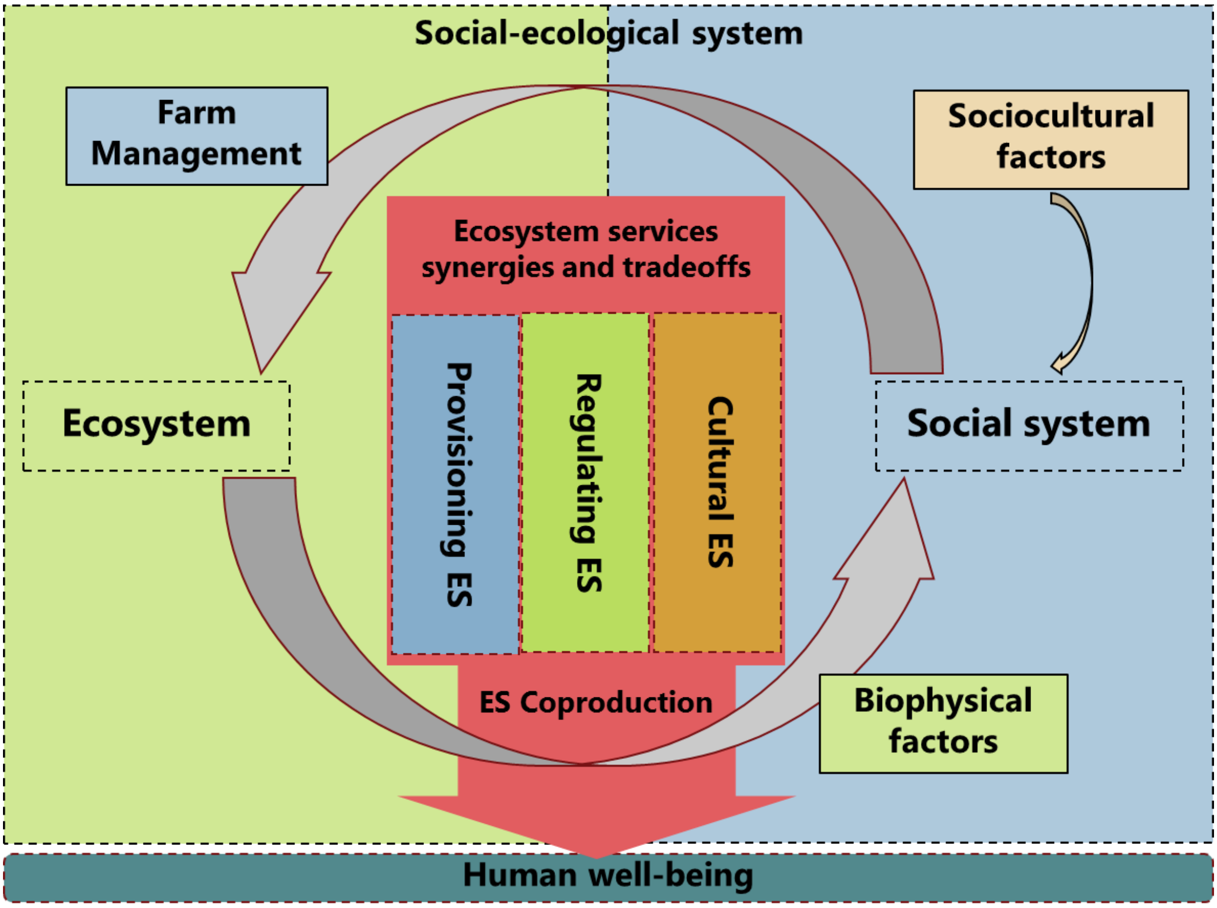

Figure 1. The two sides of the social-ecological system feed back into each other in the co-production of ES. The social system shapes the ecosystem through management, while the ecosystem sets the boundaries and limits the management through biophysical factors. Sociocultural factors also influence the management model. The interaction between all these elements generates tradeoffs and synergies in ES which define the dehesa management model and result in the provision of management-associated bundles of ES.

Methods

Study area

The study area is located in Llanos de Trujillo, part of the region of Extremadura, in South-West Spain (39º 31′ 50′′ N, 5º 56′ 04′′. Fig. 2). It includes four municipalities (Trujillo, Torrecillas de la Tiesa, La Cumbre and Aldea del Obispo) and covers a total of 94,000 ha. The climate is typically Mediterranean, with summer drought and annual rainfall of 600mm. The population density is rather low (12.8 inhabitants/km^2) and is mostly concentrated in urban areas. Since the 1970’s, the transformation of local livelihoods from being based on a diversified primary sector, where wooded rangelands and the diverse product industries associated with them were at the core, to an agrifood industry, has been accompanied by high unemployment and rural outmigration rates. The pillars of the economy have turned in the last decades to the tertiary sector, with tourism playing an important role. There are three main groups of tourists: those who are interested in nature and are attracted by the high biodiversity within agricultural landscapes (especially birdwatchers), those who are interested in game sports (especially deer and wild boar hunting), and those who are interested in the historic and cultural heritage of the region.

The modernization of society and the economy in the 1970s also brought changes in dehesa management. Traditional management was highly dependent on unpaid labor which has slowly disappeared. As a result, the low profitability of dehesa operations motivated owners to shift management towards activities requiring less labor (e.g. cattle breeding instead of sheep breeding; meat breeds instead of milk breeds) and to reduce the diversity of their production activities.

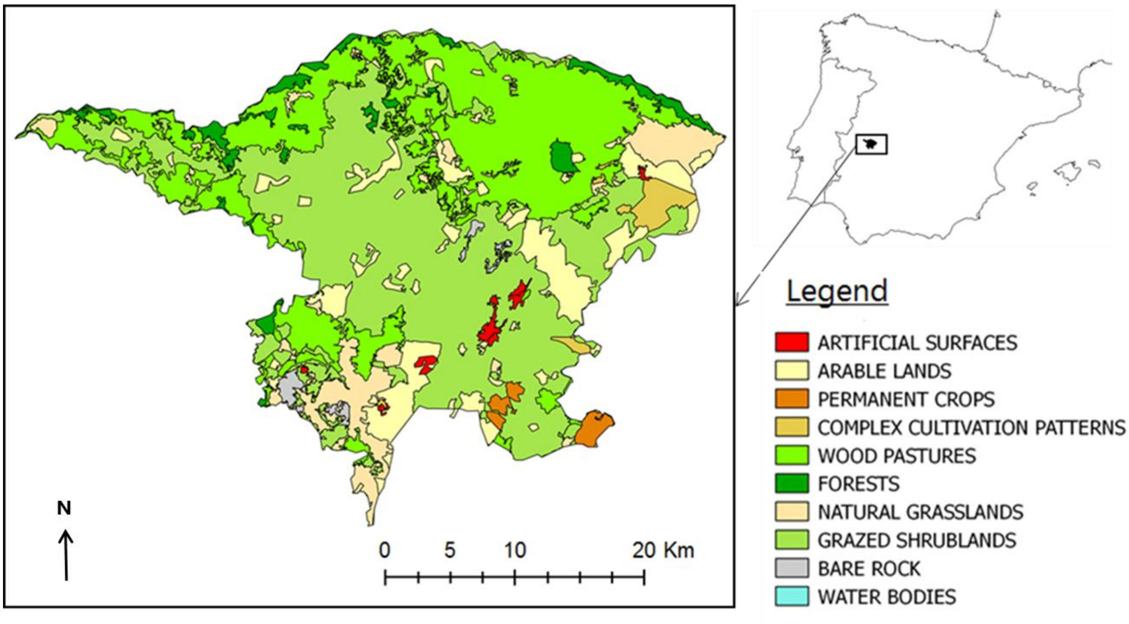

Figure 2. Location of the study area within the Iberian Peninsula and land cover map, according to CORINE 2012 data (EEA, 2016).

The landscape is composed of annual grasslands (38%), holm oak wood pastures (dehesas) (33%), shrublands (16%) and extensive cereal crops (11%) (Fig. 2). Most of the landscape is subdivided into relatively large properties (>100 ha.), which have often been owned by the same families for many generations. In the region of Extremadura the 5% largest operations together include more land than the remaining 95% (Soler and Fernández, 2015). Land tenure structure is relatively stable, and new access to land is difficult, as most of the productive land is concentrated in a few big properties. A second typical dehesa type is smaller properties with medium sized herds using rented land, often on multiple properties not far from each other.

Selection of indicators

We linked management models with ES provision by selecting system-based management indicators that are consistently associated with ecosystem functions and applicable at the local scale (Fischer and Eastwood, 2016; Palomo et al., 2016; Reyers et al., 2013; Van Oudenhoven et al., 2012). Indicators must be comprehensive, informative and consistent at different scales (Mouchet et al., 2014; Van Oudenhoven et al., 2012). In order to be both integrative and explicative regarding how the social-ecological system works, management indicators need to reflect provisioning, regulating and cultural ES categories. The selection of management indicators was, therefore, based on previous research linking management practices and ES supply, stakeholder perceptions of ES provision in the region (Fagerholm et al., 2016a; Garrido et al., 2017) and recent reviews and assessments on the most relevant ES in wood pastures and grazing systems (Modernel et al., 2016; Nieto-Romero et al., 2014; Plieninger et al., 2015; Torralba et al., 2016). Finally, we selected a total of 12 quantitative dehesa structure and management indicators that can be linked with ES provision (Table 1), including the proportion of fencing on the property that is the traditional dry stone walls. Traditional stone walls provide habitat for plants and animals and are an element of landscape beauty.

Table 1. Management indicators and sociocultural and biophysical factors used in the assessment. See Appendix A for more detailed information about how indicators were defined and calculated.

Management indicator	**Unit**	**Variable type**	**Ecosystem service linked with the management practice**	**Reference that links management practice and ES supply**
Number of commercialized products/ activities	Number	Continuous	Provisioning ES	Malinga et al., 2016
Grazing intensity	Livestock units / ha. grazing surface	Continuous	Livestock production	Andersson et al., 2015; Herzog et al., 2012; Lüscher et al., 2014; Maes et al., 2012; Stubkjaer Andersen et al., 2013
Cereal production	Ha cultivated for cereal per year / total ha	Continuous	Cereal production	Maes et al., 2012; Raudsepp-Hearne et al., 2010; Andersen et al., 2013
Firewood production	Tons of firewood per year / total ha	Continuous	Firewood production	Andersson et al., 2015; Maes et al., 2012
Number of bee hives	Number of hives / total ha	Continuous	Pollination	Maes et al., 2012
Mineral inputs	tons of mineral fertilizer / total ha	Continuous	Regulating ecosystem dis-service	Herzog et al., 2012; Lüscher et al., 2014
Capital inputs	Euros spent per year / total ha	Continuous	Regulating ecosystem dis-service	Herzog et al., 2012; Lüscher et al., 2014
Proportion of stone walls	Stone wall proportion (1 – 5)	Categorical	Habitat provision	(Collier, 2013; Manenti, 2014)
Intensity of Hunting	intensity of hunting activities (1 – 6)	Categorical	Hunting	Andersen et al., 2013
Housing facilities	Number	Categorical	Recreation	Andersson et al., 2015; Turner et al., 2014
Visitor frequency	Frequency of on foot visitors (1 – 5)	Categorical	Outdoor activities	Andersen et al., 2013
Number of non-wood forest products harvested	Number	Continuous	Wild resources harvesting	Fagerholm et al., 2016a; Malinga et al., 2016
Biophysical factors	**Unit/Categories**	**Variable type**		
Property size	Ha.	Continuous		
Diversity of vegetation cover	Shannon diversity index	Continuous		
Sociocultural factors	**Unit/Categories**	**Variable type**		
Land tenure	Owned/rented	Binomial		
Public access policy	Restricted access Limited access Public access	Categorical		

To account for the links between management and sociocultural factors we additionally included land tenure (we differentiate between owned and rented land) and public access (we differentiate between dehesas with restricted access, where access is forbidden; limited access, where properties are enclosed but gates are not closed/locked; and public access, where either the property is crossed by public paths/drove roads, or part of the property is common land); and to address biophysical factors we reported on vegetation cover type diversity and property size, resulting in a total of 16 indicators.

Data collection

We adopted a mixed-method approach, with in depth semi-structured face-to face interviews conducted between May and June 2015. There were a total of 42 interviews, covering an area of 13 452 ha, which corresponds to 20.2% of the study area (excluding urban areas). The interview guidelines comprised a total of 60 items with potential follow up questions, organized into five topics: (1) general socioeconomic information; (2) land tenure, history and personal relationship with the property; (3) vegetation cover characteristics; (4) operation productivity and land use management intensity, and; (5) multifunctionality. Interviewees were asked for precise quantitative data on the indicators and for explanations of their management choices. To avoid potential conflicts the interview did not include any questions related to controversial regulations in the area, taxes, or market prices. We used snowball sampling (Bryman, 2012) to identify and contact interviewees. We carried out the interviews on the properties managed by the interviewees to obtain direct information as well as a direct assessment of the information gathered. Following the interview, we conducted on-foot inspections of the land, partly accompanied by the managers, in order to contextualize the information given by them and to further foster discussion around place-based management decisions based on the opportunities and limitations offered by the land.

Statistical analysis

Dehesa characterization

We first classified the dehesas according to their management, sociocultural, and biophysical characteristics. To produce this classification, we carried out a hierarchical cluster analysis (HCA) based on the dissimilarities between operations. We used the standardized Gower's distance that allows the integration of mixed datasets of categorical and continuous variables (Gower, 1971) and Ward's linkage method (Ward, 1963) to maximize the separation of each new cluster and to minimize the dispersion within each new cluster. As variables, we included all management indicators and sociocultural and biophysical factors (Table 1) in the analysis.

Ecosystem services and land management associations

We carried out a Principal Component Analysis (PCA) to identify synergies and tradeoffs associated with management indicators and the other factors. However, as PCA does not allow the inclusion of ordinal variables such as land tenure and public access policy in the analysis, we only included them as supplementary variables. Thus, we projected them onto the principal components for interpretative purposes, without intervention in the calculation of the eigenvalues (Gabriel, 1995). To see how the operation types identified in the HCA were explained by the components, we also included the new cluster classes as supplementary variables. We followed the Kaiser criterion (eigenvalue > 1) to determine the significant number of components to retain and explain.

Bundles of ecosystem services

To identify bundles of management practices and how these are associated with sociocultural and biophysical factors, we used the factor loadings of the first four significant components of the PCA (Martín-López et al., 2012; Mouchet et al., 2017, 2014; Queiroz et al., 2015) for all management indicators, land tenure conditions, and access policies to carry out an HCA. As all input variables were continuous, in this case we used the Euclidean distance with Ward's technique as an agglomerative method.

Results

Dehesa characterization

The HCA classified the operations into four well-defined groups (Fig. 3). The first cluster mainly included large properties with a high diversity of land uses, and that were mostly privately owned (as opposed to public, rented, or commonly owned) properties. Operations in this cluster were associated with high values in terms of number of products, hunting intensity, housing facilities, and proportion of stone walls; and low values in livestock and cereal production, and mineral and capital inputs (Fig. 3A). A second cluster grouped operations with characteristics opposite to the first. Properties in this cluster tended to be smaller and more homogeneous in terms of land cover than those in the other clusters; with lower values in number of products, wild resources harvesting, hunting intensity, and housing facilities, and higher values in capital inputs (Fig. 3B). A third cluster grouped a few operations that were clearly differentiated by a specialization in crop production, with high values in cereal production, mineral and capital inputs, and visitor frequency (Fig. 3C). Finally, a fourth cluster grouped operations whose main defining traits were not related to property size or vegetation cover diversity but instead to public access (either through public paths or being part or all common land). Properties in this cluster showed high values for number of products, wild resources harvesting, number of bee hives, stone wall proportion, hunting intensity, housing facilities, and visitor frequency, and low values for cereal production and mineral inputs (Fig. 3D).

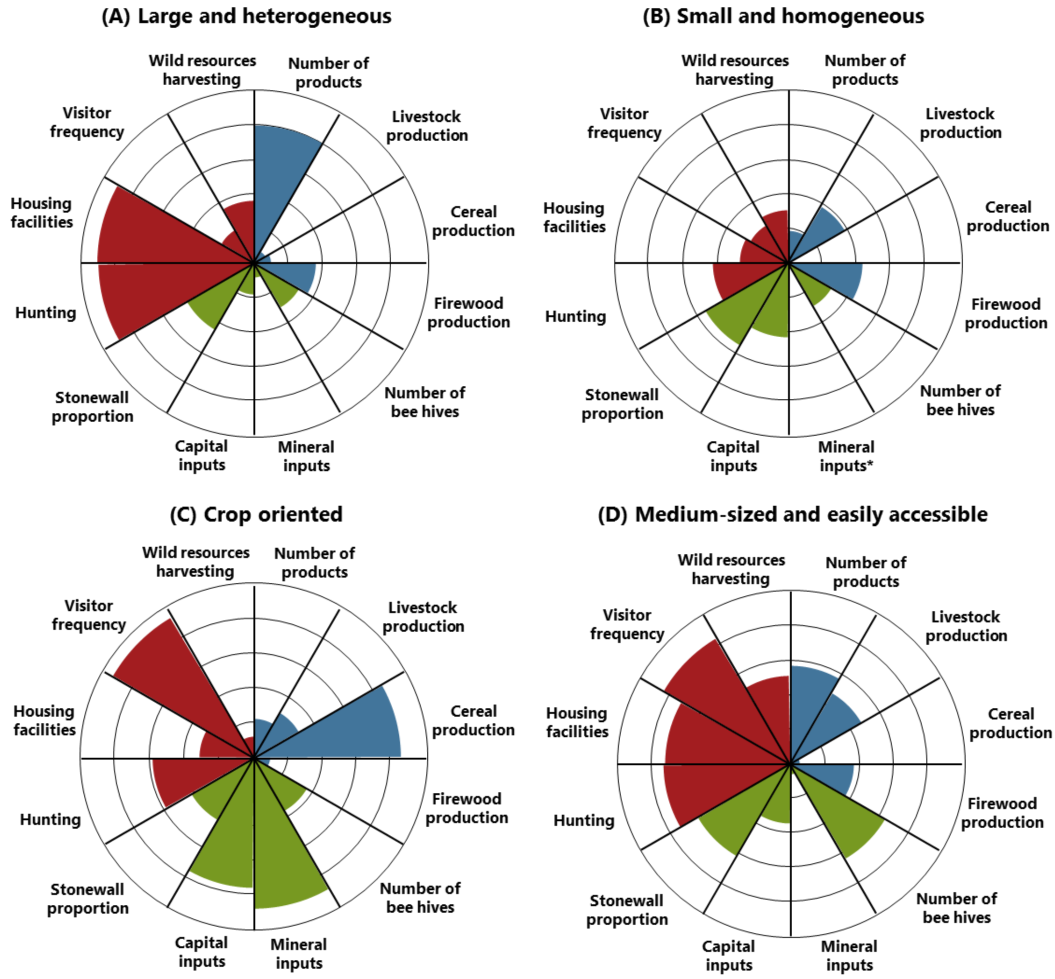

Figure 3. Flower diagrams illustrating the quantification for each management indicator by petal length. Each flower represents one of the clusters identified in the HCA. Colors of the petals refer to the ES category with which the management indicator has been associated (red-cultural, green-regulating, blue-provisioning). For a detailed look at the descriptive statistics for the four clusters identified in the HCA and the HCA dendogram, see Appendix B.

Management synergies and tradeoffs

The projection of the analyzed variables in the PCA reduced the dimensional space to 4 components (F1-4) which had an eigenvalue higher than 1 and absorbed 68.04% of the variance (Table 3). The positive side of the first component was related to larger property sizes, more wild forest products harvested, greater diversity of products provided, a larger proportion of stone walls and more intense hunting activities (Fig. 4). This positive side was also related to the first cluster of the above-mentioned HCA (Fig. 3A). On the negative side we found properties from the second cluster class (Fig. 3B) that make use of larger capital inputs. The second component was explained on the positive side by cereal production and a greater use of mineral inputs (Fig. 4), which is also associated with rented properties and properties in the third cluster from the HCA (Fig. 3C). For the third component, on the positive side, livestock production is opposed to timber production and housing facilities on the negative side. No cluster was clearly related to this component. Finally, for the fourth component, on the positive side, the number of hives, public access, and the number of visitors were opposed to properties with restricted access and high capital inputs. The positive side of this axis was related to properties belonging to the fourth cluster from the above-mentioned HCA (Fig. 3D).

Table 3. Factor loadings derived from the principal component analysis (PCA). For each variable, values in bold correspond to the factor for which the squared cosine is the largest.

	F1	F2	F3	F4
Active variables				
Property size	**0.73**	0.01	0.31	-0.14
Vegetation cover diversity	**0.55**	0.41	0.12	0.00
Number of products	**0.67**	-0.30	0.37	-0.07
Livestock production	-0.35	-0.43	**0.58**	-0.22
Cereal production	0.28	**0.86**	0.09	-0.23
Firewood production	0.01	-0.21	**-0.56**	-0.01
Number of bee hives	0.35	-0.29	0.52	**0.52**
Mineral inputs	0.27	**0.85**	0.21	-0.21
Capital inputs	**-0.53**	-0.01	0.31	-0.53
Stone wall proportion	**0.67**	-0.41	-0.12	-0.06
Hunting intensity	**0.68**	-0.18	-0.38	-0.25
Housing facilities	0.53	0.03	**-0.56**	-0.04
Visitor frequency	0.21	0.46	0.12	**0.61**
Wild forest products harvesting	**0.84**	-0.33	0.21	-0.19
Supplementary variables				
Cluster 1 - Big and heterogeneous	**0.62**	-0.28	0.04	-0.36
Cluster 2 - Small and homogeneous	**-0.66**	-0.23	-0.03	-0.02
Cluster 3 - Crop oriented	-0.13	**0.72**	0.15	-0.01
Cluster 4 - Medium-sized and easily accessible	0.27	-0.02	-0.10	**0.34**
Restricted access	0.15	-0.29	-0.04	**-0.39**
Public access	0.22	0.19	-0.03	**0.30**
Limited access	**-0.36**	0.10	0.06	0.09
Owned land	0.30	**-0.39**	0.15	-0.26
Rented land	-0.30	**0.39**	-0.15	0.26
Eigenvalue	3.91	2.57	1.85	1.19
Variance explained (%)	27.95	18.36	13.22	8.51
Cumulative variance (%)	27.95	46.31	59.53	68.04

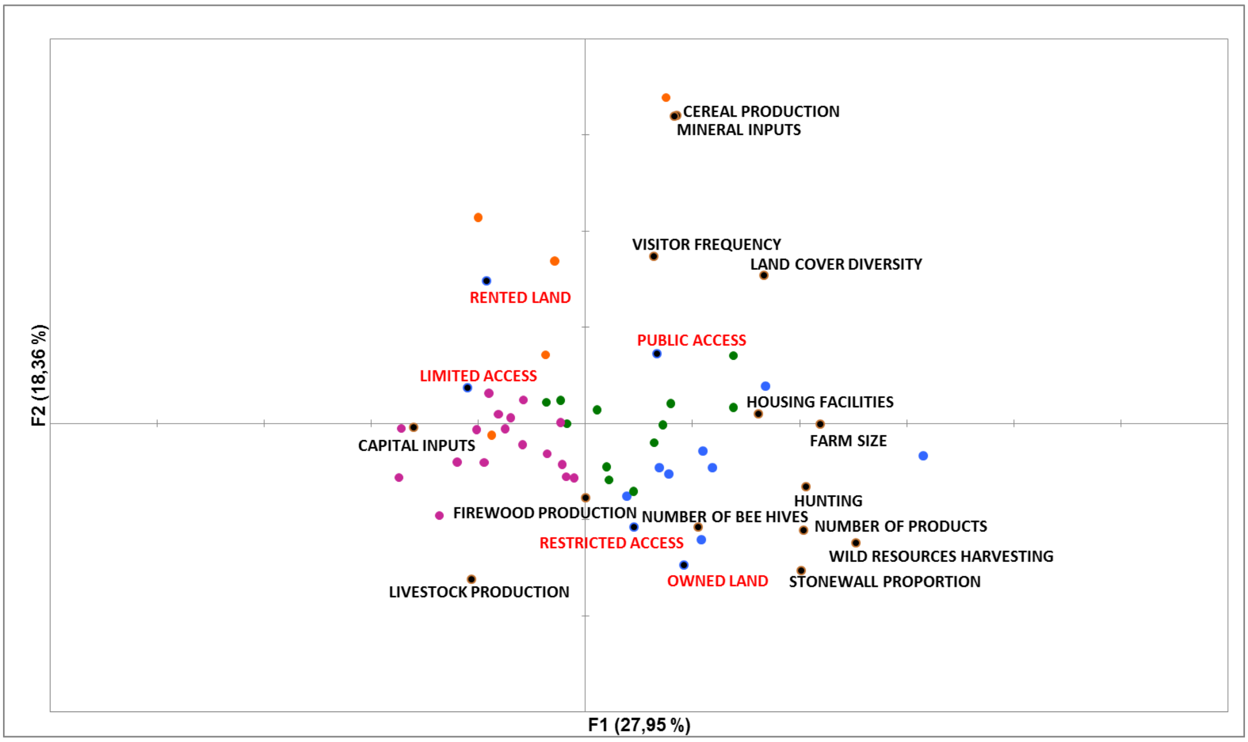

Figure 4. Biplot of the first two components in the PCA. Percentage of explained variation for each axis is given in brackets. Active variables labels (management indicators and biophysical factors) are represented in black. Supplementary variables labels (sociocultural factors) are shown in red. Properties are differentiated by colors according to the HCA group they belong to (blue: “big and heterogeneous”; purple: “small and homogeneous”; green: “medium-sized and easily accessible”; and orange: “crop focused”).

Identification of bundles of management practices and sociocultural factors

The cluster analysis with the factor loadings from the four first components of the PCA classified the management indicators into four groups (Fig. 5). Bundles I and II grouped dehesa management indicators such as mineral and capital inputs, and livestock and cereal production. Bundle I also included visitor frequency and was also linked to public access. Bundle III included hunting intensity, housing facilities, and firewood production. Finally, bundle IV grouped management indicators such as number of hives, the proportion of stone walls, wild resource harvesting, and number of products. Bundle IV was also characterized by individually owned land and restricted access to the property.

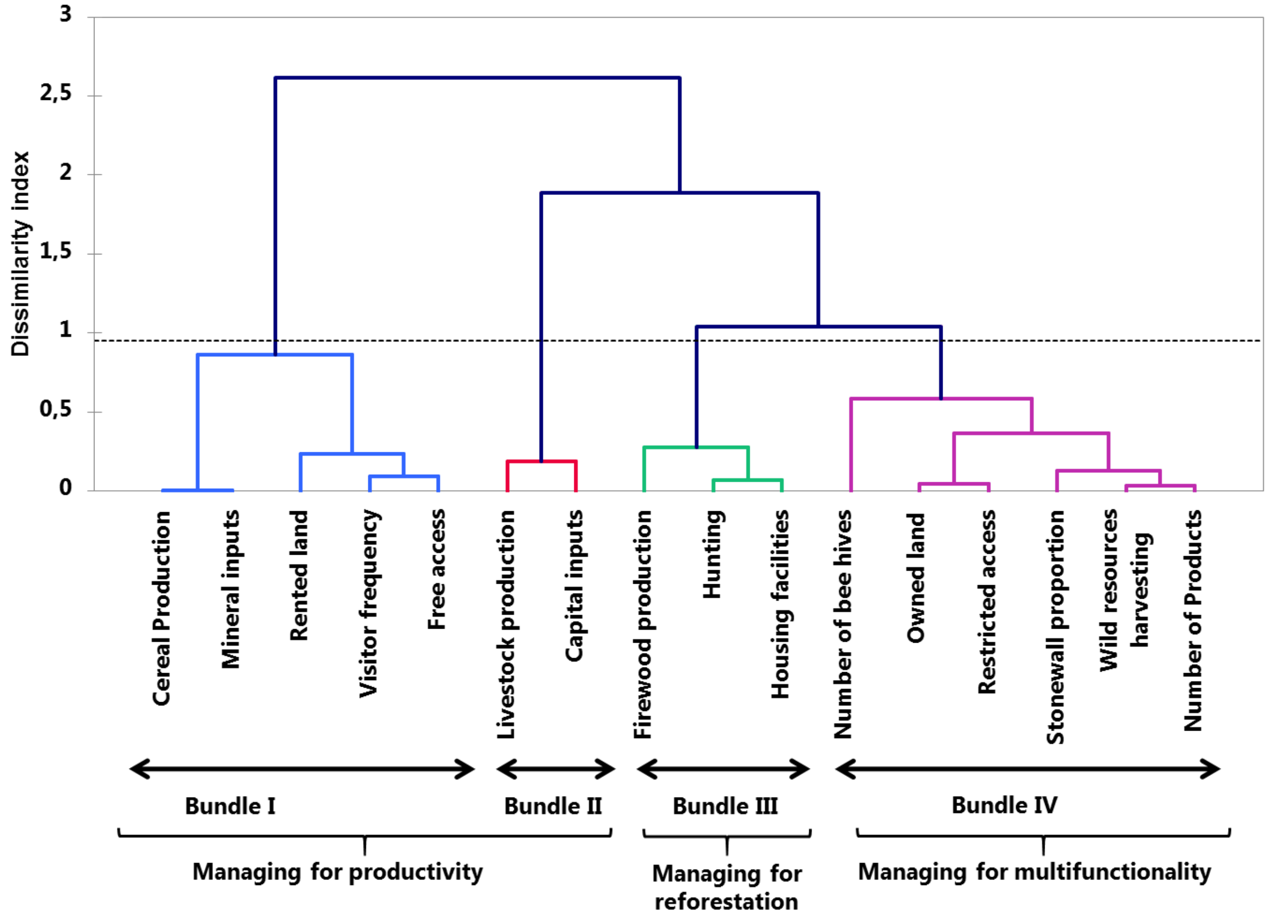

Figure 5. Dendogram of the hierarchical cluster analysis. The dendogram shows bundles of management indicators and sociocultural factors. Bundles are shown in different colors for the sake of clarity.

Discussion

Dehesa characterization

The clustering process shows that properties are differentiated based on the intensity of management and the orientation of production (Fig. 3). Both biophysical and sociocultural factors have a critical effect, segregating dehesas based on size, diversity of plant cover, public access, and land tenure. We can clearly differentiate between four main dehesa types: small operations with high stocking rates, mostly monofunctional, more productive and profitable but less environmentally sustainable; large properties, mostly individually owned, highly multifunctional and more environmentally sustainable; mid to large sized operations focused on crop production; and mid-sized properties that are easily accessible via public paths that enhance the recreational use of the dehesa.

The first group (Fig. 3A), called 'large and heterogeneous' based on its main traits, included operations with mixed and multifunctional management both in terms of production, with a higher number of products on average than the rest of the dehesas, but also in terms of the recreational use of the property, with a high number on average of non-wood forest products harvested, more housing facilities and more intense hunting activities. These dehesas are also more environmentally sustainable, closer to the traditional management, with less reliance on mineral and capital inputs. Dehesas in this group are larger, have more diverse plant cover and are mostly owned by people whose household economy does not depend on the profitability of their land. Land tenure has deep historic roots in Spain and has important sociological implications (Giner and Sevilla, 1977). Large properties, which cover most of the agricultural surface (Soler and Fernández, 2015), have often belonged to the same families for many generations and emotional bonds with the land are very strong. During the 1960s and 1970s, as the Spanish economy developed and profitability of dehesas went down, land revenue became less important for owners of large properties, while game, prestige, and other lifestyle-related interests gained significant prominence (Campos et al., 2003). Socio-cultural factors such as place attachment and social function (e.g. a family legacy) are playing a critical role in management decisions by the owners of these properties. A typical sentiment expressed by this group is captured in the statement of one interviewee: "The way I manage my farm answers to my romantic view of life. These traditions are my legacy for the next generation".

In contrast, dehesa managers from the second group (Fig. 3B), called 'small and homogeneous', have a clear focus on production, with high values for management practices related to provisioning ES, such as stocking, firewood production, or number of bee hives, requiring a higher investment of capital. This capital is mostly devoted to animal fodder, as cereal production and its associated costs play no role in this category. This group is also biophysically and socioculturally different: properties are smaller, more homogeneous and have a mixed land tenure structure. As opposed to the previous group, sociocultural factors such as place attachment play a less important role in management decisions. Managers in this group often don't own the land, have few emotional bonds with it and are highly dependent on land revenue. Management decisions oriented towards more diversified and traditional management would entail higher risk. Similarly to what has been reported in African dry grasslands, and in opposition to "the tragedy of the commons" (Hardin, 1968), in the 'small and homogeneous' dehesas we might be witnessing a trend towards "the tragedy of enclosure" (Reid et al., 2008). The prioritization of one use above all others, intensive livestock farming, might result, in the long term, in simplification, declining productivity, and increased land degradation.

Our results indicate that vegetation cover, property size, and management intensity are central factors determining the dehesa types in the study area which is in line with recent European classifications of agricultural landscapes. For example, van der Zanden et al. (2016) used a spatially-explicit typology of European landscapes based on vegetation cover, landscape characteristics, and land management. Along the same lines, recently Tieskens et al. (2017) used a multi-dimensional approach to characterize European cultural landscapes, using landscape characteristics, management intensity, and landscape perception.

Our results further show that there is a differentiated third group of operations, called 'crop oriented', where animal production plays a secondary role, while cereal production dominates (Fig. 3C). These dehesas also have a clear tendency towards single commodity production, with high values for management practices related to provisioning ES such as cereal and livestock production. They are the most intensively managed of the four types, with a high dependence on external mineral and capital inputs. The relatively low number of operations in this group reflects the minor importance of cereal production today in the study area, where the cost of importing animal fodder does not exceed the cost of producing it. Therefore, crop activities only appear in areas where soil quality is higher and rotational cycles are long (8-12 years) (Costa et al., 2014).

The fourth type identified, called ‘medium-sized and easily accessible’ (Fig. 3D), reflects an intermediate situation between the large and the small dehesa types, with average values for number of products, livestock production, firewood production, capital inputs, hunting intensity, and housing facilities. Management decisions related to these indicators seem to be governed by the property size dynamics previously discussed, where there is a gradient of intensification driven by the size of the property, with smaller properties more intensively managed. However, the main trait that characterizes this group is that all allow public access to the property, either because part of it is common land or most frequently because it is crossed by public paths. Public access is the reason for the high values for cultural ES indicators like visitor frequency and harvesting of wild resources. These results are in line with recent findings where local inhabitants and stakeholders have identified, in dehesa landscapes, cultural ES as contributing the most to their well-being (Garrido et al., 2017; Surová et al., In revision). Birdwatching, one of the principal motivations for visitors and one of the main tourist attractions in the region, requires proximity to agricultural habitats which is often possible only by public paths. Wild resources harvesting (asparagus, mushrooms, wild salads, etc.), an activity mainly of local inhabitants, is common in the region thanks to the multiple seasonal wild resources the dehesa offers, and mostly takes place by way of these common spaces. As one owner of a dehesa crossed by two public paths stated: “The neighbors cross my farm at their pleasure whether I want it or not; when it is not the asparagus season is the blackberries or the mushrooms’”. These results are in line with those of Fagerholm et al. (2016a), who observed the decisive importance of public access to land for ES provision. Interestingly, this group of dehesas also displays the highest values for the proportion of stone walls, which is likely related to the presence of public paths on the properties. The maintenance of the traditional stone walls along public paths is promoted and often supported by municipal and regional institutions.

As a whole, the characterization of these dehesas paints a clear picture of their management, and indicates, in general, that they have low stocking rates, and livestock production integrated with crop production, forestry and game habitat provision. However, traditional management has in general shifted towards more intensified management (Escribano et al., 2016; Garrido et al., 2017), with cereal production for animal fodder being relegated to a minor role. In terms of ES, higher levels of regulating and cultural ES are linked to large properties, while small properties seem to be oriented more toward provisioning ES. These patterns seem strongly connected to sociocultural and biophysical dynamics. In the current context of low profitability for secondary products like cereal, firewood and charcoal, and high dependence on European agricultural payments (that to a great degree are based on the size of the operation) small properties tend to follow a path of intensification (Gaspar et al., 2016, 2009a); increasing profitability with high stocking rates of sheep and/or cows (Gaspar et al., 2009b). An owner of a dehesa of 100 ha stated the following about why he was increasing stocking rates despite his personal preferences: “I love living and working in the fields and I love animals (…). This is my vocation and I started here because of family tradition. However, at the end of the day, my family and I need to eat”.

ES tradeoffs and synergies

The PCA shows that in ES co-production, management decisions generate multiple tradeoffs and synergies. We can infer that there are four major types of management decisions that influence ES supply.

A first group of tradeoffs is associated with the degree of multifunctionality in the dehesa (Table 3, F1). As it has been previously observed, multifunctional management diversifies habitat (higher diversity of vegetation cover types, greater stone wall proportion) and reduces reliance on external inputs (low capital and mineral inputs), generating a sustainable and extensive management that boosts regulating services (Andersson et al., 2015; Butterfield et al., 2016; Raudsepp-Hearne et al., 2010). At the same time, a multifunctional operation enhances cultural ES, diversifying recreational use of the property (higher harvesting of wild resources, hunting, and more numerous housing). However, the positive effect of multifunctionality on cultural and regulating services comes at the expense of reducing productivity, so provisioning services have lower values (livestock and cereal production).

Two groups of tradeoffs and synergies in ES co-production are related to the intensity of crop (Table 3, F2) and animal production (Table 3, F3). Crop production in wood pastures diversifies the habitat (more diverse land cover, higher proportion of stone walls) enhancing biodiversity (Moreno et al., 2016). At the same time, the lower importance of animal production and fencing in crop oriented dehesas allows for a more flexible access policy, increasing recreational use (visitor frequency). On the other hand, crop production requires greater external inputs (higher mineral and capital inputs), reduces recreational use for hunting and wild forest resource harvesting, and lessens diversified production, with fewer products, bee hives, and livestock. The tradeoffs and synergies associated with enhancing animal production include increased grazing pressure and greater reliance on external inputs and supplementary fodder (high livestock production, and high mineral and capital inputs). In exchange there are strong positive effects on provisioning services, but at the expense of recreational use of the property and sustainable management, as has been previously observed in other agricultural landscapes (Power, 2010; Raudsepp-Hearne et al., 2010).

The last group of tradeoffs and synergies is driven by how open or restricted access to the land is (Table 3 F4). Our study confirms that public access is the main factor driving recreational use (Brown et al., 2014; Fagerholm et al., 2016a; Hausner et al., 2015). Such recreational use is associated with more extensive land management (low mineral and capital inputs) and thus, provisioning services have lower values.

The tradeoffs and synergies identified are in line with previous assessments in agricultural landscapes that show tradeoffs between regulating and provisioning services (Queiroz et al., 2015; Turner et al., 2014). From a landscape perspective, different management models have the potential to complement each other. For example, an increase in the number of operations focused on crop production could meet the demand for animal fodder locally, reducing reliance on external inputs.

Management decisions will, in the end, determine the management model and the ES co-production of the system (Fig. 1). Sociocultural and biophysical factors strongly influence the manager's management model, shaping perspectives and aspirations (Forbord et al., 2014; Huntsinger and Oviedo, 2014). When the land is managed by the owner, the possibility of long term planning influences decision making: investments are amortized by the owner, European agricultural payments are almost guaranteed, and there is less need to promote profitability. Taking care of the land and providing a diverse pool of ES seems to be easier for those who own the property individually, and, most frequently, those whose household economy does not depend on ranch productivity. In contrast, landless operators can only access smaller properties and need to manage to earn enough to cover the rent (Gaspar et al., 2008). As one 32 year old operator who owns a 70 ha property said: “Access to property is the biggest challenge of my generation.” Land leasing and renting in rural Spain is largely based on oral agreements (Herrera Molina et al., 2014), which for the landless means uncertainty in management continuity and in economic returns from present investments.

Linking management practices, sociocultural and biophysical factors and bundles of ES

The cluster analysis examining the tradeoffs and synergies among management indicators and sociocultural factors shows that there is consistent covariation among them. There is an interrelationship between the ecosystem and the social system (Fig. 1). Management choices shape the ecosystem, while the ecosystem limits or increases management alternatives. These feedback relationships frame the different management models, enhancing or decreasing different bundles of ES (Fig. 5):

- Management oriented towards productivity: this management model uses a group of practices that enhance provisioning ES (livestock and cereal production) as part of intensive management with a high reliance on external inputs. Interestingly, access policy is most often generous, which creates the highest potential for shared recreational use on the most intensive operations. Land tenure is predominantly rentals in this group, which confirms that land tenure is a decisive factor influencing manager views of management (Huntsinger and Oviedo, 2014).

- Management oriented towards reforestation: management is characterized by low intensity, assigning low importance to livestock and cereal production. Instead we find management practices enhancing ES related to landscape with greater tree cover, like hunting and firewood production, findings which are in line with Queiroz et al. (2015) in a study based on a Swedish forested landscape.

- Management oriented towards multifunctionality: investing in multifunctionality is the closest model to traditional management. By diversifying production, management practices enhance a greater diversity of regulating and cultural ES. However, the direct benefits of this management are usually only available to the property owners as these lands are most often privately and individually owned and access is usually restricted.

Further work should be focused towards identifying other factors that govern these feedback relationships between management choices and ecosystem characteristics, such as soil quality and topography. Good soil quality and flat topography could be related to dehesas in which cropping activities have more prominence (Plieninger, 2006). On the other hand, in more steep topographies management oriented towards reforestation might be more appropriate. Regarding sociocultural factors, land revenue and socioeconomic status seem to have a central influence on manager choices.

Management implications

Accessibility, land tenure and property size have been found to be critical factors explaining the diversity of the ES co-produced in dehesas. Accessibility is conditioned by Spanish institutional history, characterized by the legal protection of the public use of paths and drove roads. The study area is crossed by several drove roads and public paths and has traditionally been a wintering area for transhumant pastoralists. In recent decades, with the decrease in the use of drove roads and public paths by livestock, recreational uses, including hiking, biking, or horse riding, are gaining in popularity (Oteros-Rozas et al. 2014; Starr, In revision). Our results show that these public roads and common spaces boost ES provision and thus, efforts should be made to enforce their conservation and maintenance. Currently, despite the fact that Spanish legislation prioritizes public access and use of such spaces, in certain regions like Andalucía and Extremadura, many large rangeland properties have closed off access to avoid public uses that interfere with hunting activities.

Extremadura is the Spanish region with the largest land concentration and inequity in land ownership (Gini coefficient) (Soler and Fernández, 2015). Our results confirm that most of the territory is dominated by large, private operations that provide multiple products and are extensively managed but largely inaccessible. In contrast, small properties tend to be more intensive and mono-productive due to a lack of economic flexibility, and the low productivity of the typical dry and poor soils. Within the past ten years, more than 55% of small operations (< 5 ha) have disappeared in Extremadura (Soler and Fernández, 2015). From a policy perspective, EU subsidies, on which current dehesa management highly relies (Gaspar et al., 2009b) and which are now mostly linked to property size, should acknowledge the multifunctional and heterogeneous character of the dehesa to counteract the processes of abandonment and intensification that put the dehesa at risk. At a regional level, the study area would benefit from a collective planning effort for rangeland management where land tenure and management are discussed and considered in a participatory manner that includes large, medium and small dehesas, and both landowners and land workers.

Recent studies have highlighted the need to understand how social and ecological interactions are connected with ES co-production (Fischer and Eastwood, 2016; Mouchet et al., 2017; Palomo et al., 2016). In this study we explain how biophysical and sociocultural factors shape the tradeoffs and synergies of ES co-production as determine by manager decisions. Identifying these interrelations may result in numerous benefits to managers and policy makers when managing social-ecological systems. Different access to land and capital are related to different management models, which have consequences on the supply or harnessing of ES. Policy makers should be aware of these connections in order to highlight and promote system-based policies that address the complex reality of rangeland social-ecological systems.

Acknowledgements

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Annexes

Annex A: farm management indicators, biophysical and sociocultural factors

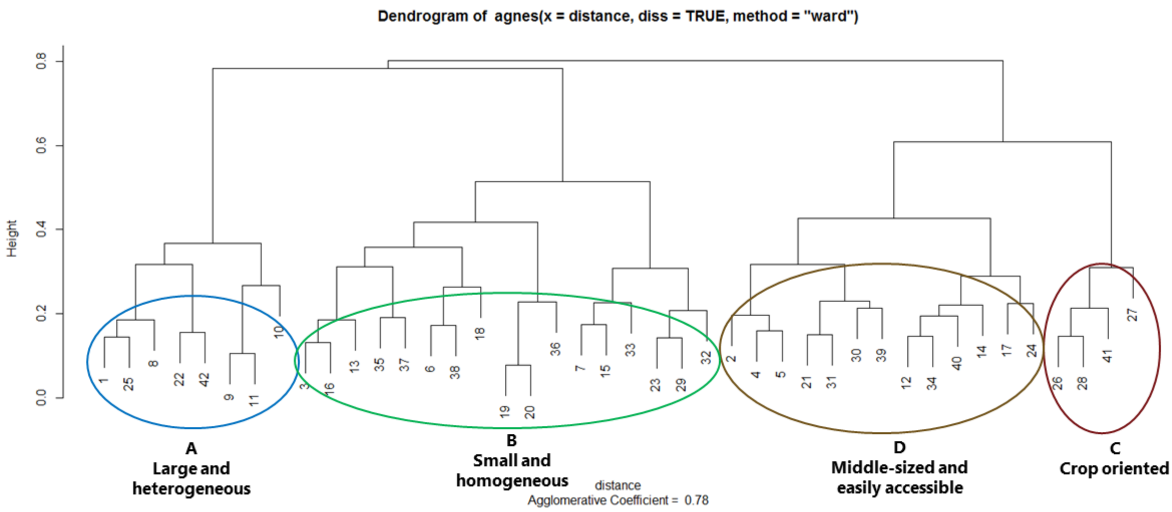
<table>
<tr><th>Number</th><th>Name</th><th>Definition and units</th><th>Variable type</th></tr>
<tr><td>1</td><td>Number of commercialized products/activities</td><td>Number of distributed farm products/activities. The products/activities appeared are: sheep, cow, pig, horse, goat, eggs, rabbit, honey, wood, acorns, olives, wool, cereal, vegetables, olives, minor hunting, mayor hunting, fishing.</td><td>Continuous</td></tr>
<tr><td>2</td><td>Grazing intensity</td><td>Livestock units / ha.: Total number of animals transformed into livestock units divided by the total grazing surface of the farm. The livestock unit is a measurement based on the resources consumed by the different animals. 1 livestock Unit (LU) corresponds to the food necessities of a cow of 500 kg, not pregnant nor lacting. The equivalencies in LU of the rest of the animals is based on the following regulatory document:
- Decreto 14/2006 http://www.juntadeandalucia.es/boja/2006/14/d1.pdf .
Animals considered and LU are the following:
<table>
<tr><th>Animal</th><th>LU</th></tr>
<tr><td>Cow with less than 12 months</td><td>0.3</td></tr>
<tr><td>Cows older than 12 months</td><td>1</td></tr>
<tr><td>Sheeps with less than 4 months</td><td>0.1</td></tr>
<tr><td>Sheeps with more than 4 months</td><td>0.15</td></tr>
<tr><td>Goats with less than 4 months</td><td>0.1</td></tr>
<tr><td>Goats with more than 4 months</td><td>0.15</td></tr>
<tr><td>Horses</td><td>1</td></tr>
<tr><td>Piglets</td><td>0.1</td></tr>
<tr><td>Adult pigs</td><td>0.25</td></tr>
<tr><td>Adult Chickens</td><td>0.015</td></tr>
<tr><td>Adult Rabbits</td><td>0.01</td></tr>
</table></td><td>Continuous</td></tr>
<tr><td>3</td><td>Cereal production</td><td>Surface in Ha. of cereal cultivated per year and divided by the total surface of the farm. Not included fallow area. Can be bigger that the area cropped as sometimes the dehesa is also cultivated</td><td>Continuous</td></tr>
<tr><td>4</td><td>Firewood Production</td><td>Tons of timber produced by year in the farm divided by the total surface of the farm. If the number was not provided it was calculated using a combination of the different indicators: density of trees, production per tree, number of trees pruned by year and/or number of ha pruned by year. If the</td><td>Continuous</td></tr>
</table>

<table>
<tr><td></td><td></td><td>pruning was done not every year but periodically, the pruning was distributed among the period.</td><td></td></tr>
<tr><td>5</td><td>Number of hives</td><td>Number of hives in the farm divided by the total surface of the farm.</td><td>Continuous</td></tr>
<tr><td>6</td><td>Mineral inputs</td><td>Amount in tons of mineral fertilizant use divided by the cultivated surface. If the number was not provided it was estimated with the area fertilized and the kg/ha used.</td><td>Continuous</td></tr>
<tr><td>7</td><td>Capital inputs</td><td>Amount of euros spent on fuel, pesticides and animal fodder per year divided by the total surface of the farm.
In case the information was not provided, it was estimated based on:
- Fertilizant: Estimation based on the amount of fertilizant used and the market price/kg of the fertilizant. The most used fertilizant was N.P.K 7-12-7 which is a mineral Fertilizant (composition: Nitrogen: 7%, P2O5: 12%, K2O: 7%). The market price of this fertilizant is 0.45Euros/kg.
- Pesticides: Estimation based on the amount of pesticides use, number of pesticides applications and the market price of the most common herbicide use for cereal crops in Extremadura which price oscillates around 12 Euros/L. If the amount of pesticides use could not be calculated due to absence of information, the expenditure in herbicides was estimated based on the area and the average expense in herbicide/ha in the area based on the rest of the cases which is 13.5 Euros/ha.
- Fuel: Estimation based on the number of fuel deposits spent, the model of the vehicle and the average price of gasoil in the region of Extremadura (1.08Euro/L).
- Animal Fodder: Estimation based on the amount of fodder and hay eaten by animal per year and/or the average market price in the region (0.24 Euros/kg fodder and 0.07 Euros/kg hay).</td><td>Continuous</td></tr>
<tr><td>8</td><td>Stone wall proportion</td><td>Material in which the fences are built. Categories from 1 to 5 ranked based on the proportion of wire-stone of the fences:
- 1: Wire fence.
- 2: More wire than stone.
- 3: More less same proportion of stone and wire.
- 4: More stone than wire.
- 5: Stoned fence.</td><td>Categorical</td></tr>
<tr><td>9</td><td>Hunting intensity</td><td>Categorical ranking based on the kind of hunting practiced, the users of the activity and the intensity of the activity:
<table>
<tr><td>Intensity</td><td>Users</td><td>Mode</td><td>Score</td></tr>
<tr><td>No hunting</td><td>-</td><td>-</td><td>0</td></tr>
<tr><td>< 10 trophies</td><td>-</td><td>-</td><td>1</td></tr>
<tr><td rowspan="2">>10 trophies</td><td rowspan="2">Owner & relatives +1</td><td>Minor +1</td><td>2</td></tr>
<tr><td>Major +2</td><td>3</td></tr>
</table></td><td>Categorical</td></tr>
</table>

<table>
<tr><td></td><td></td><td>
<table>
<tr><td rowspan="4"></td><td></td><td>Both
+3</td><td>4</td></tr>
<tr><td rowspan="3">Rented
+2</td><td>Minor
+1</td><td>3</td></tr>
<tr><td>Major
+2</td><td>4</td></tr>
<tr><td>Both
+3</td><td>5</td></tr>
</table>
We distinguish between major and minor hunting. The two game modes differ in the hunting modality takes place, the permits and taxes that are required and which species are hunted as trophies. Both types are regulated by the Spanish law in the Real Decreto 1095/1989. These legislation allows to hunt in this area the following species (only listed most common species present in the region, full list in the Real Decreto 1095/1989: https://www.boe.es/buscar/doc.php?id=BOE-A-1989-22056):
- For major hunting: wild boar (Sus scrofa), deer (Cervus elaphus), buck (Dama dama) and roe deer (Capreolus capreolus).
- For minor hunting: partridge (Alectoris rufa), rabbit (Oryctolagus cuniculus), Iberic hare (LEPUS GRANATENSIS), EUROPEAN HARE (LEPUS EUROPAEUS), FOX (VULPES VULPES), PIDGEON (COLUMBA PALUMBIS), TURTLEDOVE (STREPTOPELIA TURTUR), QUAIL (COTURNIX COTURNIX), AND THRUS (TURDUS PHILOMELOS).
</td><td></td></tr>
<tr><td>10</td><td>Housing facilities</td><td>Categorical variable that make reference to the facilities and use of facilities present in the farm for potential recreation purposes. 5 categories ranked following:
- 1: No facilities.
- 2: Basic facilities. Allow to spend the day but not the night.
- 3: Presence of Second residence.
- 4: Presence of permanent residence.
- 5: Presence of permanent and secondary residence(s).</td><td>Categorical</td></tr>
<tr><td>11</td><td>Visitor frequency</td><td>Frequency of uninvited visitants on foot. Categories from 0 to 4:
- 1: No.
- 2: Annually.
- 3: Seasonally.
- 4: Monthly-Weekly.
- 4: Every day.</td><td>Categorical</td></tr>
<tr><td>12</td><td>Non Wood Forest Products harvested</td><td>Number of NWFP mentioned as harvested by the owners. Among the NWFP mentioned were: criadilla (a local tubercle), cardillo (thistle), esparragos (asparagus), achicoria (chicory), niscalos (a species of mushroom), boletus (a species of mushroom), champignones, romaza (dock), moras (berries) and flowers.</td><td>Continuous</td></tr>
<tr><td>13</td><td>Farm size</td><td>Surface of the farm in Ha.</td><td>Continuous</td></tr>
<tr><td>14</td><td>Diversity of land cover</td><td>Shannon diversity index (H) of land use cover</td><td>Continuous</td></tr>
<tr><td>15</td><td>Land tenure</td><td>Ordinal variable distinguishing owned and rented/leased land</td><td>Ordinal</td></tr>
</table>

16	Farm access policy	Ordinal variable that categorize farms based on how easy is the access to the farm: - Restricted: fenced property - access is not allowed. - Limited: Fenced property but access is allowed. All gates are open. - Public: the farm is crossed by public paths or belongs to common land.	Ordinal

Annex B: HCA dendogram for the farm characterization



5 Annex C: Paper 3: Assessing linkages between ecosystem services, land-use and well-being in an agroforestry landscape using public participation GIS

This is a pre-print version of the following paper:
Fagerholm, N., Oteros-Rozas, E., Raymond, C.M., Torralba, M., Moreno, G., Plieninger, T., 2016. Assessing linkages between ecosystem services, land-use and well-being in an agroforestry landscape using public participation GIS. Applied Geography 74, 30-46. http://dx.doi.org/10.1016/j.apgeog.2016.06.007

Abstract
While a number of studies have applied public participation GIS (PPGIS) approaches to the spatial assessment of ecosystem services, few have considered the associations between the spatial distribution of ecosystem services and the context-specific nature of self-reported well-being. In this study, we engage the general public to identify and map a range of ecosystem services that originate in place-based, local knowledge and explore the context-dependent nature of subjective well-being. We conducted a PPGIS survey with 219 local residents in a Spanish agroforestry (dehesa) landscapes and analysed the spatial patterns of mapped ecosystem services, their relation to land cover, protected area and common land patterns. In addition, we explored the landscape values contributing to people's well-being; and the relationships between ecosystem services in different land covers, landscape values and socio-demographic characteristics. A mosaic of landscape types (i.e., the landscape) provided more ecosystem services (especially cultural and provisioning) to people compared with the individual land system of agroforestry. However, land tenure and public access significantly guided the spatial practices and values of the people beyond the preferred landscape types. The contribution of the landscape to well-being is largely related to values based on interactions among people and the landscape, as tranquillity/relaxation and people-people interactions such as being with family and friends. We discuss the specific contribution of agroforestry landscapes to the provision of ecosystem services and human well-being. We conclude that the integration of the applied methods of social-cultural assessment on the one hand links to ecosystem services frameworks but on the other hand represents a more holistic conceptualisation of people's benefits from landscapes.

Keywords
dehesa, landscape management, landscape values, public participation GIS (PPGIS), participatory mapping, silvopastoral

Introduction
Assessment and mapping of ecosystem services contributes to understanding the supply and demand of services, to supporting stakeholders in decision-making, and to informing political priorities for environmental sustainability, for example in the European Union (Maes et al., 2012). Whilst biophysical mapping and economic assessment remain a focus of ecosystem services research (e.g. Reyers et al., 2013), emerging research further integrates social-cultural perspectives (e.g. Scholte et al., 2015). Recent studies consider social complexity, analysing issues of benefit distribution, values and interests and power around ecosystem services (Daw et al., 2011; Felipe-

Lucia et al., 2015). Research is also directed towards a deeper understanding of the links between ecosystems and human well-being (e.g. Berbés-Blázquez, 2012; Bieling et al., 2014; Hausmann et al., 2015; Villamagna & Giesecke, 2014).

Participatory approaches are particularly useful to explore stakeholders' knowledge, preferences, practices, perceptions and values around ecosystem services (Villamor et al., 2014). In particular, public participation GIS (PPGIS) and a range of other participatory mapping approaches enable an assessment of the social complexity of ecosystem services (Brown & Fagerholm, 2014; Raymond et al., 2014), including multiple place-based practices and values, emerging from everyday embodied subjective experience and accumulated knowledge (Ingold, 1993; Stephenson, 2008; Williams & Patterson, 1996). They communicate the assigned environmental values, i.e. the judgements regarding the worth of objects such as places, ecosystems and species with benefits for landscape management (Ives & Kendal, 2014; van Riper & Kyle, 2014; Seymour et al., 2010).

While a number of studies have used PPGIS to elicit ecosystem services (see Brown & Fagerholm 2014 for a recent review), few studies have considered the spatial associations between the spatial distribution of ecosystem services and human well-being. Human well-being is a multi-dimensional concept, which has a fundamental role in the ecosystem services framework (Villamagna & Giesecke, 2014). The Millennium Ecosystem Assessment (MA) recognised five dimensions of well-being: 1) basic material for a good life; 2) freedom of choice; 3) health; 4) good social relations, and; 5) security (MA, 2005). These aspects represent three core domains in which humans benefit from the environment: physically, psychologically and socially. Recent research has highlighted the importance of assessing the context-specific nature of self-reported well-being. Well-being is strongly associated with perceived environmental qualities (as measured by marking of negative and positive qualities on a map using PPGIS) in both urban and suburban contexts (Kyttä et al., 2015). Weber & Anderson (2010) compared the perceived well-being benefits that park users obtained from regional and urban parks. Across both contexts, common preferences included enjoying nature, escaping personal/social pressures, escaping physical pressures and enjoying the outdoor climate. In a study of short interviews, Bieling et al. (2014) studied ways that natural surroundings and everyday landscapes contribute to people’s well-being and the kind of linkages that emerge to ecosystem services and landscape values, revealing an outstanding importance of cultural values.

Social-cultural assessment of ecosystem services and their contributions to people’s well-being have received limited attention in multifunctional agroforestry landscapes (Fagerholm et al., 2015). Agroforestry is the deliberate human management of trees/shrubs with agricultural crops or livestock (Mosquera-Losada et al., 2009). Agroforestry aims to integrate commodity production with sustainability issues (in particular related to poverty alleviation, food security and soil and biodiversity conservation), while striving to be compatible with local farming practices (Nair, 2007). In fact, agroforestry systems provide multiple ecosystem services, ranging from the provision of food, feed and fibre through to non-commodity outputs, such as climate, water and soil regulation and recreational, aesthetic and cultural heritage values (e.g. McAdam et al., 2009; Smith et al., 2013). In Europe, agroforestry has frequently shaped highly appreciated cultural landscapes with long traditions (Plieninger et al., 2015; Eichhorn et al., 2006) and has significant potential to advance sustainable rural development (http://www.agforward.eu).

Many researchers have been concerned about the insufficient focus on the social-cultural sphere and associated processes in understanding the contributions that nature's services provide to humans (e.g., Chan et al., 2012; Schröter et al., 2014; Setten et al., 2014). This concern is particularly apparent in agroforestry landscapes. Studies involving local people and other stakeholders defining agroforestry-related ecosystem services have been documented only in limited case study research (Fagerholm et al., 2015). One exception is Hartel et al. (2014) who interviewed rural inhabitants in an area of Romania about their perceptions of ecosystem services in changing silvopastoral landscapes. Provisioning services such as firewood, water and crops, but also healthy soils were particularly valued. Oteros-Rozas et al. (2014) surveyed attitudes and perceptions of ecosystem services regarding a Spanish transhumance network with residents and visitors with the most important services revealed as fire prevention, air purification and livestock. Preferences have also been studied with the use of landscape photographs, for example by Pinto-Correia et al. (2010) in a study eliciting visual preferences for Portuguese montado agroforestry landscapes. García-Llorente et al. (2012) performed a comparative analysis between different typical landscapes in Spain, including the dehesa agroforestry landscapes, with the result that dehesa is among the highest valued by people in terms of visual preference and in willingness to pay for conserving it, and also among the landscapes with more capacity to supply multiple ecosystem services.

In summary, agroforestry systems provide great potential for environmental conservation and sustainable rural development, but the ecosystem services of European agroforestry and their contributions to human well-being have not been scrutinized from a social-cultural perspective (Fagerholm et al., 2015). In this study, our aim is to understand the importance of ecosystem services from agroforestry for local people in a spatially explicit way at the landscape scale, and to reveal the contribution of agroforestry landscapes to subjective well-being. We present a first social-cultural assessment of ecosystem services provided by a European type of agroforestry through PPGIS methods. Furthermore, the relationships between contribution of a landscape to subjective self-reported well-being and spatially explicit mapping of landscape practices and values have not been explored before. The particular focus of this paper is the Spanish dehesa, a traditional, low-input, extensive agroforestry system composed of open, heterogeneous canopies of holm oak (*Quercus ilex*) and/or cork oak (*Q. suber*) with a shrub or annual herbaceous understorey. Dehesas are estimated to cover about 2.3 million ha in Spain (Moreno & Pulido, 2009).

Our specific objectives are:

1. to quantify and map the spatial distribution, patterns and intensities of ecosystem services perception by local people and explore the differences between different actors;
2. to compare and contrast the number and type of ecosystem services identified and their spatial relation to land cover, protected areas and common land patterns;
3. to identify the linkages between the perception of landscape and subjective well-being;
4. to explore the relationships between the ecosystem services demanded in different types of land covers and identified landscape values attached to subjective well-being and socio-demographic characteristics; and
5. to elucidate the specific contribution of agroforestry systems to the provision of ecosystem services.

Materials and methods

Study area

The study was carried out within the Llanos de Trujillo plains in Cáceres Province, south-western Spain (39° 31' 50'' N, 5° 56' 04'' W). The study area comprises four municipalities (Trujillo, La Aldea del Obispo, La Cumbre, Torrecillas de la Tiesa; extent: 94,000 ha, Figure 1), and is commonly regarded as a region that most residents identify with and/or depend on for their lifestyles and livelihoods. Dominant land cover types in the four municipalities are dry grassland (38%), holm oak dehesas (33%), shrublands (16%) and extensive cereal crops (11%) (Figure 2). The Llanos de Trujillo has a gently rolling relief, interrupted by river valleys and some mountains (altitude 350-550 m). Climate is typically Mediterranean with mild and humid winters and very hot summers with annual rainfall around 600 mm. The land use systems of the area provide a diverse flow of ecosystem services, with production of high-quality food, water regulation, minimization of soil erosion and the provision of recreation being most important. In total, 24% of the territory in the municipalities is part of the Natura 2000 Network of protected areas, including the extensive Almonte river system and open plains. Monfragüe national park is located in the northern part of the study area, receiving 300,000 visitors per year.

The four municipalities have in total 11,511 inhabitants, the largest one being Trujillo with 9,085 inhabitants. Trujillo has a high proportion of senior inhabitants, with almost three times more persons older than 64 years compared to people between 20 and 64 years. Population density is low (12.8 inhabitants/km²). The unemployment rate is 15%. The main economic activity is agriculture in the three small villages (between 29% and 43% of the active population). In contrast, only 7% of Trujillo's active population works in agriculture. The main agrarian activity is livestock breeding. Most of the farmlands are concentrated in large estates, with around 80% of the lands being in estates of > 100 ha extent. Tourism is increasing importance in the local economy associated with high nature values, birdwatching and gastronomy. Privately owned lands are dominant, but each municipality, with the exception of Trujillo, includes also limited extent of common land (in total 259 ha) with heterogeneous land tenure.

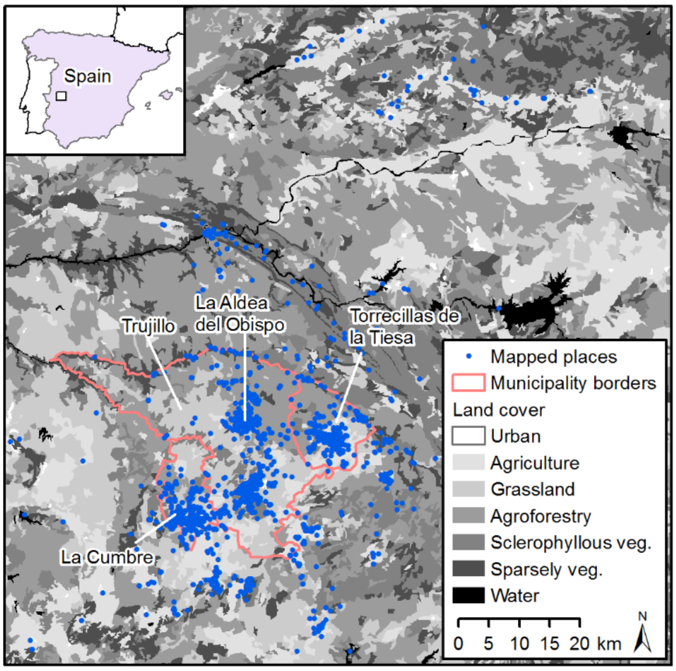


Figure 1. Study areas, the four neighbouring municipalities of Trujillo, Torrecillas de las Tiesas, La Cumbre and La Aldea del Obispo. La Aldea del Obispo is a small enclave within Trujillo.

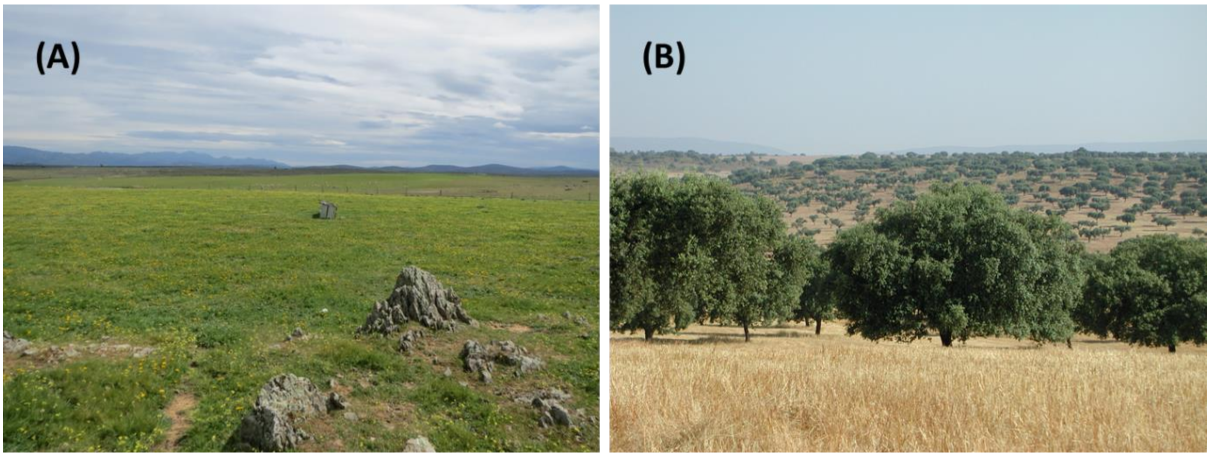


Figure 2: Examples of (A) open pasture and (B) holm oak dehesa areas.

Typology of ecosystem services with respective indicators and self-reported measure of human well-being

We developed a locally relevant ecosystem service typology that places specific focus on the social-cultural dimension of landscapes, based on the existing typologies (e.g. De Groot et al., 2002; Costanza et al., 1997; MA, 2005; EEA, 2014). In addition, typologies of landscape and ecosystem services and values for participatory research were considered (e.g. Brown & Reed, 2000; Raymond et al., 2009; Vallés-Planells et al., 2014, Appendix A). Our typology aims to capture both the tangible and abstract/symbolic/intrinsic benefits of ecosystem services in relation to local actors' everyday lives and covers provisioning, cultural, regulating and supporting services. The ecosystem service indicators, mapped by the local actors, were selected and linked to respective services based on previous studies on perceptions of ecosystem services in agroforestry systems (Campos et al., 2008 & 2009; Hartel et al., 2014) and by reflecting the results on ranking positive aspects of agroforestry by farmers and other land management stakeholders in the AGFORWARD workshops (reports downloadable through http://www.agforward.eu/index.php/en/FarmerNetworks.html).

In addition, the ecosystem service mapping approach was complemented with a self-reported measure of human well-being aiming to capture the contribution of landscape to respondent's well-being not addressed or restricted to the mapped typology or the MA categorisation. Subjective and self-reported well-being can be assessed in a variety of ways, including composite measures, life satisfaction surveys such as the quality of life index and the sustainable livelihoods framework (Villamagna & Giesecke, 2014). We applied a free-listing method to identify the linkages between the perception of landscape and subjective well-being (cf. Bieling et al., 2014). The method is rapid to perform and not restricted to applying an explicit terminology, such as ecosystem service categorisation, but allows informants openly to express their linkages to landscape.

Informants and sampling approach

Informants were chosen as full or part time local residents, including farmers and land owners, as well as people who had previously lived in the four municipalities but now living elsewhere and still working in the area. Residents were recruited through purposive stratified sampling based on three stratification criteria of: 1) municipality, 2) gender and 3) age (young people/young adults 15-29 yrs, middle-aged 30-59 yrs, seniors $\geq$ 60 yrs). The first criterion was based on geographical balance and the latter two were in proportion to the local census data (INE, 2011). Informants in each stratum were chosen by convenience sampling on site and approached in key public locations, such as market places, cafes, schools and health care centres (Bieling et al., 2014; López-Santiago et al., 2014; Scolozzi et al., 2014). Also two school classes participated. In addition, people who work or have worked in agriculture or forestry were recruited through snowball sampling.

Data collection through a web-based PPGIS survey

Data collection was performed during ten days in May 2015 through a web-based PPGIS survey operated on a laptop or tablet computer and implemented through the Maptionnaire software. The contents and functionalities were tested with eight participants in March 2015. The survey was in most cases filled in with the help of a facilitator but designed to be self-administered. The survey started with mapping as point data the informants' home locations and subsequently ecosystem service indicators categorised under: 1) activities (e.g. various outdoor activities, harvesting products from nature, spending time together with other people); 2) feeling and valuing (e.g. beautiful landscapes, appreciation of local culture, cultural heritage and history, appreciation of plants, animals and ecosystems) and; 3) special place (Appendix A). After each mapped item, a pop up window opened to collect subsequent attribute data. Informants could map an unlimited number of places for ecosystem service indicators. The background map was Bing satellite image with overlaid Open Street Map objects. In order to ensure spatial scale coherence in mapping, a minimum zoom level for point placement was given reflecting the focus on landscape scale.

Ecosystem service indicator mapping was followed by the open free-listing question (cf. Bieling et al., 2014): 'How does this area and the opportunities it offers contribute to your well-being? Please briefly write and describe here anything that comes to your mind (e.g. list shortly the three most important things)'. The subsequent survey pages included questions on socio-demographic characteristics and self-estimated knowledge of and relationship to the study area, shown to have a significant influence on ecosystem service perceptions (e.g. Brown & Reed, 2009; Palomo et al., 2013; Lopéz-Santiago et al., 2014; van Riper & Kyle 2014).

Analysis

Characteristics of informants and identified ecosystem services were analysed through descriptive statistics and Chi square tests for significant associations. The spatial distribution, patterns and intensities of mapped ecosystem service data were described, firstly, by calculating the Euclidian distance between informant home and mapped locations as it was expected that variation in distance might explain spatial patterns (Brown et al., 2002; Fagerholm et al., 2012). Secondly, we studied the spatial arrangement of the indicator point layers with nearest neighbour statistics (NN) to explore random distribution (Ebdon, 1985). NN statistics measures the Euclidian distance between each point and its nearest neighbours and divides this with the distance in a hypothetical randomly distributed point layer. Thirdly, we generated density surfaces from the point layers using quadratic Kernel function (Silverman, 1986) – a method widely applied to describe intensity and visualise the spatial patterns of ecosystem service indicators mapped through PPGIS (Brown & Fagerholm, 2014).

In order to analyse land cover types and conservation status of the locations mapped by the informants, each ecosystem service indicator layer was overlaid with CORINE land cover (2006, EEA, 2013) and Natura 2000 protected area data (EEA, 2012). Due to the small width of the linear features (200 m for rivers) in the Natura 2000 data, the data set was buffered with 300 m distance to appreciate the uncertainty in point placement (cf. Lechner et al., 2014). In addition, these shares on places mapped on various land covers and protected areas were compared with the spatial extent of land cover types and Natura 2000 areas in the study area as a proxy measure to indicate potential under- or over-representation. For this purpose, an extended study area was defined including the four municipalities and areas outside them with mapped point locations, collectively buffered to a radius of 1,000 m defining the landscape context. A spatial layer of common land was produced based on contextual knowledge and overlaid with ecosystem service indicator layers. As Natura 2000 data, also common land was buffered with 300 m radius for the analysis. Common land extent in the four municipalities and the shares of mapped places were compared.

The answers from the open free-listing question were coded following the Cultural Values Model (CVM) developed by Stephenson (2008, cf. also Bieling et al., 2014), which presents an approach for conceptualizing the multiple ways in which people value landscapes. The holistic model integrates landscape as biophysical and social-cultural phenomenon under three components of values attributed to landscapes: forms, practices and processes, and relationships. We identified 28 landscape values within the three categories including ‘forms’ such as physical, tangible and measurable aspects (e.g., nature, historic features, good food); ‘practices and processes’ including both human practices and natural processes (e.g., clean water, hunting, health), and; ‘relationships’ i.e. values based on people–people interactions in the landscape or on people–landscape interactions (e.g. tranquillity, freedom, social interactions). Bieling et al. (2014) showed in their study that people’s responses to the wellbeing question go beyond the ecosystem services category and, therefore, we also chose the more inclusive CVM for analysis.

Finally, we performed a Redundancy Analysis (RDA), i.e. a multivariate ordination technique (e.g. Rao, 1964; Martín-López et al., 2012) that allows for simultaneous observation and analysis of more than one outcome variable. RDA is the multivariate analogue of regression and we used it to explore the potential relation between landscape perception (i.e. the frequency of ecosystem services mapped by individuals on different types of CORINE land cover classes, dependent variables), subjective well-being (i.e. the landscape values identified by individuals, independent variables) and socio-demographic characteristics of respondents (independent variables). For this analysis, in order to have a comparable number of observations per CORINE category, we merged them into six land cover categories (urban, agriculture, water, grassland, agroforestry and sparsely vegetated) that had sufficient ecological similarity in the study area (Tables 3 and 5).

Results

Informant characteristics

The majority of the informants lived in Trujillo and the three other study area municipalities (94%) with the rest scattered across the neighboring areas (Table 1). Both genders were almost equally represented with 46% of informants being 30-59 years old, 24% under 30 years and 30% above 60 years. Almost a fifth (18%), especially men, were working in agriculture or forestry (29% of men but only 7% of women, $\chi^2(1, N=219) = 19.26$, $p = 0.000$). Self-estimated knowledge of the area was claimed extremely good (40%) or quite good (39%) with only 5% indicating poor knowledge of the area. Those who had a residential relationship to the area tended to estimate their knowledge higher compared to those who worked or had moved out from the area ($\chi^2(12, N=215) = 49.0$, $p = 0.000$).

Identified ecosystem services and their spatial patterns

A total of 2,594 places were mapped in the survey as significant sites of ecosystem service provision with a mean amount of 12 places per informant (min 3, max 30, SD 4.2, Table 2). These sites were located on average 9.2 km from the informants' homes (see Appendix B for distance, nearest neighbor and intensity analyses) and the majority (58%) of places were related to cultural services. Places for outdoor activities (17%), mainly for walking, were the most mapped. These areas were valued by all informant groups, but people working in agriculture and forestry valued them to a lower degree (14%) than all other groups ($\chi^2(1, N=219) = 3$, $p = 0.034$). Outdoor activities showed the second most clustered pattern on the landscape (NN ratio 0.31, Z -27.47) and were located closest to informants' home (mean 3.3 km, Figure 2A).

Frequently mapped cultural services were also sites of beautiful landscapes, social interaction and culture and heritage values (12%, 10% and 10% of mapped places respectively, Table 2). Beautiful landscapes were related to oak trees and the dehesa, to views of the mountains and rivers, and to the panoramic view from the old castle of Trujillo. They were found around the study area, although with a statistically clustered pattern (NN ratio 0.43, Z -19.06). Sites for social interaction were especially related to places where people gathered for a picnic with family or friends or for the town festivities mainly in the vicinity of settlement areas (mean distance to home 5.6 km, max 0.59 points/ha). Culture and heritage values were mainly related to the town of Trujillo, historical bridges in the landscape and other built structures (monuments). These sites showed the most clustered pattern (NN ratio 0.26, Z -22.52) and the highest intensity (max 2.12 points/ha in old Trujillo) out of all indicators (Figure 3B). Inspirational, spiritual and religious values (5% of mapped places) and sites for intrinsic value of nature (4%) were among the lowest mapped among cultural services, and the latter were more often identified by young people compared to other age groups ($\chi^2(1, N=219) = 2$, $p = 0.011$). Sites for these two values were found scattered in the landscape, resulting in rather low spatial intensities (mean 0.02 points/ha).

Provisioning services totaled to 24% of all mapped places (Table 2). Provision of farm products, mainly meat and eggs, represented 11% of mapped places and were less identified by young people than all other groups ($\chi^2(1, N=219) = 6$, $p = 0.007$). Places for harvesting wild products, such as asparagus and fish, had a share of 13%. Men identified these services more often than women ($\chi^2(1, N=219) = 3$, $p = 0.032$), and young people less than other age groups ($\chi^2(1, N=219) = 6$, $p = 0.013$). Harvesting was much more scattered around the landscape (Figure 3C) compared with sites for farm products located closer to settlement with a higher spatial intensity (mean distance to home 8.5 vs. 4.7 km, max 0.35 vs. 0.66 points/ha).

Out of regulating and supporting services sites for appreciation of plants, animals and ecosystems were identified more than sites for appreciating environmental capacities such as water regulation (10% vs. 5% of all mapped sites). Both of these were located furthest from homes (< 16 km) with scattered patterns (NN ratio 0.43/0.42, Z -17.35/-13.22) resulting to low spatial intensities (mean 0.2-0.3 points/ha, Figure 3D). Special places presented 3% of all mapped places with the smallest spatial extent (4,384 ha) and the most scattered pattern (NN ratio 0.65, Z -5.84), most likely due to the limited number of these places.

6.3.3 Spatial relation of mapped services to land cover, protected areas and common land patterns

When looking at the relationship to land cover, most of the mapped places were distributed in grasslands (27%), and the rest on agricultural (21%) and agroforestry (18%) areas, urban surfaces (17%), sclerophyllous vegetation or forest (11%), sparsely vegetated areas (6%) and water (1%) (Table 3, Figure 2). Almost half (45%) of all sites for provisioning services were found on grasslands and agroforestry areas. Farm products were also especially related to urban areas, where people commonly had chicken and homegardens. Cultural services were also most prevalent in grassland (28% of the mapped cultural services), urban areas (22%) and agroforestry areas (18%). Sites for outdoor activities, social interaction and beautiful places were especially found on grasslands and agroforestry areas. The sites for appreciation of local culture, cultural heritage or history dominated in urban areas. Grasslands and agroforestry areas (23% and 20% of mapped sites respectively) were the most typical for regulating and supporting services.

Comparison of these figures to the spatial extent of different land covers in the extended study area showed that sclerophyllous vegetation/forest (11% of places vs. 19% of land), agroforestry areas (18% of places vs. 25% of land) and water (1% of places vs. 2% of land) were less represented than the extent of the land cover. Agricultural areas, grasslands and sparsely vegetated areas showed slight overrepresentation. Then again, urban areas were much more characterized by mapped places (17%) compared to the spatial extent of this land cover type (1%).

Forty-one percent of all mapped places fell inside Natura 2000 protected areas, which corresponded to their spatial extent in the extended study area (42%). In the extended study area the proportion of protected areas increased significantly compared with the four municipalities (24%) which highlights that people actively search for certain ecosystem services in these areas. Especially regulating and supporting services were related to protected areas, with appreciation of plants, animals, wildlife, and ecosystems presenting the highest share of 61% of mapped places within Natura areas. More than half of the places were found within Natura 2000 areas also for environmental capacities, beautiful places and appreciations of local culture, cultural heritage or history. Least related to protected areas were farm products and outdoor activities.

Common land areas occupied only 0.3% of the four municipalities, with half of them (53%) being grasslands and the rest arable land (26%), agroforestry areas (18%) and urban areas (3%). These land areas small in extent attracted 7% of all assigned places by informants. They were especially related to outdoor recreation (34% assigned to common land), farm products (20%) and social interaction (16%).

Landscape values contributing to subjective well-being

Between 9 and 11 landscape values were identified under the three categories of landscape values (Table 4). Clearly the most frequently mentioned were the relationships, especially tranquility/relaxation and social interaction, which 74% and 32% of informants mentioned respectively. More than 10% also mentioned nature (forms), no contamination/clean environment, work, fresh/clean air, quality of life/living well and outdoor activities (practices and processes) and family interaction (relationships). When respondents were asked about the contribution of the local landscape to subjective well-being, many values that had not been identified within the ecosystem services framework were mentioned (e.g., tranquility/relaxation, place attachment, quality of life/living well, and comfort/everything is close).

Linkages between the perception of ecosystem services provision in different land covers, subjective well-being and socio-demographic characteristics of respondents

The RDA indicates a statistically significant relationship between the frequency of mapped ecosystem service indicators in the different categories of land cover, the subjective well-being and the socio-demographic characteristics of respondents ($p < 0.0001$, from 500 permutations). The first three axes (with eigenvalue > 1, after Kaiser criterion) absorbed 88.6% of inertia (Appendix C). The first axis (38.3% of inertia) opposed agroforestry, in the positive side, and urban landscapes, in the negative (Figure 4). More intensively mapped ecosystem services in agroforestry areas were associated with older male respondents working in agriculture or forestry, and with a self-reported high knowledge of the area. These respondents related their well-being with nature, biodiversity, health, the good relation between low prices and good services and the resulting comfort. On the opposite side, people mapping more ecosystem services in urban areas were typically women and students that tended to relate their well-being with historic features, beauty, tranquility and leisure. The second axis (33.9% of inertia) was largely influenced by a high frequency of mapped ecosystem services in grasslands and pasturelands, particularly by people with a high level of formal education, that work as administrative workers, professionals or managers. These people related the effects of the landscapes on their well-being to a clean environment, freedom, silence, hunting, fishing, harvesting and other outdoor activities. The third axis (16.4% of inertia) was represented by agriculture on the positive side and urban landscapes on the negative. Older people, retired and those working in the administration tended to relate their well-being with family interaction, comfort and tranquility. On the opposite side, respondents dedicated to home duties or students more frequently mapped ecosystem services more intensively in urban landscapes. They also perceived the relation between the landscapes and their well-being through biodiversity and cultural features/traditions.

Table 1. Informant characteristics.

	n[1]	%
Municipality		
Trujillo	94	42,9
La Cumbre	49	22,4
Torrecillas de la Tiesa	47	21,5
Aldea del Obispo (La)	15	6,8
Aldeacentenera	4	1,8
Zorita	4	1,8
Ibahernando	2	0,9
Jaraicejo	2	0,9
Herguijuela	1	0,5
Madroñera	1	0,5
	219	100,0
Gender		
Men	112	51,1
Women	107	48,9
	219	100,0
Age category		
15-29 yrs	53	24,2
30-59 yrs	100	45,7
≥ 60 yrs	66	30,1
	219	100,0
Work related to agriculture or forestry		
No	179	81,7
Yes	40	18,3
	219	100,0
Household size		
1	20	9,3
2-3	113	52,6
4-6	82	38,1
	215	100,0
Household monthly net income		
Above median (≥2200 €)	57	30,3
Below median (≤2200 €)	131	69,7
	188	100,0
Highest level of education		
Higher university degree	18	8,8
Polytechnic or lower university degree	19	9,3
Vocational training	28	13,7
Upper secondary school / college	24	11,7
Primary or secondary school	102	49,8
No formal schooling	14	6,8
	205	100,0
Relationship to study area		
I live here full time	181	82,6
I live here part time or seasonally	17	7,8
I work here and live in another place	14	6,4
I used to live here but I currently live outside this area	3	1,4
	215	100,0
Self-estimated knowledge of the area		
Extremely good	88	40,2
Quite good	86	39,3
Moderate	30	13,7
Quite poor	11	5,0
Extremely poor	0	0,0
	215	100,0

[1]Number of informants varies according to informants who responded each question.

Table 2. Number of mapped points and their relative proportion for all informants, women, men, different age groups, and agricultural and forestry workers.

	All (n=219)		Men (n=112)		Women (n=107)		15-29 yrs (n=53)		30-59 yrs (n=100)		≥ 60 yrs (n=66)		Agric./forestry (n=40)		Non-agric./forestry (n=179)	
	no. of places (2597)	% places	no. places (1352)	% places	no. places (1242)	% places	no. places (605)	% places	no. places (1193)	% places	no. places (796)	% places	no. places (495)	% places	no. places (2099)	% places
Provisioning services	**627**	**24,2**	**352**	**26,0**	**275**	**22,1**	**120**	**19,8**	**296**	**24,8**	**211**	**26,5**	**149**	**30,1**	**478**	**22,8**
Farm products	294	11,3	156	11,5	138	11,1	49	8,1	139	11,7	106	13,3	65	13,1	229	10,9
Harvested products	333	12,8	196	14,5	137	11,0	71	11,7	157	13,2	105	13,2	84	17,0	249	11,9
Cultural services	**1495**	**57,6**	**753**	**55,7**	**742**	**59,7**	**370**	**61,2**	**668**	**56,0**	**457**	**57,4**	**259**	**52,3**	**1236**	**58,9**
Outdoor activities	429	16,5	221	16,3	208	16,7	101	16,7	191	16,0	137	17,2	69	13,9	360	17,2
Social interaction	270	10,4	128	9,5	142	11,4	80	13,2	117	9,8	73	9,2	47	9,5	223	10,6
Beautiful landscape or landmark	306	11,8	158	11,7	148	11,9	67	11,1	143	12,0	96	12,1	60	12,1	246	11,7
Appreciation of local culture, cultural heritage or history	254	9,8	133	9,8	121	9,7	61	10,1	116	9,7	77	9,7	41	8,3	213	10,1
Inspirational, spiritual or religious place, feeling or value	136	5,2	59	4,4	77	6,2	29	4,8	57	4,8	50	6,3	21	4,2	115	5,5
Appreciation of a specific place as such, independent of any benefit to humans	100	3,9	54	4,0	46	3,7	32	5,3	44	3,7	24	3,0	21	4,2	79	3,8
Regulating/supporting services	**398**	**15,3**	**211**	**15,6**	**187**	**15,1**	**90**	**14,9**	**190**	**15,9**	**118**	**14,8**	**74**	**14,9**	**324**	**15,4**
Appreciation of plants, animals, wildlife ecosystems etc.	257	9,9	139	10,3	118	9,5	55	9,1	120	10,1	82	10,3	43	8,7	214	10,2
Appreciation of environmental capacity to produce, preserve, clean, and renew air, soil and/or water	141	5,4	72	5,3	69	5,6	35	5,8	70	5,9	36	4,5	31	6,3	110	5,2
Other special place or area to me	**74**	**2,9**	**36**	**2,7**	**38**	**3,1**	**25**	**4,1**	**39**	**3,3**	**10**	**1,3**	**13**	**2,6**	**61**	**2,9**
Total	**2594**	**100,0**	**1352**	**100,0**	**1242**	**100,0**	**605**	**100,0**	**1193**	**100,0**	**796**	**100,0**	**495**	**100,0**	**2099**	**100,0**
Mapped places per informant	**11,8**		**11,1**		**11,6**		**11,4**		**11,9**		**12,1**		**12,4**		**11,7**	

Table 3. Land cover classes (Corine Land Cover, CLC, 2006) and Natura 2000 areas, and common land areas characterising ecosystem services and their indicators mapped by the informants. Land cover (LC) class share (%) of extended study area sums up to 99.9% as there are some minor land cover classes in the study area where mapped places were not assigned to, and these were excluded from the table.

LC category	**Urban**		**Agriculture**						**Grassland, pasture**		**Agroforestry, sclerophyllous, forest**					**Sparsely vegetated, wood/shrubland**					**Water**	**Total**		
LC class (CLC level 3 value)	Continuous urban fabric (1)	Discontinuous urban fabric (2)	Non-irrigated arable land (12)	Permanently irrigated land (13)	Fruit trees and berry plantations (16)	Olive groves (17)	Complex cultivation patterns (20)	Land principally agriculture, with natural vegetation (21)	Pastures (18)	Natural grasslands (26)	Agro-forestry areas (22)	Broad-leaved forest (23)	Coniferous forest (24)	Mixed forest (25)	Sclerophyllous vegetation (28)	Mineral extraction sites (7)	Transitional woodland-shrub (29)	Bare rocks (31)	Sparsely vegetated areas (32)	Burnt areas (33)	Water bodies (41)	LC total	**Natura 2000 (inside)**	**Common land (inside)**
Provisioning services	**76**	**1**	**52**	**0**	**0**	**8**	**56**	**60**	**0**	**168**	**116**	**9**	**1**	**0**	**41**	**0**	**27**	**0**	**0**	**0**	**12**	**627**	**197**	**57**
Provisioning services %	***12,1***	***0,2***	***8,3***	***0,0***	***0,0***	***1,3***	***8,9***	***9,6***	***0,0***	***26,8***	***18,5***	***1,4***	***0,2***	***0,0***	***6,5***	***0,0***	***4,3***	***0,0***	***0,0***	***0,0***	***1,9***	***100,0***	***31,4***	***9,1***
Farm products	70	0	17	0	0	3	37	39	0	70	44	1	0	0	12		1	0	0	0	0	294	70	39
Harvested products	6	1	35	0	0	5	19	21	0	98	72	8	1	0	29		26	0	0	0	12	333	127	18
Cultural services	**333**	**1**	**80**	**3**	**3**	**14**	**91**	**103**	**0**	**411**	**262**	**36**	**0**	**3**	**83**	**1**	**45**	**1**	**18**	**0**	**7**	**1495**	**622**	**120**
Cultural services %	***22,3***	***0,1***	***5,4***	***0,2***	***0,2***	***0,9***	***6,1***	***6,9***	***0,0***	***27,5***	***17,5***	***2,4***	***0,0***	***0,2***	***5,6***	***0,1***	***3,0***	***0,1***	***1,2***	***0,0***	***0,5***	***100,0***	***41,6***	***8,0***
Outdoor activities	54	0	50	1	0	3	42	47	0	147	57	1	0	0	18		6	1	1	0	1	429	115	61
Social interaction	43	0	16	1	0	3	24	15	0	72	71	5	0	0	12		7	0	0	0	1	270	106	30
Beautiful landscape or landmark	44	1	4		1	4	8	11	0	84	62	21	0	2	34		12	0	16	0	2	306	160	5
Appreciation of local culture, cultural heritage or history	136	0	2	1	0	2	6	12	0	44	32	2	0	0	6		10	0	1	0	0	254	150	14
Inspirational, spiritual or religious place, feeling or value	38	0	5	0	0	2	8	13	0	35	17	5	0	0	7	1	5	0	0	0	0	136	49	3
Appreciation of a specific place as such, independent of any benefit to humans	18	0	3	0	2	0	3	5	0	29	23	2	0	1	6	0	5	0	0	0	3	100	42	7
Regulating/supporting services	**14**	**1**	**19**	**3**	**1**	**8**	**7**	**12**	**1**	**90**	**78**	**43**	**3**	**1**	**56**	**0**	**42**	**0**	**11**	**1**	**7**	**398**	**230**	**10**

Regulating/supporting services %	***3,5***	***0,3***	***4,8***	***0,8***	***0,3***	***2,0***	***1,8***	***3,0***	***0,3***	***22,6***	***19,6***	***10,8***	***0,8***	***0,3***	***14,1***	***0,0***	***10,6***	***0,0***	***2,8***	***0,3***	***1,8***	***100,0***	***57,8***	***2,5***
Appreciation of plants, animals, wildlife ecosystems etc.	7	1	11	1	1	6	5	7	1	57	47	32	2	0	32	0	33	0	10	0	4	257	156	5
Appreciation of environmental capacity to produce, preserve, clean, and renew air, soil and/or water	7	0	8	2	0	2	2	5	0	33	31	11	1	1	24	0	9	0	1	1	3	141	74	5
Other special place or area to me	**15**	**0**	**9**	**0**	**0**	**2**	**3**	**7**	**0**	**17**	**9**	**4**	**0**	**0**	**4**	**0**	**2**	**0**	**1**	**0**	**1**	**74**	**26**	5
Other special place or area to me %	***20,3***	***0,0***	***12,2***	***0,0***	***0,0***	***2,7***	***4,1***	***9,5***	***0,0***	***23,0***	***12,2***	***5,4***	***0,0***	***0,0***	***5,4***	***0,0***	***2,7***	***0,0***	***1,4***	***0,0***	***1,4***	***100,0***	***35,1***	***6,8***
All	**438**	**3**	**160**	**6**	**4**	**32**	**157**	**182**	**1**	**686**	**465**	**92**	**4**	**4**	**184**	**1**	**116**	**1**	**30**	**1**	**27**	**2594**	**1075**	**192**
All %	***16,9***	***0,1***	***6,2***	***0,2***	***0,2***	***1,2***	***6,1***	***7,0***	***0,0***	***26,4***	***17,9***	***3,5***	***0,2***	***0,2***	***7,1***	***0,0***	***4,5***	***0,0***	***1,2***	***0,0***	***1,0***	***100,0***	***41,4***	***7,4***
LC class/Natura 2000/common land share (%) of study area	***1,2***	***0,1***	***8,6***	***0,7***	***0,5***	***2,7***	***3,7***	***2,8***	***0,1***	***25,6***	***24,6***	***6,0***	***0,6***	***0,2***	***11,7***	***0,0***	***8,0***	***0,1***	***0,4***	***0,0***	***2,2***	***99,9***	***41,9***	***1,3***

Table 4. Number and percentage of informants mentioning specific landscape values categorised as forms, practices and processes, and relationships.

	Informants mentioning	% informants mentioning
Forms		
Nature	45	20,5
Biodiversity	14	6,4
Natural/farm products	12	5,5
Historic features	11	5,0
Climate	10	4,6
Low prices/high services	9	4,1
Cultural features/traditions	6	2,7
Good food	3	1,4
Practices and processes		
No contamination/clean environment	29	13,2
Work	27	12,3
Fresh/clean air	24	11,0
Quality of life/living well	24	11,0
Other outdoor activities	19	8,7
Health	13	5,9
Leisure/entertaiment	12	5,5
No noise	6	2,7
Hunting/fishing	4	1,8
Harvesting	4	1,8
Clean water	1	0,5
Relationships		
Tranquility/relaxation	162	74,0
Social interaction	70	32,0
Family interaction	25	11,4
Place attachment	19	8,7
Beauty	18	8,2
Comfort/everything is close	17	7,8
Optimism/happiness/love	13	5,9
Safety	10	4,6
Freedom	10	4,6

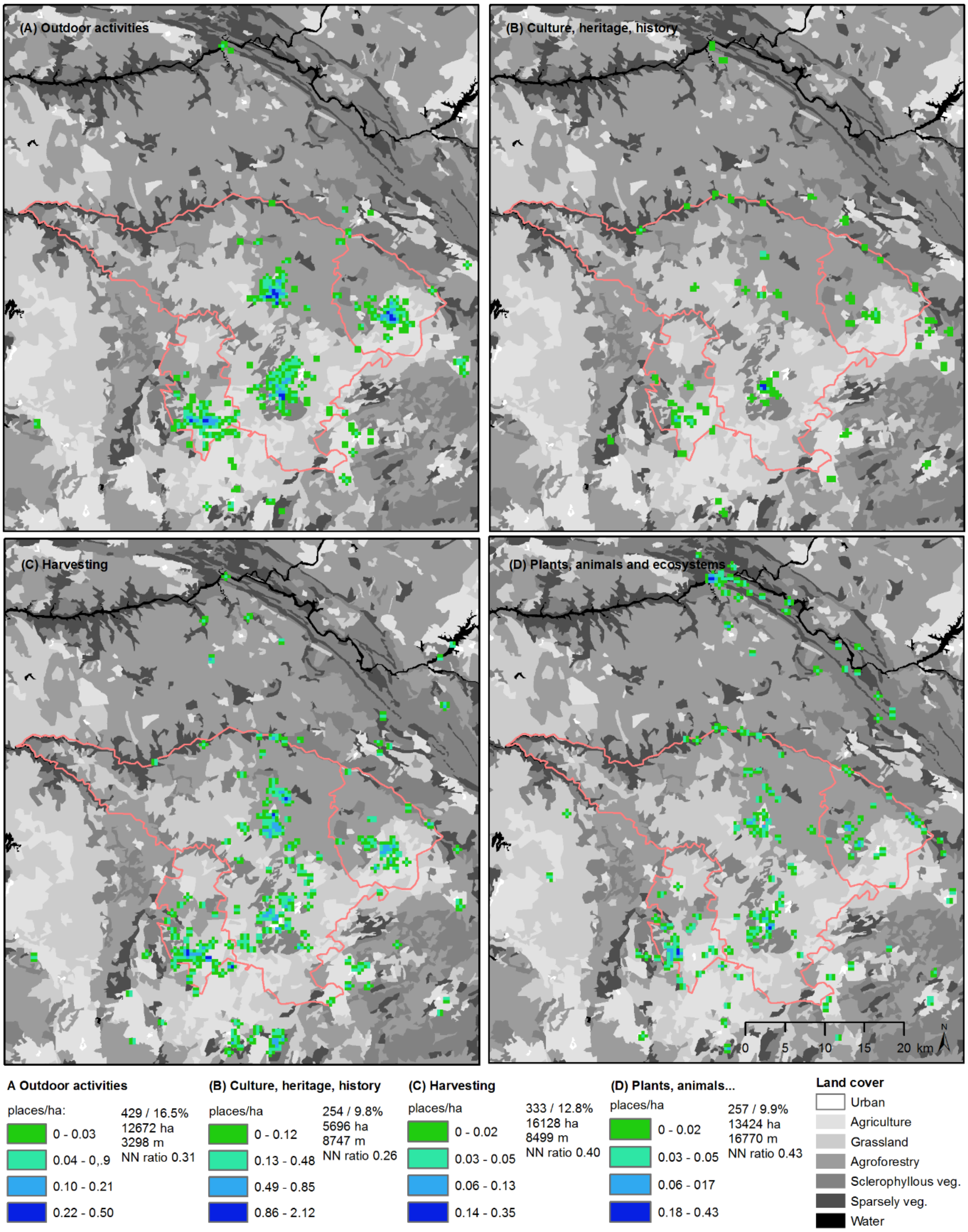


Figure 3. Spatial intensity (points/ha) for four ecosystem service indicators of outdoor recreation (A), appreciation of local culture, cultural heritage or history (B), harvested products (C) and appreciation of plants, animals and ecosystems (D). Descriptive data indicate the number of mapped points and relative proportion of all mapped points per indicator, area (ha), average distance (m) from informant home to mapped point locations, and nearest neighbour ratio.

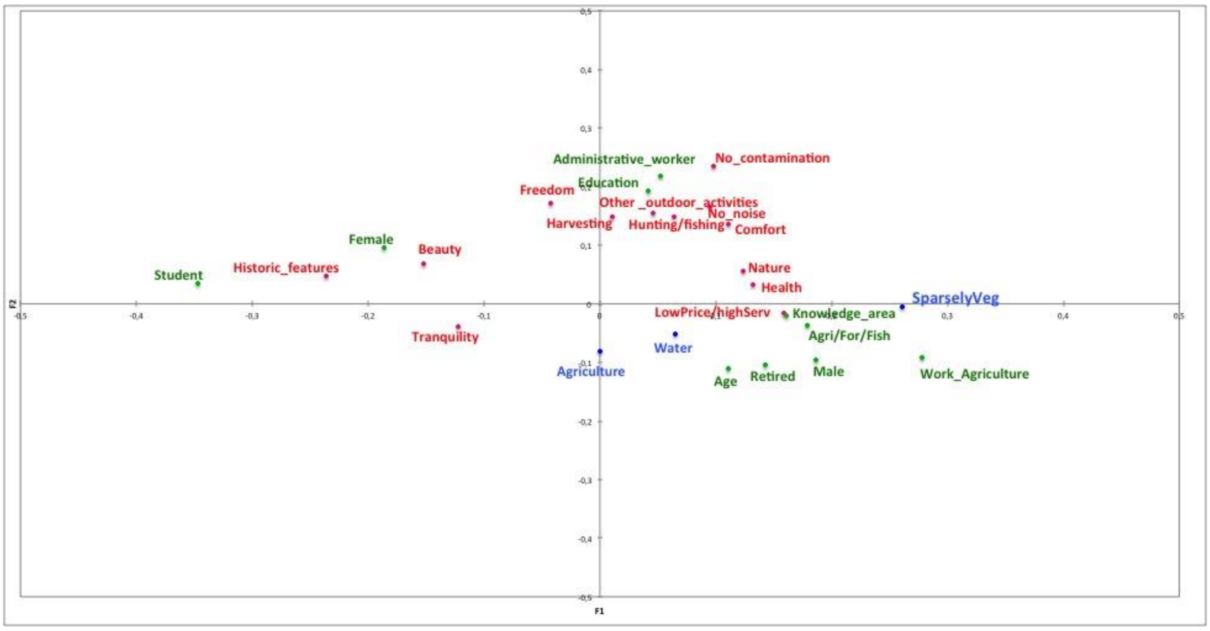


Figure 4. Scatter plot of the first two axes of the redundancy analysis (RDA). In blue, dependent variables, i.e. land cover types. In red and green, independent variables, i.e. socio-demographic and landscape values respectively. For a good readability, only variable with the largest absolute values of the scores in the first two axes are represented.

Discussion

Key findings from ecosystem service mapping

Our participatory mapping identified a local-level appreciation for all categories of ecosystem services. The clearest appreciation was expressed for provisioning and cultural services including outdoor recreation, harvested products, aesthetics, farm products and social interaction. This finding shows that people practice multiple forms of recreational, hobby, small-scale farming and gathering activities that generate coupled provisioning and cultural services. Sites for outdoor activities, farm products and social interaction were also found closest to informants home, which represent the common and important practices and values in everyday life. Sites for recreation and social interaction were found closest to people's place of residence, coinciding with the findings presented by Brown et al. (2002) and Fagerholm et al. (2012). Outdoor activities and culture and heritage values were also the most spatially clustered services. While outdoor activities cover extensive areas surrounding all municipalities, the culture and heritage values were more clustered with the city centre of Trujillo.

Appreciation for ecosystem services was relatively consistent and homogenous across municipalities, genders, age groups and different professions. However, there were differences in two aspects: younger people tended to have less appreciation for provisioning services, which is possibly an indication of a loss of practical engagement with nature through agricultural practices (cf. Gómez-Baggethun et al., 2010). Farmers expressed more appreciation for provisioning services and less for cultural services, especially for outdoor recreation, which confirms our hypothesis that they have different ways of engaging with the local landscape and more 'productivist behavior' compared with residents involved in professional occupations (Burton, 2004, 2011; de Snoo et al., 2013). Also Bieling et al. (2014) observed that farmers' relationship to land is more often based on material factors and less on recreation.

Relations between ecosystem services and use, protection and ownership of land

The spatial overlay of land cover and ecosystem services did not show any areas of over or underrepresentation, except for urban areas that have a high coverage of cultural and heritage values, and provisioning services related to homegardens. Ecosystems outside settlement areas were rather similar in their service provision. We may conclude that people appreciate ecosystem services provided by the heterogeneous structure of various land covers, which represent the landscape as a whole, rather than assigning values on individual land systems.

Protected areas showed a clear pattern of low provisioning and very high regulating services, in particular appreciation of plants, animals, wildlife and ecosystems (as also found by Castro et al., 2015). Although the overall landscape is multifunctional, there is obviously a separation between protection and production landscapes. Similarly, Raymond & Curtis (2013) found that formally acknowledged areas of high environmental significance attracted more social values related to conservation, e.g. biodiversity, natural significance and intrinsic values. Interestingly, cultural ecosystem services were appreciated inside and outside Natura 2000 areas to a similar degree, so evidently both production and conservation landscapes are able to provide them.

The clearest pattern was found for the small share of common lands, which had disproportionally high levels of provisioning and cultural services. These results support the view that land tenure and public access to land are important determinants of ecosystem service provision (Brown et al., 2014; Hausner et al., 2015). We conclude that public access to land guides the spatial practices and values of the people beyond the potentially preferred landscape types. Hence, interpretation of data collected with a PPGIS method also requires the acknowledgement of land tenure and access patterns, especially in the context of dehesa landscapes with extensive areas without public access. Strong differences between ecosystem service provision among different forms of land tenure was also found in biophysical studies (e.g. Schaich & Plieninger, 2013).

The contribution of landscapes to subjective human well-being

The open-ended well-being question posed allowed us to recognise landscape values that had not been mapped as ecosystem services, such as tranquillity and comfort. Many of the identified values were linked to the constituents of well-being in the MA (MA, 2005), especially to freedom, health, social relations, and security. Our approach revealed that the contribution of landscape to subjective well-being is largely related to relationships, i.e. the values based on interactions among people and the landscape, as tranquillity/relaxation and people-people interactions such as meeting with family and friends. Stephenson (2008), working with indigenous Maori communities, found that older people who had more experience with different elements of the landscape mentioned relationships more frequently, and that their understanding of the landscape arose from its temporality (e.g. historic events, traditions). In contrast, we found, on one hand, that older people and those with a self-reported high knowledge of the area linked their well-being to nature, biodiversity, health and low price level for living combined with good services, i.e. to forms and practices. On the other hand, students and young people, who might have limited experience with different elements of the landscape, tended to express the significance of landscapes in terms of relations, for example leisure. These trends were related to urban areas, aligning with patterns that emerged in the ecosystem service mapping.

The role of agroforestry

One of the starting points of our study was the assumption that, based on evidence from biophysical assessments (Smith et al., 2013; Torralba et al., submitted), agroforestry systems would generally provide higher levels of ecosystem services than other land use systems. Indeed, our respondents allocated multiple ecosystem services to agroforestry lands within our study area. However, the intensity was not higher than for the surrounding agricultural or semi-natural areas. These areas clearly differ from agroforestry land in their vegetation structure and visual appearance but they are also managed by low-input land-use systems, have a high share of semi-natural habitats and are of overall high nature value (Veen et al., 2009). Moreover, grasslands are also culturally relevant to local people (Stenseke, 2006). Again, we find that it is less individual land-use systems, but rather our study landscape as a whole that provides ecosystem services to people, though agroforestry is an important part of this landscape with long traditions and historical roots. The trends in our RDA, which found that people working in agriculture and forestry and those with a better knowledge of the area had a higher appreciation for the ecosystem services in agroforestry areas, point to a second explanation: the dehesas of our study area are mostly in large private ownership and usually do not offer access to the public. Many people simply may not have physical access to these lands and are therefore unable to allocate ecosystem services to them as discussed above.

Consideration of the method

Our research approach was based on the engagement of the general public to map ecosystem services that originate in place-based local knowledge and to the exploration of the context-dependent nature of subjective well-being. The applied approach was successful in capturing experience-based individual practices, uses and values related to these landscapes and related the direct and indirect ecosystem benefits to the actual people that derive and demand them. However, differences between the mapping and the self-reported well-being approaches could be observed.

PPGIS approaches have been applied to successfully assess especially provisioning and cultural benefits (e.g. Raymond et al., 2009; Sherrouse et al., 2011; Brown et al., 2012; Fagerholm et al., 2012) which our study also confirmed. In particular, cultural services are often inferred from proxies such as recreation and tourism locations, scenic beauty or cultural heritage sites. In fact, the recent literature on ecosystem services indicates that the mapping of cultural services lags behind mapping of other services (Crossman et al., 2013; Martínez-Harms & Balvanera, 2012). Hence, there is a need to acknowledge and map a broader variety of cultural services (Chan et al., 2012; Daniel et al., 2012; Setten et al., 2012). Our well-being approach managed to capture the context-specific social-cultural values arising from and related to the landscape and natural surroundings as a whole, placing emphasis not on predefined value typologies but on a grounded perspective. Consistent with earlier work (Berbés-Blazquez, 2012; Bieling et al., 2014), certain values were not conceptualised as ecosystem services. We conclude that the integration of these two methods of social-cultural assessment on the one hand links to established ecosystem services frameworks but on the other hand acknowledges a more holistic nature of people’s benefits from landscapes.

Based on the experiences from this study, we believe that our facilitated approach (as opposed to the more frequent type of self-administered surveys) has high potential to increase data quality and participant motivation, and to reduce dropout rate during the survey. Survey data collection with an online interface and a facilitated approach has to our knowledge not been applied with web-based

PPGIS so far. Facilitation allowed in-depth discussion with the informants on the meanings and placement of the mapped attributes. This increased spatial data precision and probably also the amount of mapped attributes compared to self-administered surveys.

Our research had focus on one time layer (present) and was performed at local scale and we highlight that comparative assessments across spatial and temporal scales would be needed. Also, involvement of a broad set of actors beyond local residents such as visitors, local action groups, farmer or conservation associations and authorities, would be of importance when truly aiming to capture multiple interests, values and power asymmetries.

Conclusions

Our study shows that in multifunctional and heterogeneous landscapes it is less individual land systems or ecosystems that provide multiple and coupled ecosystem services to people, but instead it is the landscape as a whole in which all land systems share a key role. However, land tenure and public access significantly guide the spatial practices and values of the people beyond the potentially preferred landscape types. Hence, we call for further clarification of the role of land systems, land tenure and also of the different categories of protected areas to ecosystem service provision.

Our study also highlights the importance of the multidimensional and context-specific, social-cultural sphere in understanding the contributions that nature's services provide to humans and their well-being. To advance understanding of these relationships, more research should be directed to the links between ecosystems and human well-being in the context of natural surroundings and everyday landscapes, including a systematic exploration of the various social-cultural assessment methods and their specific contributions.

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Annexes

Annex A: Ecosystem service typology and respective indicators developed the PPGIS survey in the study landscape context. In the survey, each indicator was approached through the question 'Do you find some particular place or area special in this landscape?'.

Ecosystem service category	Ecosystem service	Ecosystem service indicator	Operational definition (related survey question: Do you find some particular place or area special in this landscape?)	Survey category: Doing (D)/Feeling or valuing (F/V)	References
Provisioning	Food	Farm products	I appreciate, produce or can buy farm products here	D	Brown, 2012; Fagerholm et al., 2012; Lopez-Santiago et al., 2014; MA, 2005
	Food	Harvested products	I harvest fruits, berries, mushrooms, fish, game etc.	D	Lopez-Santiago et al., 2014; MA, 2005
Cultural	Recreation	Outdoor activities	I practice outdoor sports, walking, hiking, biking, dog walking etc.	D	Brown, 2012; MA, 2005; Plieninger et al., 2013
	Social relations	Social interaction	I spend time together with other people	D	Brown, 2012; Fagerholm et al., 2012; MA, 2005; Plieninger et al., 2013
	Aesthetic values	Beautiful landscape or landmark	I enjoy seeing this beautiful landscape or landmark	F/V	Brown, 2012; Fagerholm et al., 2012; Lopez-Santiago et al., 2014; MA, 2005; Plieninger et al., 2013
	Cultural diversity, cultural heritage values	Appreciation of local culture, cultural heritage or history	I appreciate the local culture, cultural heritage or history	F/V	Brown, 2012; Fagerholm et al., 2012; MA, 2005; Plieninger et al., 2013
	Inspiration, spiritual and religious values	Inspirational, spiritual or religious place, feeling or value	I am inspired by feelings, new thoughts, religious or spiritual meanings etc.	F/V	Brown, 2012; Fagerholm et al., 2012; MA, 2005; Plieninger et al., 2013; Vallés-Planells et al., 2014
	Existence value	Appreciation of a specific place as such, independent of any benefit to humans	I appreciate this place just for its existence regardless of benefits for me or others	F/V	Brown, 2012, Fagerhom et al., 2012, Raymond et al., 2009

Regulating/ supporting	Provisioning of habitat, biodiversity	Appreciation of plants, animals, wildlife ecosystems etc.	I appreciate the plants, animals, wildlife, ecosystems etc.	F/V	Brown, 1212; Lopez-Santiago et al., 2014; MA, 2005
	Erosion control, soil fertility, water and climate regulation, air quality maintenance	Appreciation of environmental capacity to produce, preserve, clean, and renew air, soil and/or water	I appreciate the environmental capacity to produce, preserve, clean, and renew air, soil, and/or water	F/V	Brown, 2012; Bieling et al., 2014; Lopez-Santiago et al., 2014; MA, 2005
Other	-	-	Other special place or area to me	-	Brown, 2012

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Annex B: Summary of statistics on spatial patterns on ecosystems service indicators mapped by the informants including distance from home to mapped places (mean, minum, maximum, and standard deviation), nearest neighbour statistics (average nearest neighbour distance, ratio, and Z score (all significant at the level of 0.000)), and intensity as Kernel density surface statistics (area, points/ha min, max, mean, standard deviation).

	Distance (m) from home				**Nearest neighbour**			**Intensity (Kernel density) surface grids**				
	mean	min	max	SD	Ave NN dist. (m)	NN ratio	Z score	area (ha)	mean	min	max	SD
Provisioning services												
Farm products	4699	1	103480	10758	1253	0,40	-19,56	9584	0,03	9,7E-10	0,66	0,06
Harvested products	8499	18	73276	12542	1162	0,40	-20,79	16128	0,02	1,7E-08	0,35	0,03
Cultural services												
Outdoor activities	3298	0	84437	9693	730	0,31	-27,47	12672	0,03	1,4E-07	0,50	0,05
Social interaction	5573	33	82254	9880	1181	0,37	-19,80	10688	0,04	4,7E-09	0,59	0,03
Beautiful landscape or landmark	10903	50	110074	16449	1409	0,43	-19,06	12544	0,02	4,5E-07	0,87	0,06
Appreciation of local culture, cultural heritage or history	8747	5	87810	14161	791	0,26	-22,52	5696	0,04	1,3E-06	2,12	0,17
Inspirational, spiritual or religious place, feeling or value	8361	20	74140	15329	1679	0,41	-13,25	6192	0,02	7,1E-08	0,31	0,03
Appreciation of a specific place as such, independent of any benefit to humans	10332	33	108417	18991	2249	0,45	-10,43	6016	0,02	5,1E-13	0,20	0,02
Regulatign/supporting services												
Appreciation of plants, animals, wildlife ecosystems etc.	16770	101	109820	19892	1536	0,43	-17,35	13424	0,03	8,7E-10	0,43	0,02
Appreciation of environmental capacity to produce, preserve, clean, and renew air, soil and/or water	16206	170	105860	22687	1731	0,42	-13,22	8000	0,02	4,2E-07	0,19	0,02
Other special place or area to me	7840	4	89520	15583	3568	0,65	-5,84	4384	0,02	4,8E-10	0,13	0,02

Annex C. Scores for the redundancy analysis (RDA) variables and statistics. Numbers in bold are those with highest absolute value, i.e. related to the corresponding axis.

	Axis 1	Axis 2	Axis 3
Dependent variables (land cover categories)			
LC1+LC2+LC7_Urban	**-1,380**	0,332	**-1,039**
LC12+LC13+LC16+LC17+LC20+LC21_Agriculture	0,000	-0,081	**1,542**
LC41_Water	0,065	-0,051	-0,051
LC18+LC26_Grasslands_Pasturlands	0,568	**2,742**	0,082
LC22+LC23+LC24+LC25+LC28_Agrofor_Forestry_SchlerVeg	**2,559**	-0,428	-0,569
LC7+LC29+LC31+LC32+LC33_SparselyVeg_WoodlandShrub	0,261	-0,006	-0,074
Independent variables			
Socio-demographic characteristics			
Age	**0,110**	**-0,110**	**0,138**
Knowledge SL	**0,160**	-0,020	-0,105
Education	0,041	**0,193**	-0,045
Gender-Female	**-0,186**	0,097	-0,034
Gender-Male	**0,186**	-0,097	0,034
Occupation-Agricultural, forestry or fishery worker (e.g. farmer)	**0,179**	-0,036	-0,054
Occupation-Clerical support or administrative worker	0,052	**0,219**	**0,121**
Occupation-Community or personal service worker	-0,054	**0,118**	**0,122**
Occupation-Home duties / parenting	-0,026	-0,091	**-0,108**
Occupation-Labourer	0,064	-0,088	-0,001
Occupation-Manager or professional	0,018	**0,100**	-0,046
Occupation-Other	-0,151	0,006	-0,005
Occupation-Retired	**0,143**	**-0,103**	**0,113**
Occupation-Service, shop or market sales worker	-0,007	0,008	0,135
Occupation-Student	**-0,347**	0,034	**-0,167**
Occupation-Unemployed	0,087	-0,037	-0,007
Work_Agriculture	**0,278**	-0,091	-0,057
Wellbeing variables (landscape values)			
Forms – Biodiversity	**0,119**	**0,109**	**-0,113**
Forms – Nature	**0,123**	0,056	-0,084
Forms - Good food	-0,056	-0,051	0,063
Forms - Natural/farm products	0,092	0,065	0,005
Forms- Climate	-0,023	0,054	-0,021
Forms - Cultural features/traditions	-0,024	0,068	**-0,113**
Forms - Historic features	**-0,236**	0,047	-0,062
Forms - Low prices/high services	**0,159**	-0,016	-0,032
Practices - No noise	0,095	**0,166**	0,031
Practices - Clean water	0,021	0,015	0,001
Practices - Fresh/clean air	0,063	0,040	-0,066
Practices - No contamination/clean environment	0,098	**0,236**	-0,093
Practices - Hunting/fishing	0,064	**0,148**	0,019
Practices – Harvesting	0,011	**0,148**	-0,056
Practices - Leisure/entertainment	**-0,100**	-0,057	-0,039
Practices - Other outdoor activities	0,046	**0,154**	-0,013
Practices – Work	0,096	-0,084	0,032
Practices – Health	**0,132**	0,033	0,035
Practices - Quality of life/living well	-0,039	0,005	-0,052

Relationships - Family interaction	-0,056	-0,011	**0,212**
Relationships - Social interaction	-0,078	-0,084	-0,012
Relationships - Comfort/everything is close	**0,111**	**0,135**	**0,123**
Relationships - Tranquillity/relaxation	**-0,123**	-0,039	**0,116**
Relationships - Place attachment	0,028	0,022	0,059
Relationships – Beauty	**-0,152**	0,070	-0,009
Relationships - Optimism/happiness/love	0,098	0,061	-0,013
Relationships – Safety	-0,098	0,008	-0,022
Relationships – Freedom	-0,042	**0,171**	0,025
Eigenvalue	*3,323*	*2,938*	*1,426*
% of variance explained	*38,310*	*33,875*	*16,440*
Cumulative % of variance explained	*38,310*	*72,185*	*88,624*
Total inertia	*11,598*	*10,255*	*4,977*

6 Annex D: Paper 4: Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe

This is a pre-print version of the following paper:

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Abstract

Wood-pastures are agroforestry systems created and maintained by multifunctional management. As such, wood-pasture systems provide a model ecosystem for the sustainable integration of food production and biodiversity conservation. Values attached by the local farmer communities to the woody vegetation from pastures were of crucial importance in shaping the physiognomy of these landscapes and their temporal dynamic. Nevertheless, these values went through sharp changes during the past decades, typically resulting in the transformation of wood-pasture systems either in pastures without trees, high forests or other landuse forms. Here we assess the values of scattered trees (mature and old) from oak wood-pastures by traditional farmers from a traditional rural region of Transylvania (Romania). Our study region is one of the richest ancient oak wood-pasture regions of lowland Europe. Mature scattered trees were appreciated mostly for their tangible values (especially shade for livestock) while old trees were appreciated for their intangible values (e.g. age, beauty and relaxation, cultural identity). When trees were perceived as deteriorating, farmers suggests their removal from wood-pastures. As the hollowing, often drying trees have disproportional habitat values for several organisms, maintaining these trees on managed pastures is a key conservation and sustainability challenge.

Keywords

agroforestry systems, silvopastoral systems, sparse trees, old trees, ecosystem service, traditional farming

1 Introduction

Wood-pastures are multifunctional agroecosystems managed primarily by livestock grazing, where woody vegetation was valued by the local communities for its multiple services and functions (Hartel and Plieninger, 2014). Wood-pastures are special agroforestry systems; they can have a wide variety of physiognomies, ranging from pastures with scattered trees (i.e. 'savannah-like' system) to more closed grazed woodlands (Goldberg et al., 2007; Rackham, 2013). Values attached to the woody vegetation and grassland component of wood-pastures as well as the ways how these values changed through time had an important driving role in shaping the physiognomy and ecosystem properties of these landscapes. For example, the erosion of the values attached to scattered trees on pastures resulted in their trade-off and the emergence of monofunctional pastures (without trees) specialized mainly for livestock (grass) production. On the contrary, the increase of the timber value of trees resulted in the conversion of several wood-pastures in high forests managed primarily for timber production (Hartel and Plieninger, 2014). The changing societal demands for agricultural and timber commodities, the loss of extensive, multifunctional management, the changing land use and nevertheless the policy mismatches (Bergmeier et al., 2010; Beaufoy, 2015; Plieninger et al., 2015) resulted in a sharp decline of wood-pasture systems all over Europe, in the past century.

Wood-pastures of Europe are getting increasing interest, both in the agricultural and environmental policy and research, due to their exceptional ecological, socio-cultural and economic values (see e.g. Eichorn et al., 2006; Bergmeier et al., 2010; Beaufoy, 2015; Plieninger et al., 2015 for reviews). Wood-pasture systems indeed have the potential to integrate food production with biodiversity conservation and the maintenance of resilient agroecosystems (Oppermann, 2014).

Despite their overall deterioration and loss in several western and central European countries, spatially extent oak wood-pasture systems are still well represented in Transylvania (Romania) (Hartel et al., 2013; Moga et al., 2016). Wood-pasture systems from Transylvania are particularly attractive for addressing the values farmers attach to multifunctional farming systems and the implications of these for multifunctional management. The values and practices which produced and maintained these wood-pastures and their natural and cultural values are sharply deteriorating (Fischer et al., 2012; Hartel et al., 2013), due to the fast socio-economic and institutional transitions these systems undergoes in the recent decades (Hartel et al., 2016). Hence, it is of utmost importance to understand the tangible and intangible values represented by sparse trees in pastures to farmers in these rural social-ecological systems.

Our goals were: (i) To explore the values associated with scattered, mature trees (hereafter ‘mature trees’) with intact crown on oak dominated wood-pastures as perceived by the farmers; (ii) To explore the values associated with large, old oak trees (hereafter ‘old trees’) with intact trunk and crown from wood-pastures, and finally (iii) To explore the perceptions of farmers related to the old trees which collapsed (hereafter ‘collapsed trees’) on pastures. We differentiated between the three categories of trees (i.e. mature, old and collapsed) for two main reasons. First, oak wood-pasture systems from our study region are unique in harboring a high number of large, old oak trees (Hartel et al., 2013). These trees confers an outstanding ecological value to these wood-pastures. Second, we expected that the various types of values associated to the scattered trees by farmer’s changes as the overall condition and productivity of the trees change with their age. Understanding the types of values farmers associate to various tree age (and condition) categories on wood-pastures, and how these values determines their attitudes and actions towards scattered may help in designing more effective conservation measures targeting these trees on farmland. We discuss our findings also from the perspective of the Common Agricultural Policy (CAP), which is one of the most significant policies affecting scattered trees on pastures within the European Union.

2 Materials and methods

2.1 Study area and villages

The studies were conducted in the Saxon cultural region of Southern Transylvania (central Romania). The rural region from this part of Transylvania is undergoing major social, institutional and cultural changes (Hartel et al., 2014; Hanspach et al., 2014). While the socio-economic capitals are eroded, the villages being characterized by economic poverty and low community cohesion (Mikulcak et al., 2015), the natural capital is exceptionally well preserved, with high levels of biodiversity and a wide range of ecosystem services (Fischer et al., 2012; Hanspach et al., 2014; Dorresteijn et al., 2015). The characteristic physiognomy of wood-pastures for this region is a pasture with scattered trees, typically oak and pear (Hartel et al., 2013).

The region where we carried out our research on wood-pastures covers *ca* 3,600 km^2, out of which *ca* 860 km^2 are covered by Natura 2000 regulations (Hartel et al., 2013; 2014). Within this region we selected the villages for our study in a way to capture the existing diversity of oak wood-pastures from the region. Every village selected for this study had at least 100 ha of oak wood-pasture in the vicinity. Eight villages were studied, out of which four had substantial number of large, old oak trees in their wood-pastures (i.e. over 20 such trees, as defined by Moga et al., 2016). The human population size in the studied villages ranged between *ca* 200-600 inhabitants while one locality had *ca* 1,500 inhabitants. This range of rural inhabitants is general for the whole region of the Saxon villages from Southern Transylvania.

The farming technology applied in the study region still retains several features which were common up to the 19th century, including the less use of agrochemicals, the use of human labor instead of large machineries (Fischer et al., 2012). We refer to these farming practices and the farming landscape physiognomies created and maintained by them as 'traditional'.

2.2 Selecting the interviewees

Farming was a substantial component of the household economy for every interviewed person. Semi-structured interviews were conducted generally at the people's home or in the farmland (see below for the themes and the interview process). The final interviews were preceded by pilot interviews in order to test the applicability of the methods and the reaction of the interviewees. The pilot interviews were carried out on 22 persons about which we knew that they are knowledgeable regarding the agricultural practices and history of their village and region. The pilot interviews were followed by 92 interviews which constituted the sample for our study. Interviewed persons were approached either randomly, or by using the snowball method, that is, potential interviewees were recommended by our local contacts and/or other interviewees. Seven to 18 interviews were made per village. The degree of trust of the interview process was increased with the local origin of the two persons conducting the interviews (TH and Árpád Szapanyos). While everybody from our study region speaks well Romanian (all interviewees being Romanian citizens), if the interviewee requested it, we were able to conduct interviews also in Hungarian. In order to further increase the trust of the participants, we allowed the participation of every person present in the interview process. Major contradictions between the participants in the same interview rarely occurred and if happened, consensus emerged quickly between them. The formal occupation of the interviewed persons was typically diverse (e.g. due to the seasonal employments) because of the regionally low availability of job opportunities. Annex 1 presents for the structure of interviewees.

2.3 The themes addressed in the interviews and the interview process

Table 1 presents the five themes and the associated questions used consecutively in the interview process. The method of photo elicitation has been frequently used as a complementary tool for interviews in landscape and environmental studies (e.g. Surová and Pinto-Correia, 2008; Sherren et al., 2010; Milcu et al., 2014). We also applied this method, by showing characteristic photographs about grazed landscapes and trees in order to assure that the interviewed persons have a good understanding on the broad landscape physiognomies and trees we were interested in. These photographs visualized representative pastures without sparse trees and wood-pastures for the study region (Annex 2) as well as large, old and hollowing oak trees (Annex 3). The pictures originated from the studied region (see above) but from different villages than those selected for our study. We showed no livestock in these pictures, in order to focus on trees and not to have the interviewees distracted by the presence of livestock. For assessing the perceptions and attitudes of rural inhabitants towards old and collapsed trees (themes 4 and 5, Table 1) we used pictures visualizing oaks (Annex 3) because these trees were the most common in the wood-pastures from the studied region, including villages (Hartel et al., 2013). These pictures also represented humans in order to help the interviewee in assessing the relative size of the trees (Annex 3).

We note that the Theme no. 3 ('The use of leaves and acorn as nutrient source for livestock', Table 1) was added after the (and as a result of) pilot interviews. In the pilot interviews the 'tree hay' was mentioned by two (9%) and the use of acorn by five (23%) interviewees, from all three villages where the pilot study was conducted. Given the high importance of tree fodder in traditional farming in Europe (see below) and the scarcity of written information about these resources we decided to introduce these as separate themes for the final interviews. The questions from Theme 3 (Table 1) were asked even if the interviewee mentioned 'acorn' and 'tree hay' in the previous themes.

2.4 Data analysis

Every interview was recorded with the agreement of the interviewee and then transcribed. The transcripts were analyzed using open coding technique: each narrative was decomposed in codes (items), that is, succinct summaries of broad topics addressed under each theme (Bryman, 2012; Saldaña, 2012). The codes emerging from our analysis are presented in Table 1.

In order to better explore the patterns within our data we presented the frequency of codes within a specific theme across each interview. We opted to do this order to provide better insights into the possible patterns within the data. This quantification of the qualitative data will not deprive the full potential of qualitative analysis to show the richness of knowledge (e.g. Green, 2001).

Table 1. The five major themes and the specific questions asked to address these themes within the semi-structured interviews. The codes extracted from the narratives of the interviewees are also shown.

Theme	Questions	Codes emerged from the decomposition of the narratives
1. Tree species on pastures	*Can you enumerate please the most common trees on wood-pastures? [we showed the pictures from Annex 2]*	Codes represented the name of tree species named by interviewees. In the results we presented the most common trees ('oak', 'pear', 'apple', 'hornbeam', 'beech') while the tree species sporadically mentioned (i.e. less than 5%) were pooled in the 'other species' category. Examples of trees included in this category were: 'ash', 'willow', 'black locust', 'cherry'.
2. Mature scattered trees on pastures	*Why are there trees on pastures? [pictures from Annex 2]* *Which pasture is better from your perspective: that with trees or that without trees? [pictures from Annex 2]*	Responses on first question were decomposed in 11 codes: 'shadow for livestock', 'microclimate', 'acorn', 'pear (fruits)', 'good for grass', 'erosion control', 'timber', 'beauty and relaxation', 'wildlife (habitat, food, species)', 'soil fertility', 'rubbing spot for buffalo'. Responses on the second question were coded as 'prefer pasture', 'prefer wood-pasture', 'prefer both'
3. The use of leaves and acorn as nutrient source for livestock	*What about the use of tree-hay and acorn? I heard that in the past people used dried tree leaves as livestock fodder. Do you know anything about that?*	In the context of the present study we considered the awareness about these specific goods of the trees (acorn, tree hay): 'yes' and 'no'. Hartel et al. (2016) explored in detail the nature of experiences of interviewees with tree hay (these being mentioned in the discussion part of this study)
4. Large, old oaks	*Have you seen such trees before?* *[we showed the upper photographs presented in Annex 3]* *What do you think about these trees on pastures? [upper photographs from Annex 3]*	Responses were decomposed into overall 16 codes such as: 'amount (reflecting the [high] number of trees in the surrounding pastures)', 'shadow', 'acorn', 'fruits', 'wildlife (habitat, food)', 'symbol', 'cultural identity', 'age', 'history', 'large size', 'habitat for honeybee', 'beauty and relaxation', 'nodes on trunk', 'hard to cut', 'cut if hollowing', and 'threat (to livestock, people)'.
5. Collapsed trees on pastures	*What do you think should happen when the trees start to hollow and dry? [we showed the lower photographs presented in Annex 3]* *What happens with these trees when these trees fall down? Dried, hollowing trees can be removed freely, or is a special permit needed for this?*	The responses were decomposed in seven codes such as 'should be cleaned from pasture (i.e. 'clear it')', 'firewood', 'burned by shepherds', 'clear by burning [on pasture]', 'nodes hard to cut', 'hollows', 'soil fertility'. For the removal of the trees we considered if interviewees expressed the need for 'formal' (e.g. 'Permit from forestry', 'permit from town hall') or 'informal' (e.g. decision of farmer) agreements.

3. Results

3.1 Trees on wood-pastures

Trees were specified 244 times by 85 interviewees. The oak, represented in the region by *Quercus robur* and *Q. petraea* (Hartel et al., 2013) was the most commonly mentioned tree on wood-pastures (34% of all tree species mentioned), followed by pear (*Pyrus communis* and *P. pyraster*, 25%), apple (*Malus sp.* 11%), beech (*Fagus sylvatica*, 9%), hornbeam (*Carpinus betulus*, 9%) and other species such as willow (*Salix sp.*), cherry (*Prunus avium*), various shrubs (11%).

3.2. The values of mature trees on pastures

This theme was addressed by 88 out of the 92 interviewees. 'Shadow for livestock' was the most commonly cited role for scattered mature trees on the pastures (over 90% of the interviewees). Figure 1 shows a sharp drop in the proportion of interviewees associating other values for mature trees on pastures, including 'pear (fruit)' (24%), 'acorn' (23%), 'wildlife (habitat, food)' (17%) and others (Figure 1, Quote 1). When specifically asked (Theme 3, Table 1), 63% of the interviewees were aware about the value of 'acorn' and 61% about the value 'tree hay' respectively.

Opinions about preferences for pastures with scattered trees and/or pastures without trees were expressed by 79 interviewees: 85% of these expressed 'preference for wood-pasture' while 6% of them expressed preference for pasture without trees (i.e. because large crowns hamper grass production) and 9% expressed that trees (for shade) and open areas (for high grass productivity) are equally important on pastures.

Quote 1. *'These trees are kept for shade. For example the sheep, the cattle and the buffalo gather together under the tree in the noon for shade. The oak is left also for acorn and the wild pear for brandy and plum. The wild pear and apple trees were so many in a pasture close to the village…all were left for providing shade.'* (Male, 62 years)

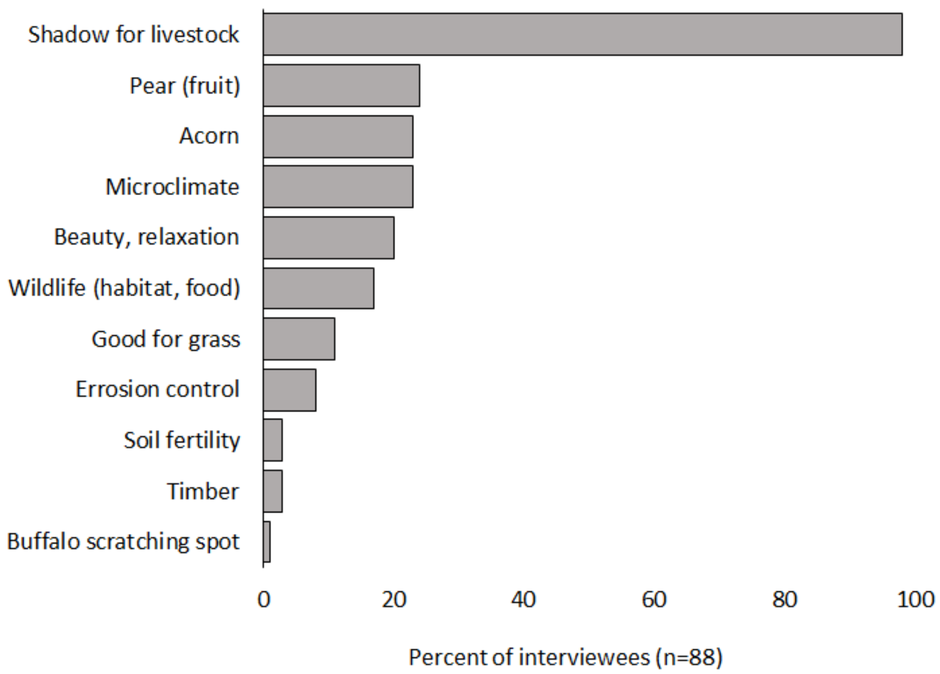

Figure 1. Values attached to mature trees from pastures by the interviewees.

3.3 The value of old oak trees

This theme was addressed by 89 out of 92 interviewees. 'Age', 'beauty and relaxation', 'cultural identity', 'large size' and 'history' and 'amount' were the most commonly associated values to large, old oaks (Figure 2). Perceptions about the (high) number of old oaks in the vicinity of the village (i.e. 'amount', Table 1) were expressed only from the four villages with substantial number of large, old trees in their vicinity (Quote 2). The existence of 'nodes on trunk', the difficulties related to cutting ('hard to cut') and the existence of 'threat (to livestock and people)' were also expressed by some interviewees (Figure 2). 'Acorn', 'shadow', 'wildlife (habitat, food) and the 'fruit' value of large, old oaks was perceived by a low proportion of interviewees (Figure 2).

Quote 2: *'Yes, we have several in the pasture near our village. Over 100, even! Beauties. We say that they are also the history of the Saxons, because these trees have approximately the same age as the Saxon culture. Because when the Saxons came 850 years ago in Transylvania, maybe these trees were small then, so that they experienced the history of the local population.'* (Male, 75 years)

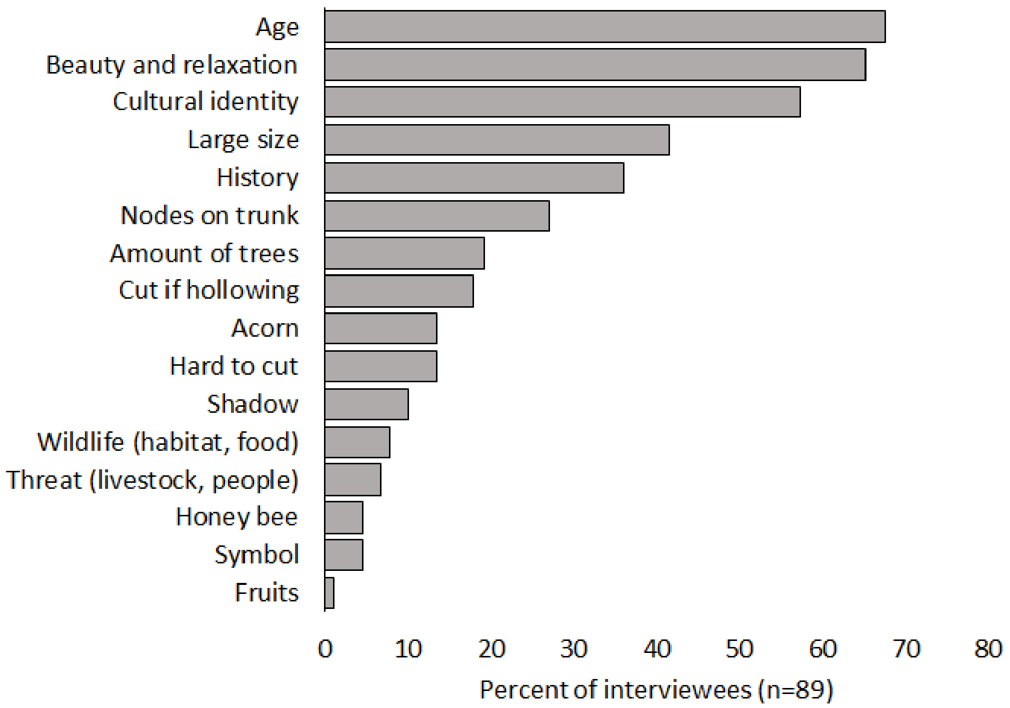

Figure 2. Values attached to old oaks trees from pastures by the interviewees.

3.4 The collapsed trees

This theme was addressed by 88 out of 92 interviewees. The perceptions and attitudes of the interviewees related to the hollowing, drying trees were mostly negative (Figure 3): these trees should be cleared ('clear it' – 91%, 'clear by burning' – 13%, 'burned by shepherds' – 10%) and used for 'firewood' whenever this is possible (51%) (Quote 3). The existence of 'nodes hard to cut' (Quote 4) was expressed by 22% of interviewees and a small percentage of people (4%) expressed that hollowing, drying trees contribute to 'soil fertility' (Figure 3). Dried trees can be removed with a 'permit from forest service according to 30% of interviewees, and 'permit from the town hall' according to 22% of the interviewees. The rest of the interviewees did not respond to this question.

Quote 3. *'Well, you see this [oak] may be so old that is no longer good for anything. So, the wood, I have seen that the wood if it is very old it is not burning, it has no power to burn, just like a kind of peat on fire, smoking. These trees should be cleaned because they rot, even the oak, which is a durable tree will lose its value.'* (Male 45 years)

Quote 4. *'When I was a child around the 70`s, there was a man here in the village who was dealing with these large oaks. This man made coal from these trees and this was used to make horse shoes. … So in those times we didn't throw anything away. But now the dried trees are fallen on the pasture, someone who finds them will cut the good parts for firewood and the remains are left there.'* (Male, 56 years).

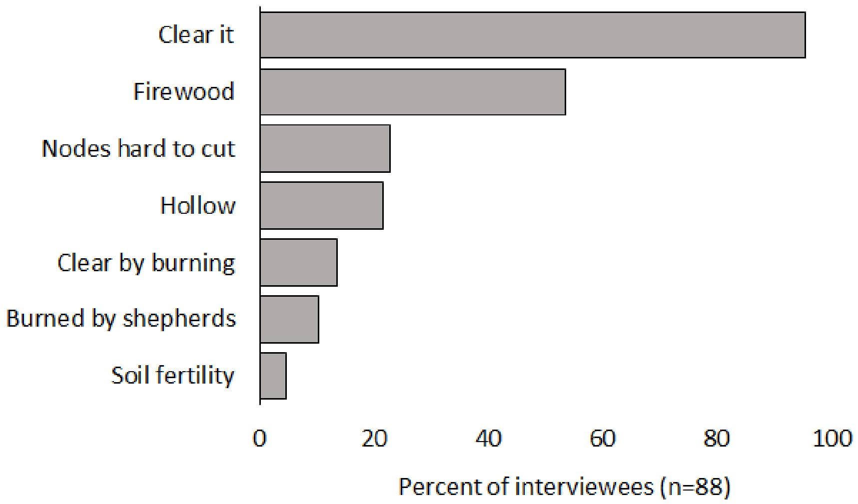

Figure 3. The perception of the interviewees about the collapsed trees on wood-pastures.

4 Discussion

In this study we addressed the values attached by farmers to the scattered trees in pastures in a rural region of Eastern Europe which retains still several traditional land use forms. We showed that farmers identified several values related to trees, some of them representing various types of ecosystem services (e.g. shade, fruits, and erosion control). Furthermore, we identified several types of values which go beyond the usual types of ecosystem services, representing relationships (e.g. scratching spot for buffalo, wildlife habitat, identity, threats), forms (e.g. tree species, size of the tree, the existence of nodes on trunk, amount of old trees) and practices (e.g. hollowing trees should be cut, clear by burning) (see Stephenson, 2008, for the description of relationships, forms and practices within the cultural values model). We furthermore showed that the values reflecting relationships, forms and practices are changing with the ageing of the trees and perceived changes in the tree condition related to age. These changes impose challenges for the maintenance of diverse size and age categories of trees on pastures. Below we will discuss our findings, including their potential implications for policies targeting sparse trees and old trees from pastures.

4.1 Scattered mature trees on wood-pastures

The high proportion of the interviewees pointing towards 'oak', 'pear' and 'apple' is in line with recent findings on tree inventories on wood-pastures (Hartel et al., 2013) and historical records (Oroszi, 2004).

We found that 'shadow for livestock' was recognized by a disproportionally high percentage of interviewees compared to other values of mature trees on pastures. These findings are similar with findings from other farming landscapes in Europe and elsewhere (e.g. Scambler, 1989; Fairweather, 1996; Seabrook et al., 2008). Pastoralism was always of crucial importance for the local communities from southern Transylvania, the traditional communities preferring cattle and buffalo (Dorner, 1910). The shadow provided by scattered trees for livestock in extremely hot summers is very important both from the perspective of animal welfare and the economic value of livestock (Hahn, 1999; Schütz et al., 2010; Tucker et al., 2008).

Oak wood-pastures were central for the economy of the rural communities for several centuries in the European lowlands, both as sources of acorn (mast) for fattening as well as grazing areas for pigs (Szabó, 2013; Jørgensen, 2013). Furthermore, pear (fruits) and tree hay were also commonly used in the past rural societies of Europe (up to the 19th century), including the Saxon region of Transylvania (see Paládi-Kovács, 1983; Austad, 1988; Robinson, 1986 for tree hay and Oroszi, 2004 for pear fruits). Farmer communities from Spain and Sweden also valued wood-pastures primarily for their provisioning ecosystem services (Garrido et al., 2017a;b). A study from Spain also the value of trees for erosion control (68%), habitats for wildlife (66%), beauty (66%), improvement of pasture quality (59%) and shade (48%), as perceived by farmers (Plieninger et al., 2004). Ranchers from California also valued oak woodlands for their beauty, recreation and lifestyle benefits (Huntsinger et al., 2010). Our study also identified similar types of values, but these were associated in a lesser extent to sparse trees from wood-pastures, excepting the shade value (Figure 1). The differences between the above studies may be caused by the regional particularities of the farming systems as well as by the applied research methodologies to assess farmer`s values attached to oak trees.

Our study revealed that only a small proportion of interviewees mentioned freely (i.e. being not specifically asked) the acorn, the same being true also for pear, while the tree hay was not mentioned by the interviewees. During our extensive field trips to wood-pastures and other landscape elements in this region (Remarkable Trees of Romania, 2016) we never witnessed acorn or tree hay collection, further confirming the overall low current values of these ecosystem services for the local communities. However, when specifically asked (Theme 4, Table 1) a substantial proportion of interviewees confirmed the high value of acorn and tree hay for livestock feeding (this study). Hartel et al. (2016) further explored the nature of knowledge and experience of farmers with tree hay (the same interviewees as those used for the present study) and showed that farmers directly experiencing tree hay were significantly older (i.e. average 66 years, SD=13) than those persons who indirectly experienced it (e.g. through stories, average 47 years, SD=13) and those who were not aware about tree hay at all (43, SD=12). Overall, the above findings suggests that the importance of provisioning ecosystem services of the trees such as acorn, tree hay and pear (fruits) are decreasing for the rural communities in our study region. For tree hay Paládi-Kovács (1983) noted that it was commonly made up to the end of the 19th century in Hungary '*but in the 20th century even its memory has been blurred*' from large regions of this country. Hartel et al. (2016) mentioned the institutional prohibition, and the increasing availability of more efficient and easier available fodder resources to compensate for potential shortages in the recent times as being the main reasons for the abandonment of tree fodder. Gómez-Baggethun et al (2010) also documented a sharp intergenerational decline of traditional ecological knowledge in Spain, the main reasons being the availability to modern technology to co-produce provisioning ecosystem services. The above presented results are confirmed by decreasing trends reported recently for traditional pasturing practices for Hungary since the 1940`s (Varga et al., 2016).

Our study shows that the majority of the farmers preferred wood-pastures to pastures, because of the above mentioned values of scattered trees relative to livestock and pasture environment. Research carried out in recent years suggest that scattered trees do not affect negatively the grassland productivity (Rivest et al., 2013), scattered trees can improve the overall microclimate, soil fertility and groundwater conditions in agricultural landscapes (Moreno et al., 2007).

4.2 Old oak trees and collapsed trees on wood-pastures

Large old trees are keystone ecological structures (Lindenmayer and Laurance, 2016) and have several intangible values including aesthetic and cultural, religious and spiritual and historical values (Blicharska and Mikusiński, 2014). Sherren et al., (2010) showed that Australian farmers commonly appreciated scattered trees on pastures for their beauty, they considered that these trees are iconic components of the farming landscape. Furthermore, they found that dead trees were appreciated for their biodiversity, highlighting the need for educational projects to increase knowledge on the values of old, hollowing or dead trees (Sherren et al., 2010). Our findings confirmed that farmers from the traditional cultural landscapes of Southern Transylvania appreciate large, old trees for their cultural values (Figure 2), but their biodiversity value was recognized only by a small proportion of interviewees (less than 10%, Figure 2) (see also Roellig et al., 2015 for Estonia). This highlights the need for conducting awareness rising projects related to the ecological values of large, old and hollowing trees. Furthermore, interviewees highlighted several features of the old trees which increase the difficulties around processing them (e.g. nodes, the need for being cut when they hollow, Figure 2). According to the great majority of farmers when the trees start to deteriorate they should be cleared from pasture (and used for firewood whenever possible). The inventory of large, old trees from the wood-pastures of the study region (Remarkable Trees of Romania, 2016: https://arboriremarcabili.ro/en/) revealed a high number of large oak trunks left on the pastures: farmers carefully removed those parts of the trees which are accessible for firewood and abandoned those parts with large nodes and hollows. As pasture burning is prohibited by law in Romania, these trunks still persist in several ancient wood-pastures from this region, revealing a potential conflicting situation between the traditional (informal) rules and the formal policies. Technical reports originating from the 19th century detailed the amount of dynamite recommended to explode oak trees with various sizes (overviewed by Lukács, 2013). Moga et al. (2016) explained the exceptionally high number of old oak trees in the wood-pastures from the Saxon region of Transylvania, as being the result of the dramatic socio-economic conditions (reflected in land abandonment) following the complete collapse of the Saxon culture and society after 1989; the socially and economically weak local communities had not enough capital to remove these trees from pastures.

5 Conclusions

Trees on wood-pastures have several values. Tangible values (e.g. shadow for livestock, provisioning ecosystem services) were associated more to the mature trees while intangible values (e.g. age, beauty, cultural identity) were associated to old trees. We showed that the most recognized value of scattered mature trees on the wood-pastures is their shade for livestock. Several other values (such as the fodder value) were probably more recognized in the past than in present; this situation creates a ‘value gap’ between the current fine scale structural elements of the pastures (e.g. trees) and the local communities. In this situation, the vulnerability of the scattered trees for being removed from pastures increases. In this context, there is a need for developing a socio-economic context for (re)connecting rural societies with their wood-pastures. The Common Agricultural Policy (CAP) can have a role in this, for example through the explicit recognition of the value of hollowing, drying trees within the Good Agricultural and Environmental Condition (GAEC number 7 promotes the maintenance of scattered trees on farmland) and the Statutory Management Requirements (SMR). Furthermore, by explicitly promoting the regeneration of sparse trees in wood-pastures, the CAP could contribute to the sustainability of wood-pastures and the multitude of values related to trees.

An effective strategy for the sustainability of the old trees should consider also the adoption of new paradigms within the institutions (at national, regional and local levels) directly responsible for the management of the multifunctional high nature and cultural value landscapes such as the wood-pastures. Increasing societal awareness around the values of wood-pastures with old trees, the inclusion of these wood-pasture systems in landscape labeling for agricultural products or touristic destination and explicit policies for these trees (Becker and Freeman, 2009; Blicharska and Mikusiński, 2014; Lindenmayer et al., 2014a,b; Moga et al., 2016).

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Annexes

Annex 1. The structure of the interviewed sample

Number of persons participating in the interview process	Number of cases	Gender of persons in the group	Gender of the main interviewee	Ethnic group of the main interviewee (number of cases)
1	54	-	Female: 17 Male: 37	Romanian: 35 Hungarian: 6 Saxon: 7 Roma: 6
2	28	Homogenous female: 2 Mixed: 22 Homogenous male: 4	Female: 7 Male: 21	Romanian: 16 Hungarian: 8 Saxon: 1 Roma: 3
3	8	Homogenous female: 1 Male dominated: 5 Female dominated: 2	Female: 2 Male: 6	Romanian: 5 Roma: 2 Hungarian: 1
4	2	Male dominated	Male: 2	Romanian: 1 Roma: 1
Sum	92		Female: 26 Male: 66	Romanian: 57 Hungarian: 15 Saxon: 8 Roma: 12
Average age of the main interviewees: 53.4 years, SD = 16.26 (Min-Max: 19-88)				

Annex 2

Photographs showing pastures without trees (upper pictures) and pastures with mature sparse trees (lower pictures) used to elicit discussions with interviewees.

Annex 3

Photographs showing large, old oak trees with healthy crown (upper pictures) as well as hollowing, drying trees (lower pictures) to elicit discussions with interviewees. The pictures were shown consecutively according to the 'Theme 4' and 'Theme 5' (see Table 1).

7 Annex E: Paper 5: Stakeholder perspectives of wood-pasture ecosystem services: A case study from Iberian dehesas

This is a pre-print version of the following paper:
Garrido, P., Elbakidze, M., Angelstam, P., Plieninger, T., Pulido, F, Moreno, G., 2017. Stakeholder perspectives of wood-pasture ecosystem services: A case study from Iberian dehesas. Land Use Policy 60, 324–333. http://dx.doi.org/10.1016/j.landusepol.2016.10.022

Abstract
Ecosystem services (ES) research has rapidly gained momentum in environmental policy and practice. However, qualitative socio-cultural approaches are still limited, and therefore, ES important for people, are currently not commonly captured. We performed 34 face-to-face semi-structured interviews to describe stakeholders' appreciation of ES from dehesa landscapes in northern Extremadura, Spain. A total of 45 ES were mentioned, and compared among different sectors and levels of governance. At the local level, people appreciated especially provisioning and cultural services. In contrast, regional level respondents showed more appreciation for regulating and supporting services, which included biodiversity conservation and climate regulation. Private and public sector respondents appreciated provisioning services more, whereas the civil sector mentioned supporting and regulating services more. For instance, water regulation was only mentioned by civil and public sector respondents, while genetic resource preservation was only expressed by the private sector. All sectors noted cultural services as key ES. We discuss most mentioned ES by respondents, the co-production nature of ES in wood-pastures, as well as cultural services as key ES of dehesas in coupled social-ecological systems. We conclude with policy recommendations drawn from the insights of this study.

Keywords
Dehesa landscape, Qualitative approach, Socio-cultural valuation, Social-ecological system, Traditional knowledge and practices, Transhumance

1. Introduction

Wood-pastures are land use systems that have been part of European landscapes from prehistoric times on (Mosquera-Losada et al., 2009), often characterising entire regions (Grove and Rackham, 2003). Wood-pastures can be defined as a land use that combines scattered trees with grazing animals (Rackham 2008; Costa et al., 2014). They occur in most biogeographic regions in Europe, but have declined sharply due to land use change, including both intensification and abandonment of agriculture (Bergmeier et al., 2010). Recent estimates of the areal extent of wood-pastures amount to 203 000 km^2 in the EU27 (Plieninger et al., 2015), of which the Mediterranean biogeographical region contains 54%. In Spain and Portugal, there are around 73 000 km^2 of wood-pastures, where they occur mainly as holm oak (*Quercus ilex*), cork oak (*Q. suber*), and Pyrenean oak (*Q. pyrenaica*) wood-pastures (named dehesas and montados, respectively) (Plieninger et al., 2015). Such wood-pastures host outstanding biodiversity (Bugalho et al., 2011; Diaz et al., 2013), and provide various ecosystem services (ES) including provisioning, regulating, supporting and cultural services important for human well-being. As a consequence, they are considered as archetypes of High Nature Value farmland systems in Europe (Oppermann et al., 2012).

The management of these ES and nature values of wood-pastures poses, however, many challenges because of the institutional structure of the EU that is organised within mono-functional sectors. Several sectors are relevant at various administrative levels, but none of them acknowledge the characteristics and values of wood-pastures as a multifunctional system. For example, in the Common Agriculture Policy (CAP) the presence of too many trees can make pastures ineligible for direct payments (Beaufoy, 2014; Jakobsson and Lindborg, 2015). In EU conservation policy, management of wood-pasture habitats typically focuses on natural processes and aims to maintain or restore ungrazed, dense and tall forest, not recognising that livestock grazing supports many of the biodiversity and ES of wood-pastures (Bergmeier 2008; Plieninger et al., 2015). In addition, citizens are frequently not aware of the ES that they receive from wood-pastures (Gaspar et al., 2016). Taken together, this complicates the design of effective mechanisms to safeguard biodiversity and the provision of ES in wood-pastures. Novel policy frameworks such as payments for specific ES of wood-pastures have been proposed (Bugalho et al., 2011). However, the consequences of fostering some services (e.g., carbon sequestration) at the expense of other ES and for the wood-pasture system as a whole are not clear (Caparrós et al., 2013).

From a research perspective the ES framework has enhanced the understanding of human-nature relationships (Turner and Daily, 2008) gaining strong momentum in environmental policy and practice (MA, 2005; TEEB, 2010; Gómez-Baggethun et al., 2010; EC, 2013a,b; Hauck et al., 2013). This research framework has, however, been dominated by biophysical assessments and economic valuation approaches (Vihervaara et al., 2010; Nieto- Romero et al., 2014). In contrast, relatively little attention has been given to assessments of ES as perceived by stakeholders (Vihervaara et al., 2010), although such a socio-cultural perspective is critical to successfully tackle land management issues linked to human well-being (Martín-López et al., 2012). Additionally, qualitative socio-cultural valuation of ES is important to identify potential trade-offs and synergies among services demanded by different stakeholder categories, and is therefore critical as evidence-based input for landscape planning, management and stewardship (Raudsepp-Hearne et al., 2010). This is also captured by European green infrastructure policy (EC, 2013 a,b).

ES are frequently produced by the combined effect of different natural ecosystem processes, and/or co-generated by natural processes in combination with human activities (Fischer and Eastwood 2016; Palomo et al., 2016). Hence, ES in cultural landscapes, have been recently reframed as socio-ecological services (Huntsinger and Oviedo, 2014). Capturing the aspect of human-nature co-production is important to avoid mistakes caused by narrow assumptions about “natural” systems, and to understand the need for multifunctional landscape management (O’Farrell and Anderson, 2010; Huntsinger and Oviedo, 2014). Therefore, there is a theoretical and practical need for better understanding of how wood-pasture ES are co-produced by social and ecological factors (Huntsinger and Oviedo, 2014), how different wood-pasture ES are valued by different stakeholders (Gaspar et al., 2016) and how multiple ES can best be managed in a sustainable, integrated manner (O’Farrell and Anderson, 2010).

Most studies analysing stakeholders’ demands for ES have been performed at the local level and have focused on a few services and narrow stakeholder profiles (Martín-López et al., 2012). While some research on socio-cultural valuation of ES is currently emerging (Oteros-Rozas et al., 2014; Villamor et al., 2014; Scholte et al., 2015), a systematic review by Fagerholm et al. (2016) highlighted a general scarcity of such research approaches on European wood-pastures. This review found a clear bias towards assessments of the potential supply of regulating, supporting and provisioning services, whereas cultural services have been mostly reduced to aesthetic values. Quantitative methods clearly dominate the research arena (Fagerholm et al., 2016). Therefore, there is a need to broaden research approaches by carrying out qualitative socio-cultural assessments of ES in wood-pastures. Iberian dehesa landscapes represent a good model system to assess the importance of stakeholders' perceptions on ES due to its vast biogeographical extension and biological importance.

Qualitative approaches "interpret phenomena in terms of the meanings people bring to them" (Denzin and Lincoln, 2011), and are therefore fundamental to articulate the expression of ES important for people (Chan et al., 2012a, 2012b). To tackle the abovementioned knowledge gaps, this study presents a qualitative socio-cultural assessment of ES for the dehesa landscape of northern Extremadura (Cáceres region), Spain. The aim of the study is three-fold: (1) to perform an in-depth survey of the full suite of wood-pasture ES, as perceived by stakeholders, (2) to compare how stakeholders from different sectors and levels of governance perceive ES provided by dehesas. This approach allows to (3) explore particular services that are not commonly included into ES assessments, and are therefore rarely and poorly documented. We discuss most mentioned ES by respondents, the co-production nature of ES in wood-pastures, as well as cultural services as key ES of dehesas in coupled social-ecological systems. We conclude with policy recommendations drawn from the insights of this study.

2 Materials and methods

2.1. Study area

The Extremadura region is located in southwestern Spain (ca. 39°N, 6°O) (Supplementary material, Fig. S1 in the online version at DOI: http://dx.doi.org/10.1016/j.landusepol.2016.10.022), covering a total area of more than 40 000 km^2 (Ezquerra Boticario and Gil Sanchez, 2008). The province of Cáceres was selected as the study area; it includes 219 municipalities grouped in 10 agro-regions based on agricultural productivity indexes in compliance with CAP requirements, with a total population of 412 498 (Fernández et al., 2012). The mean population density is relatively low (21 people/km^2) in comparison to the country mean population (91 people/km^2); ranging from 7 people/km^2 in Brozas agro-region to 38 people/km^2 in Plasencia. One of the main pillars of the economy is agriculture, along with the industry derived from it. This region produces wine, olive oil, cheese and meat products among others (Fernández et al., 2012). Agricultural land represents 15% of the total area; grasslands 29%; forest land 48%; and others 9%. The main cultivated species are oats (*Avena sativa*; 16%), grassland species (14%), corn (*Zea mays*; 14%), cereals for winter forage (12%), tobacco (*Nicotiana tabacum*; 8%), peas (*Pissum sativum*; 6%), wheat (*Triticum aestivum*; 4%), rice (*Oryza sativa*; 4%), tomato (*Solanum lycopersicum*; 3%), and onion (*Allium cepa*; 3%). Among tree groves olive predominate (*Olea europaea*; 83%); there are also orchards and vineyards (Fernández et al., 2012). The service sector contributes the most to the gross domestic product (GDP), followed by construction, industry and agriculture. Additionally, services comprise 51% of the active population, agriculture 32%, construction 12% and the industry 4% (IMT, 2015). The total forest and woodland cover equals 16 000 km^2 of which 77% (12 370 km^2) correspond to dehesas (Pulido et al., 2010).

Dehesa is the major cultural landscape element covering more than 25% of the study area (Ezquerra Boticario and Gil Sanchez, 2008; Pulido et al., 2010). The dehesa is mostly privately owned by big estates (>100 ha). The land tenure system includes privately owned dehesas, municipally owned, i.e., dehesa estates which belong to villages and the use of the different resources (especially the grazing regimes) are assigned by auction to local ranchers; in case no local ranchers exist others can also apply, and commons, i.e., dehesa estates which are commonly owned by villagers normally through a certain kind of cooperativism. For this study respondents belonging to the first two categories were included. Tree species such as holm oak, cork oak and Pyrenean oak dominate the tree canopy of dehesas. Tree density varies (10–100 ha^{-1}) depending on land use (Moreno and Pulido, 2009). The trees are a fundamental component of the dehesa system, producing not only feed (acorns, fodder, browse), energy (firewood and charcoal), and cork, but also creating favourable micro-climatic conditions for herbaceous understory and providing shelter for livestock (Joffre et al., 1988; Marañón, 1988). The traditional multi-purpose land management has generated a mosaic of habitats with high plant species diversity both at local (Marañón, 1985) and landscape scales (Moreno et al., 2016). The dehesa landscape has been fundamental for the rural economy (Campos, 2004), while supporting high biodiversity values (Díaz et al., 1997; Olea and San Miguel, 2006) for which it has been included in the EU Habitat directive 92/43 (Costa et al., 2014).

There has been a clear transition from the dehesa as an agro-silvo-pastoral system, to a simplified wood-pasture during the last decades (Mosquera-Losada et al., 2009). Traditionally, native cattle breeds, merino sheep, goats and Iberian pigs were free ranging in dehesas (Marañón, 1988), and pig fattening with acorns was important for the agrarian economy (Parsons, 1962). Agricultural practices were performed in long rotation periods (3–12 years; depending on soil productivity), in combination with pruning and lopping activities of the oaks to facilitate sunlight to reach the ground and to maximize acorn production (Moreno and Pulido, 2009). These practices also prevented shrub encroachment and soil compaction. Seasonal migratory herd movements (transhumance) were common, traditionally conveying more than 3 million sheep from the north to wintering areas in the southern part of the Iberian peninsula (Klein, 1920). These seasonal movements utilized a specific network for the migration of herds called drove roads (‘cañadas’). Today such drove roads are legally protected (Law 3/1995) and serve as green infrastructure for ecosystem connectivity (Olea and San Miguel, 2006; EC, 2013a), thus contributing to biodiversity conservation (Garzón-Heydt 2004; Hevia et al., 2013), especially under future global change scenarios (Oteros-Rozas et al., 2014).

Currently, new activities and land uses, such as eco-tourism, birdwatching and recreational big game hunting, are gaining momentum on dehesa estates (Table 1), while agricultural practices are becoming less important. Recreational hunting has become an important socio-economic activity for private dehesa estates after the abandonment of the traditional uses and rural depopulation (Olea and San Miguel, 2006; Moreno and Pulido, 2009). Today ranchers are mostly specialized in the production of single livestock species, i.e., cattle, sheep, goats, fighting cattle or pigs, although combinations commonly occur. Additionally, the dehesa landscape is currently threatened by tree regeneration failure (Plieningeret al., 2004), oak diseases (Brasier, 1996), land use change, transformation or abandonment (Bugalho et al., 2011) as well as land use intensification (Moreno and Pulido, 2009; Bergmeier et al., 2010; Plieninger et al., 2012, 2015).

2.2. Data collection and analysis

For our study, a stakeholder is defined as a person or a group that has an investment, share, or interest in something, in our case the dehesa landscape. Stakeholder profiles by sectors and levels of governance, representative for the dehesa in the study area, were identified through communication with experts and official authorities. Snowball sampling (Atkinson and Flint, 2004; Bryman, 2008) was then used to identify concrete interviewees. This sampling strategy resulted in total 34 respondents, including 19 at local and 15 at regional level that represented civil (n = 4), private (n = 17) and public (n = 13) sector stakeholders. These set of respondents comprised a good representation of the variety of stakeholder profiles in the study area (Table 2). The respondents included ranchers; dehesa managers (personnel hired to run the ranch); a beekeeper; representatives of environmental NGOs, a forest company, and a farmer association; hunters and a hunting manager, as well as municipal and regional officials.

Semi-structured interviews (Holme et al., 1997; Kvale and Brinkmann, 2009) were conducted during September–December 2013 (for interview manual, see Supplementary material, Appendix). Interviews began with a brief introduction about the purpose of the study and the concept of ES. Respondents were then asked about ES from dehesa landscapes in terms of products, services, and values. Each respondent had full freedom to elaborate and answer the questions. The interviews lasted from 20 to 118 min, and were taken by the first author in Spanish. All interviews were digitally recorded and transcribed.

Interviews were analysed using qualitative content analysis (Bryman, 2008), i.e. the themes that emerged during the analysis were coded and grouped into main categories (e.g., particular landscape goods, services and values, perceived by the different groups of stakeholders; Table 3 and Table S1). To identify how ES had been addressed in the interviews we applied the ES Coding Protocol (CP) proposed by Wilkinson et al. (2013), which allowed for consistent coding of all analysed interviews (Garrido et al. in press). The CP included four categories of ES: supporting (coded A), provisioning (B), regulating (C) and cultural services (D) (MA, 2005). Additionally, each category contained a number of ES (Table 3 and Table S1).

Table 1. Traditional management and current trends in dehesas.

Traditional management (<1960)	**Trend (relative to traditional system)**
Cattle	Increase
Sheep	Decrease
Goat	Decrease
Pig	Increase
Transhumance	Decrease
Cereal cropping	Decrease
Tree pruning	Decrease
Firewood production	Decrease
Charcoal production	Increase
Cork production	Increase
Tree planting	Increase
Hunting	Increase
Agrotourism	Increase

Table 2. Number of interviews conducted among the selected stakeholder categories at civil, public and private sectors and local and regional levels of governance.

	Local	**Regional**	**Total**
Civil	Naturalist (1)	Environmental NGO (3)	4
Private	Landowners (9) Estate Managers (2) Butchery (1)	Beekeeper (1) Game Manager (1) Nature Guide (1) Farmer Association (1) Forestry Company (1)	17
Public	Municipal officials (6)	Drove road Info Center (1) Official CAP (1) Wildlife Care Center (1) National Park official (1) Regional officials (3)	13
Total	19	15	**34**

3. Results

3.1. Perception of ecosystem services at local level

Provisioning services were the most appreciated among local-level respondents (Table 3, Fig. 1). The most mentioned services were livestock (19/19), including meat from different cattle breeds, kid, lamb, pork and a variety of value-added products from Iberian pigs such as ham, and pastures (18/19). This was in accordance to the importance of livestock ranching of the dehesas (see Table 3). Important fodder (15/19) sources were acorns mainly from *Quercus ilex* and *Q. suber*, tree leaves, suckers from *Q. pyrenaica*, pods from *Fabaceae* species, shrubs and tree branches. Firewood (14/19) from traditional canopy pruning (lopping), charcoal (13/19) including small coal locally called “cisco or picón”, and crops (11/19) used today as fodder for livestock were commonly appreciated (Table 3). Other ranchers acknowledged the value of native breeds of livestock; this was explained as “*we utilized native cattle breeds because they are better adapted and consequently less susceptible to diseases as well as they consume more efficiently the resources and need less external food supplies*”. Regarding crop production a farmer stated: “*Wheat is sown for human consumption in better soils, and barley, oats and rye (or triticale) as pastures for livestock*”. All respondents considered these traditional agricultural practices important, but nowadays these types of land use had become unprofitable, and focus mainly on providing summer forage for livestock and removing pyrophyte shrub species to reduce wild fire risk. Wild game was also considered important (13/19), especially the traditionally rooted small game (rabbit (*Oryctolagus cuniculus*) and partridge (*Alectoris rufa*)), as well as the more profitable red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*) on private estates (Table 3). Cork and wool were appreciated as provisioning services by many respondents (10/19), as well as milk (9/19) derived from goat and sheep for the production of diverse traditional cheese products (Table 3). Additionally, respondents referred to other products from dehesas such as cheese, olives, olive oil, vine, eggs, chickens, fighting bulls, honey, pollen, Iberian ham and sausages.

Cultural services were the second most appreciated category (Table 3, Fig. 1). Traditional knowledge (18/19), as well as recreation and eco-tourism services (18/19), were highly appreciated. The former along with cultural heritage (16/19) were commonly expressed by those local respondents whose ancestors came as transhumant herders and settled in Extremadura. Traditional practices and knowledge were highlighted in relation to pruning techniques, including tree formation, firewood extraction, lopping intended to open the canopy to maximize acorn production for holm oaks and for cork extraction. These cultural ES were also mentioned in relation to cattle ranching, goat, sheep, and swine herding. Several claims can exemplify the traditional knowledge associated with the different activities and professions. For instance, one respondent stated: *"during winter time the herd (sheep) sleeps within small mobile fences, so we can fertilize all pastures by moving the fencing until the whole area is covered. During the rainy season (autumn) they are free ranching, selecting denser forested steep areas to sleep safely. Wet valleys cannot be fertilized until they are dry, during summer time*". In relation to forest resources, the respondents explained as following: "*the first two cork extractions have no economic value, from the third onwards, if you take a good care of the tree, you can have economic profit from it at around 30 years of age. Cork debarking has to be done by professionals, every nine years"* and *"tree management (pruning) is fundamental, we still do it in the traditional way in a 10 year rotation period. We also hire local people to do it, who we know have good expertise*". Cultural landscape values (14/19), as well as education and knowledge (13/19), were considered important ES. Landscape beauty, human well-being and health related benefits (10/19) were also usually appreciated at local level. "*The most important values are to have a quality life and to work in this marvellous environment; it is a privilege*", said one respondent regarding landscape beauty and well-being. Finally, sense of place/identity values (8/19) were given significant appreciation by many respondents. As a local butcher mentioned "*I was born in Extremadura and the dehesa is our identity, and the word dehesa is constantly in our mouth. ... all social activities take place in the dehesas*".

Supporting services were mentioned primarily in relation to biodiversity, in particular species richness/diversity (13/19), but also structure (8/19), and primary production (5/19) (Table 3). Respondents commonly commented on the high species richness and structural diversity of the dehesa. One respondent said, "*It is a really healthy woodland, with trees of all age classes and high structural diversity*". He also mentioned the importance of having several endangered species such as the Iberian lynx (*Lynx pardinus*) and the black stork (*Ciconia nigra*). Another respondent highlighted the biodiversity values of the dehesa by saying "*I want to maintain the dehesa to be able to protect all species within, many of them are unique*".

Regulating services were not commonly mentioned (see Table 3, Fig. 1). Natural hazard regulation was the exception, and locally considered the most important (11/19) (Table 3). For instance a rancher claimed in relation to seasonal herd movements (transhumance) that "*it is fundamental to alleviate animal pressure in the system at this critical time and it also reduces soil erosion processes because when animals come back to the dehesa, there is a higher abundance of resources and thus livestock exerts lesser pressure on the pasture and therefore on the soil*". Another respondent stated: "*The maintenance of seasonal herd movements is crucial for climate change mitigation since herds transport and distribute a significant amount of plant seeds and therefore facilitate the adaptation of plants to new environments*". Additionally, a fighting cattle rancher mentioned the importance of regulating services exerted by trees. He commented "*Trees prevent erosion by protecting the soil, generate particular moist conditions and water regime, and this generates a different local micro-climate which allowed for different plant alliances under the tree canopy*".

Table 3. Ecosystem services mentioned by interviewees at local and regional levels of governance. Integers represent number of interviewees who mentioned such service or value. The categories are adapted from Wilkinson et al. (2013). In parenthesis the relative importance of the services as function of the total number of respondents at that level is represented, as well as the total number of respondents at local and regional levels.

A. Supporting Services	**Local (n=19)**	**Regional (n=15)**	**B. Provisioning Services**	**Local (n=19)**	**Regional (n=15)**
A1. Water cycling	2	1	B1. Food agriculture		
A2. Soil formation	1	1	B1a. Crops	11	3
A3. Nutrient cycling	2	2	B1b. Pastures	18	4
A4. Primary production	5	8	B1c. Fodder	15	6
A5.Photosynthesis	1	0	B1d. Livestock	19	10
A6. Biodiversity			B1e. Milk	9	0
A6a. Species	13	13	B1f. Other	13	4
A6b. Structure	8	10	B2. Food wild		
A6c. Function	3	9	B2a. Wild game	13	2
			B2b. Asparagus and mushrooms	4	2
			B2c. Fish and crayfish	4	1
			B3. Fresh water	1	0
			B4. Water-energy	0	0
			B5. Water-transportation	0	0
			B6. Biochemicals/genetic resource	4	0
			B7. Fiber		
			B7a. Timber	3	2
			B7b. Wood	0	0
			B7c. Cork	10	1
			B7d.Wool	10	2
			B8. Fuel		
			B8a. Firewood	14	3
			B8b. Charcoal	13	4
Total-Supporting	**35 (1.8)**	**44(2.9)**	*Total-Provisioning*	**161(8.5)**	**44(2.9)**
C. Regulating Services			**D. Cultural Services**		
C1. Climate regulation	3	7	D1. Social relations	5	3
C2. Air quality regulation	1	2	D2. Cultural landscape	14	8
C3. Water regulation and			D3. Heritage	16	6
purification	2	5	D4. Historical remains	3	3
C4. Disease and pest			D5. Sense of place/identity	8	4
regulation	2	3	D6. Aesthetic	2	2
C5. Natural hazard			D7. Landscape beauty	10	6
regulation	11	5	D8. Inspirational	0	0
C6. Erosion regulation	4	4	D9. Recreation and eco-	18	8
C7. Pollination	1	2	tourism	13	12
C8. Seed dispersal	4	2	D10. Education and	10	3

C9. Noise regulation	0	0	knowledge D11. Well-being and health D12. Traditional knowledge D13. Spiritual and religious values	18 4	9 2
Total-Regulating	**28(1.5)**	**30(2.0)**	*Total-Cultural*	**121(6.4)**	**66(4.4)**

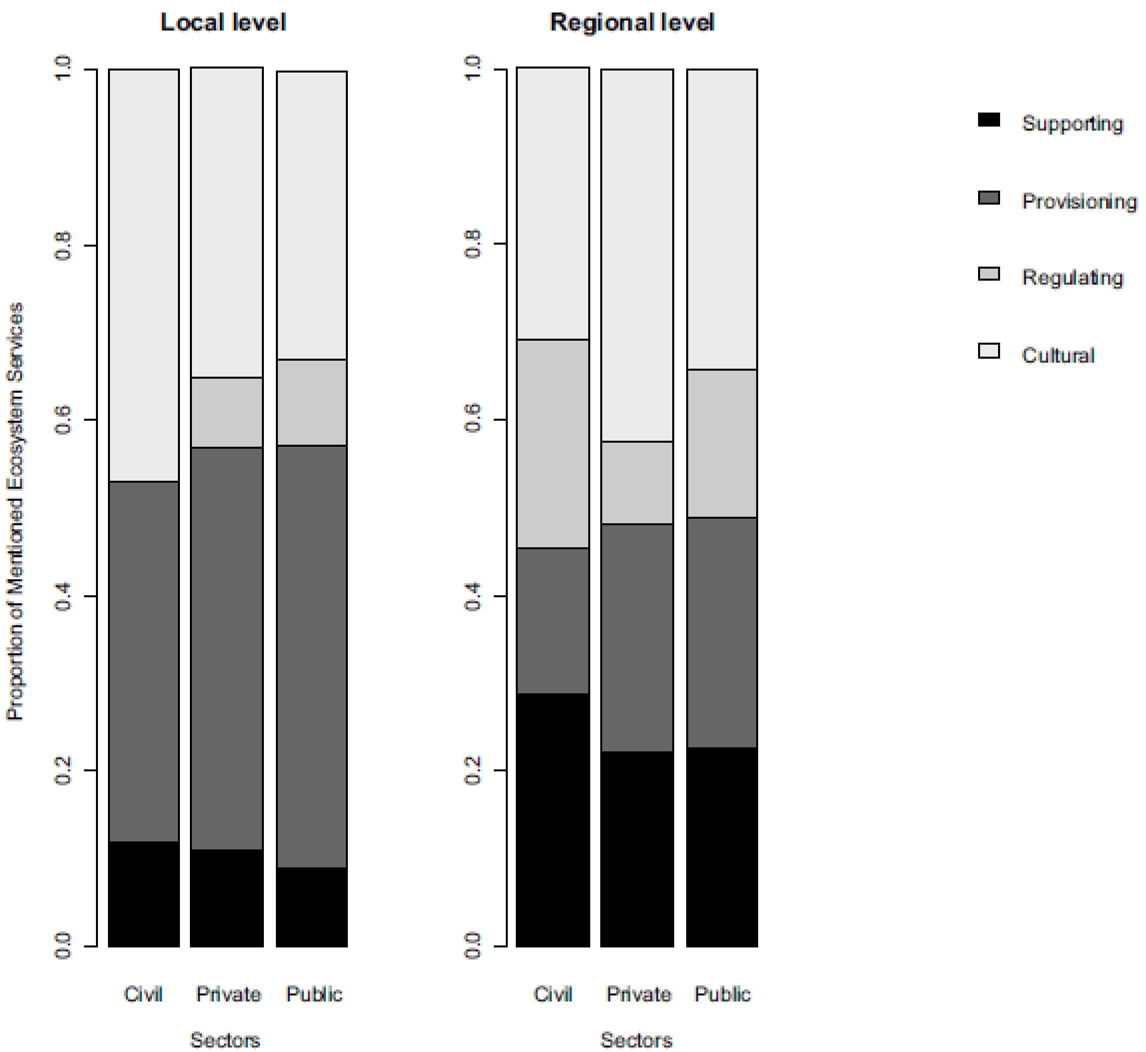

Figure 1. Proportion of ecosystem services mentioned by stakeholders at local and regional levels.

3.2. Perception of ecosystem services at regional level

Regional respondents appreciated cultural services the highest (Table 3, Fig. 1). Education and knowledge (12/15) were the most commonly mentioned service by respondents. As a regional official commented: "*In the national park the dehesa landscape constitutes a significant proportion. . ..there are 13 different programs concerning environmental education as well as ongoing research about the dehesa within the national park*". Traditional knowledge (9/15) was the second most appreciated service by respondents (Table 3). Such knowledge related to the diverse traditional management activities and knowledge required to perform the multiple inter-connected practices necessary for the integrated management of the silvo-pastoral components of dehesa ranches. For example, one respondent explained in relation to traditional tree management: "*In the region there is a long tradition of professionals specialized in cork extraction and holm and cork oak pruning. This is due to the fact that we have 4500 ha of commons, so everyone interested can learn from a maestro and work and practice at the common land. It is a knowledge transmitted from generation to generation. The knowledge required for these specialized practices has disappeared in many places so we work and develop formative courses and activities."* Cultural landscape (8/15) related to regional traditions and identity values were generally appreciated. Further, recreation and eco-tourism (8/15) were also commonly highlighted by respondents, especially, the great potential of dehesas for recreational activities. "*Bird watching activities have an enormous potential in the region because it is increasingly demanded by both national and international birdwatchers. They are generally interested in species they don't have in their home countries, species with reduced populations or endangered, like for example Iberian imperial eagle, Bonelli's eagle, blackstork, shorttoed eagle, black vulture...".*

Provisioning and supporting services were equally appreciated by respondents (Table 3). Livestock (10/15) and fodder (6/15) were particularly mentioned (Table 3). One respondent commented: "*Traditional holm oak lopping aims at maximizing acorn production, which is the most important product these trees provide; holm oak acorns have a high carbohydrate and nutrient content (higher than other oak species) which is an excellent fodder source for pigs and ruminants. Pruning activities generate various sub-products important for local economies, such as firewood, charcoal, "cisco or picón" small dimension charcoal, and other fodder resources in form of leaves and twigs*".x

Biodiversity components were the most appreciated among supporting services, especially in relation to species (13/15), but also to structural (10/15) and functional (9/15) diversity of the dehesa (Table 3). A nature guide explained: "*In the dehesa you can find forest bird species, as well as bird species from open and ecotone habitats; therefore the species diversity is enormous since all species belonging to three different habitats co-occur in the dehesa landscape*". Another respondent stated the relation among biodiversity and traditional practices such as transhumance. This respondent commented: "*Transhumance generates biodiversity both within the dehesa system as well as outside, and offers the possibility of plant adaption to climate change*". He explained further why: "*Livestock herds transport a high content of seeds of different species, herds walk around 20 km per day, so seeds excreted after three days would have moved 60 km or 140 km if excreted after a week. Thus transhumant herds help to disperse and find new ecological niches at higher altitude to species that otherwise might gone extinct in their local original habitats, which ensure the survival of the species and palliate climate change effects*". Another beneficial aspect: "*The drove roads or "cañadas" are ecological corridors connecting all Spanish ecosystems and hence they are also ecosystems themselves, since they have never been cultivated, nor fumigated, or hunted. Actually it has been recently discovered new ant species only living in drove roads*", the same respondent mentioned. Primary production was also clearly appreciated for more than half of the respondents (8/15) at regional level.

Regulating services were mentioned the least at regional level (see Fig. 1, Table 3), although these were more appreciated by regional than by local respondents (Table 3). Climate regulation (7/15) scored the highest, followed by water regulation and purification (5/15) and natural hazard regulation (5/15). Erosion and disease and pest regulation were also commented to a lesser extent

(extent (4/15) (Table 3). One respondent stated: "*Holm oak fix nutrients in the soil, generates a micro-climate under the canopy with higher relative humidity, and the savannah landscape structure allows for the development of traditional agriculture and pastoral activities which inturn, prevent wild forest fires*".

3.3. Perception of ecosystem services among sectors

Comparison of ES perceptions among stakeholders from different sectors shows that the profile of ES and their relative importance for stakeholders from a particular sector depends on the level of governance (Fig. 1). Provisioning services were more appreciated by private sector respondents; cultural services were acknowledged in a more balanced way by all sectors; supporting services were relatively more mentioned by civil sector respondents as well as regulating services (See Supplementary material 3.3, and Table S1).

4 Discussion

4.1. Dehesa ecosystem services are perceived at multiple levels

The ES most commonly mentioned in wood-pasture dehesas were livestock (provisioning ES), followed by traditional knowledge, recreation and eco-tourism (cultural ES), and species richness/diversity (supporting ES). Additionally, respondents frequently mentioned education and knowledge, cultural landscape, cultural heritage (cultural ES); pastures and fodder (provisioning ES). Our results are in line with previous socio-cultural valuation studies of ES. Livestock was considered among the most important ES for social well-being among stakeholders, as well as nature recreation activities, rural tourism and environmental education (Oteros-Rozas et al., 2014). This may be a consequence of urban users increasingly demanding environmental education as well as recreational and eco-tourism activities (Martín-López et al., 2012); services which are increasingly being demanded in Europe (Harrison et al., 2010).

Our results revealed clear differences in the perception of ES among stakeholders from different sectors at local and regional levels (Table 3, Fig. 1). At local level, respondents appreciated especially goods and services that are frequently enjoyed on-site, whereas regionally, respondents showed more appreciation towards services that are more abstract in their nature, that include global common goods such as climate regulation and water regulation and purification. While locally provisioning services were most acknowledged, regionally cultural services were most commonly mentioned. Genetic resources were only acknowledged locally for instance. Regulating services such as natural hazard regulation was commonly mentioned locally, while regionally climate regulation was more appreciated (Table 3). This highlights the importance of studying the demand on ES by different groups of stakeholders at different levels of governance, especially those that are responsible for land management and governance (Oteros-Rozas et al., 2014). Failing in doing so may result in incomplete understanding of what people care about, and consequently undermine future management and planning as well as other policy implementation measures. Among sectors such differences were also appreciated. Private and public sector respondents appreciated provisioning services more, where as the civil sector mentioned more supporting and regulating services (Table S1, Fig. 1). For instance, climate regulation was proportionally more commented by the civil sector. Water regulation was only mentioned by civil and public respondents, and genetic resource preservation was only expressed by private sector respondents (Table S1). Each sector appreciated dehesas for clearly more than one ES category, which reinforces the notion of multi-functionality of dehesas. The land tenure system was also a determinant factor for the perception of services; respondents responsible for the management of public dehesas emphasized further the importance of the system as the arena where all local festivities and celebrations were taken place, as well as for spiritual and religious values. They also perceived the importance of dehesas as providers of recreational activities important for villagers such as fishing, traditional hunting, mushroom and asparagus picking and, nature related activities more than compared to private sector respondents.

Traditional knowledge and practices were among the most mentioned ES by respondents. Livestock grazing is one of such management practices considered fundamental to maintain an open landscape structure that supports biodiversity. In this line, a positive relation between plant diversity and enhanced ecosystem functioning has recently been found (Finn et al., 2013). However, high stocking levels, mainly of cattle in the study area, can lead to negative consequences for biodiversity, soil erosion and oak regeneration (Mosquera-Losada et al., 2009). This situation is nowadays common as ranches are usually oriented towards meat production. In many cases native rustic breeds have been cross-bread with Charolaise and Limousine to increase meat production. This is explained by the fact that ranchers' profit is based on the slaughtered weight of the animal and not on the quality of the meat per se. Previous European agri-environmental schemes have also triggered the increase in cattle stock (Bergmeier et al., 2010). Surprisingly, stocking levels are not regulated (with the exception of organic meat production), and there has been a tendency in recent decades of higher stocking levels in comparison to the traditional extensive-oriented lower levels (Table 1). We argue that the current practice of livestock grazing for provisioning ES may create negative consequences for the dehesa system in the long term and threaten its stability. In addition, probably due to production oriented ranching, there is a current mismatch between livestock feeding and resource availability, leading to the abandonment of certain traditional practices and resulting resources. For example, trees were traditionally used as fodder bank for feeding livestock in winter by pruning daily a few trees, while today livestock are frequently artificially fed (Fig. 2). Similarly, traditional practices such as transhumance has been positively related to biodiversity (Hevia et al., 2013), as well as to tackle oak tree regeneration failure (Carmonaet al., 2013). According to respondents this traditional practice (transhumance), which is nowadays mostly abandoned, allowed wood-pastures to recover from the pressure livestock exerted to the system, by taking advantage of feed resources elsewhere and providing flexibility and mobility in response to climate variability (Oteros-Rozas et al., 2012). Natural hazard regulation, in particular fire prevention, was the most commonly mentioned regulating service, and has been previously negatively associated to livestock grazing (Zumbrunnen et al., 2012). However, many marginal lands have been abandoned in recent decades, resulting in shrub encroachment of dehesas, and thus high probability of wild fire occurrence. Unfortunately goat shepherds and goats are to date in clear decline (Table 1), and have a paramount role, as mentioned by respondents in the study, to reduce wild fire occurrence. To conclude, our results revealed a wide range of ES delivered by dehesas at multiple spatial scales and for a diverse group of stakeholders. However, to sustain such ES provision, traditional land use is fundamental (Bugalho et al., 2011).

4.2. Ecosystem services are co-generated in dehesa landscapes

Our stakeholder-based qualitative approach enabled us to capture priority ES important for people (Chan et al., 2012a), as well as facilitated the in-depth understanding of the intertwined natural and anthropogenic as well as socio-cultural complexity of dehesas. For instance, the traditional ecological knowledge in terms of low livestock stocking levels maintains higher diversity of grass species; a correlation recently demonstrated at continental level (Finn et al., 2013). Grazing at low stocking levels reduces also soil erosion and wild fire risk; oak tree management generates firewood, fodder and charcoal, as well as favourable micro-climatic conditions under the tree canopy where other plant species alliances thrive (Marañón, 1988). Under the canopy of trees, shade is provided for livestock; traditional land management practices shape the landscape upholding valuable cultural landscape characteristics and services to people, while fostering potential recreational uses. Because these interconnections are co-generated by human management of ecosystems, the delivered ES by dehesas may be seen as socio-ecological services (Huntsinger and Oviedo, 2014). This is in line with recent studies that highlight the actual human co-production nature of ES (Palomo et al., 2016). Taking pruning and lopping traditional tree management practices as an example, several services were co-produced by the combined interaction of human activities and ecosystem components and processes: (1) the pruning action itself opens up the tree canopy facilitating the light to reach the soil; this is important for agricultural purposes, (2) to open the canopy fosters a more productive floriation and thus a greater acorn production; acorn is still important feed for livestock, and specially for swine herds, (3) tree canopy formation by pruning enlarges the tree crown, thus improving shade conditions for livestock, especially important during summer time, (4) canopy widening enhances the area under the canopy with particular microclimatic conditions where characteristic plant alliances thrive, (5) fallen branches are a source of fodder for livestock in times of need (winter), (6) remnant branches can also be used either as firewood or as raw material to produce charcoal. These are just examples of services co-generated in dehesa landscapes (Fig. 2).

However, due to its multi-functional character, the dehesa system is far from being understood by strict mono-sectorial policies (Guzmán Álvarez, 2016). Further, the disappearance of dehesa multi-functional practices and products can be partially attributes to the actual low profitability of the generated secondary products. Ranchers and herders stressed the low profitability of farming and ranching, comparing it with market prices obtained 30–40 years ago. They also commented that quality was not prized by the market. High quality extensively produced products had the same market value than conventional intensively produced ones, and thus many ranchers have changed to higher productive breeds or mix-breeds. In contrast, one of the main objectives of the EU Common Agricultural Policy is to support farming communities with quality, value and diversity of food produced sustainably. In this line, the new CAP reform has attempted to tackle crop diversification by introducing a "greening" element. Pillar I greening promotes three different measures such as (1) farm-scale crop diversification, (2) permanent grassland retention and (3) ecological focus areas (EU Regulation No. 1307/2013). However, this reform may function poorly in systems like dehesa. How can then multi-functionality and promotion of the diversity of practices and associated products be fostered? In this regard, recent research has highlighted the most relevant factors in the purchase of food products by consumers (Gaspar et al., 2016). These were: price, quality, brand name and origin, and therefore may suggest the development of Protected Designation of Origin (PDO), and their identification with quality brands. Such PDOs should encompass geographical areas rather than specific products, and be related to specific traditional management practices to ensure the highest quality of the product as well as the diverse and holistic sustainable management of farmlands.

4.3. Cultural services are key ecosystem services of dehesas

Our study clearly shows that cultural services were the most important ES delivered to people by dehesas. Many individual ES included into this category are unfortunately not commonly captured in ES assessments based on biophysical or economic approaches. For instance, traditional knowledge appeared as the most mentioned cultural service in wood-pasture dehesas and was revealed as the second most mentioned service among the 45 ES commented by stakeholders. Cultural landscape and heritage services were also frequently acknowledged. Our results highlight the importance of cultural ES for people, since among the top eight services, five were related to cultural aspects (Table 3). The importance of cultural ES as key services, has previously been highlighted (Plieninger et al., 2013). Maintaining such key cultural services is a milestone in landscape conservation and planning. This new knowledge can also guide more integrative agri-environmental policies deeming to be crucial for a more balanced future (Plieninger et al., 2015). Additionally, traditional knowledge and practices such as transhumance appeared to be an important factor for holm oak tree regeneration of dehesas (Carmonaet al., 2013), and may therefore influence the system maintenance and stability. The abandonment of such traditional practices however, may endanger the provision of important services for people and the conservation of dehesa landscapes in the long term. A paramount question arises based on the presented results: how to integrate cultural ES into land use policy? To date, the importance of cultural ES associated to aesthetical and recreational values of landscapes have already been acknowledged (Daniel et al., 2012). However traditional knowledge, heritage values, cultural landscape, as well as education and knowledge have neither yet been targeted, nor included into political commitments. These immaterial dimensions are highly valued services in dehesas, and should therefore be implemented into specific policies and complemented in the existing ones so land managers and ranchers can be financially supported for the supplied services to society (Gaspar et al., 2016). This may potentially be achieved by the creation of specific Payment for Ecosystem Services (PES) integrated into CAP agri-environmental schemes.

Fig. 2. Illustration exemplifying ecosystem services co-generation in dehesas. Tree pollarding co-generates ecosystem services. Leafy branches serve as fodder and thereafter as small size charcoal (cisco or picón). Firewood is also provided, as well as a wider tree crown to enhance acorn production and shade conditions. Today, easy accessibility to fodder supplement is common and livestock is frequently supplemented with straw fodder. Photo by F. Pulido.

5 Conclusion

Dehesas provide an unusual wide range of ES to people. There were clear differences in the perception of ES among stakeholders representing different sectors and levels of governance. At the local level, people appreciated especially provisioning and cultural services. In contrast, regional level respondents showed more appreciation for regulating and supporting services linked to biodiversity and climate regulation. Private and public sector respondents appreciated more provisioning services, whereas the civil sector mentioned more supporting and regulating services. All respondents mentioned the importance of cultural ES. Our qualitative approach enabled us to capture important cultural services such as traditional knowledge, cultural landscape and heritage values, which are rarely included into ES assessments based on biophysical and economic valuations. This illustrates the critical importance of maintaining cultural ES and traditional practices for the functioning of the dehesa system. Qualitative approaches to understand stakeholders' appreciation of ES in wood-pasture landscapes provide new ways of understanding the rationale behind social preferences towards ES. This may facilitate the inclusion of values, which are poorly captured by most commonly used ES research methods, and thus fostering cultural landscape conservation in the long term.

Several policy conclusions could be drawn from the insights of this survey. Firstly, the multi-functionality that our respondents attributed to dehesas suggests that payment schemes directed to promote individual ES are insufficient or even counter-productive. Fostering of ES bundles may be more promising. Specific agri-environmental schemes could be developed to support management that address the provisioning, regulating and especially the cultural services of dehesas at the same time. Secondly, the insight that the most important ES of dehesa are co-generated by interacting social and ecological systems points out that rewilding strategies (that exclude human uses, as currently being established in some parts of the Iberian Peninsula) may not be suitable to safeguard the full range of biodiversity and ES in dehesas. Rather, reinforcing the feedbacks of the social and ecological systems in dehesas (e.g., through developing markets for traditional and new regional quality products) are needed. This could be achieved by the development of Protected Designation of Origin mechanisms, although such designations should focus on geographical areas rather than on specific products, and be related to specific traditional management practices to ensure the highest quality of such products as well as to secure a holistic sustainable management of farmlands. Thirdly, cultural services are key ES, but we are not aware of a single payment scheme that would explicitly address the cultural services of dehesas (beyond tourism). Current management and support instruments should be sensitized toward a better awareness of cultural ES, and therefore the implementation of specific policies to financially support land managers and ranchers for the supplied services to society represent a future challenge in which research and policy making should focus upon. This could be potentially tackled by the creation of specific PES integrated into CAP agri-environmental schemes.

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Supplementary material

3.3. Perception of ecosystem services among sectors

Cultural ES were equally appreciated by all respondents irrespective of sectorial division. However, private sector respondents mentioned cultural services slightly more frequently (5.8) than civil (5.3) and public sector (5.2) respondents (Fig. 1, Table S1). Inspirational aspects were the only service not mentioned by any sector, whereas the other 12 cultural services were more or less acknowledged by all respondents. Traditional knowledge was the most appreciated service for private (15/17) and public sector (10/13) respondents, and also mentioned by the civil sector (2/4). Recreational activities and the potential for eco-tourism were also commonly mentioned by all respondents from all sectors, and especially by the private (14/17), but also by the public (10/13), and to a lesser extent by civil sector (2/4) respondents. The importance of hunting, fishing as well as asparagus and mushroom picking activities, as traditionally enrooted into the culture was also stressed. A municipal official commented on the importance of accessibility and public use of dehesas for recreation, hunting and fishing activities as well as highlighted the significant role of mushroom picking both for the municipality and the general public. The civil sector likewise highlighted recreational activities such as bird watching. Education and knowledge services were mainly highlighted by private sector respondents (14/17). Cultural landscape was highly appreciated by both civil (3/4) and private sector (14/17) respondents, whereas heritage values were similarly mentioned by all (Table S1).

Provisioning ES were more appreciated by private sector respondents (6.6), followed by the public (5.9) and civil sectors (3.5) (Fig. 1, Table S1). All three sectors appreciated livestock and pastures, as well as to a lesser extent fodder (Table S1). Natural pastures were stressed by stakeholders as a really important product due to the paramount role in livestock ranching. Municipal officials also stated the importance of pastures as source of income from leasing to herders and ranchers. For instance in one municipality the contract with the rancher compelled them to not only use pastures for livestock ranching but also to cultivate a certain proportion of land to remove potential woody fuel from the dehesa and thus prevent forest fires. Wild game was also appreciated by private and public stakeholders, as well as other products such firewood, charcoal, cork and wool (Table S1). For dehesa estates with cork oak trees, cork was an important product. For some stakeholders this production was fundamental. As one respondent mentioned "In my estate the main products are cork and Iberian pigs, although we cultivate a bit of wheat to feed pigs during summer".

Regulating services were relatively more often mentioned by civil sector (2.5) stakeholders, closely followed by public (2.0) and at last private sector (1.3) respondents. The civil sector emphasized climate regulation (3/4). Water regulation and purification as well as climate regulation were generally acknowledged by the public sector, while private sector respondents highlighted natural hazard regulation (8/17). For instance two ranchers mentioned the multiple benefits of seasonal herd movements such as transhumance: "We lease summer pastures in the mountains. This allows us to have all animals well fed and on the other hand, to have a good autumn pasture production in the dehesa by reducing the grazing pressure". Public officials highlighted the role of domestic animals in preventing forest fires and stressed climate change as potential threat for the stability of the system. In municipal dehesas the reduction of shrubby understory (to avoid wild forest fires) was performed by regional administration officials.

Supporting services were again relatively more frequently mentioned by the civil sector (3.5), and primarily focused on biodiversity values (Table S1). Biodiversity values, especially species richness were the most appreciated services by all sectors (see Table S1). For instance, one municipal official commented "The biodiversity here is enormous, we have special protection areas (SPA), a biosphere reserve (BR), National and Natural parks and special areas of conservation (SAC) due to the high biological and bio-cultural values of the region". Primary production was commonly appreciated by all sectors, with special emphasis given by civil and private sector respondents (Table S1).

Table S1. Ecosystem services mentioned by interviewees from civil, private and public sectors. Integers represent number of interviewees who mentioned such service or value. The categories are adapted from Wilkinson et al. (2013). In parenthesis the relative importance of the services as function of the total number of respondents at that level is represented, as well as the total number of respondents per considered sector.

A1. Water cycling	0	2	1
A2. Soil formation	0	1	1
A3. Nutrient cycling	1	2	1
A4. Primary production	2	8	3
A5.Photosynthesis	0	1	0
A6. Biodiversity			
A6a. Species	4	10	12
A6b. Structure	4	6	8
A6c. Function	3	5	4
Total supporting ecosystem services	**14(3.5)**	**35(2.1)**	**30(2.3)**
B1. Food Agriculture			
B1a. Crops	1	7	6
B1b. Pastures	2	13	7
B1c. Fodder	1	14	6
B1d. Livestock	4	14	11
B1e. Milk	1	6	2
B1f. Other	2	10	5
B2. Food wild			
B2a. Wild game	1	8	6
B2b. Asparagus and mushrooms	0	2	4
B2c. Fish and crayfish	0	1	4
B3. Fresh water	0	1	0
B4. Water-energy	0	0	0
B5. Water-transportation	0	0	0
B6. Biochemicals/genetic resource	0	3	0
B7. Fiber			
B7a. Timber	0	2	3
B7b. Wood	0	0	0
B7c. Cork	0	8	3
B7d.Wool	2	6	4
B8. Fuel			
B8a. Firewood	0	9	8
B8b. Charcoal	0	9	8
Total provisioning ecosystem services	**14(3.5**	**113(6.6)**	**77(5.9)**
C. Regulating ecosystem services			
C1. Climate regulation	3	2	5
C2. Air quality regulation	1	1	1
C3. Water regulation and purification	1	0	6
C4. Disease and pest regulation	0	2	3
C5. Natural hazard regulation	2	8	6
C6. Erosion regulation	1	4	3
C7. Pollination	1	1	1
C8. Seed dispersal	1	4	1
C9. Noise regulation	0	0	0
Total regulating ecosystem services	**10(2.5)**	**22(1.3)**	**26(2.0)**
D. Cultural ecosystem services			
D1. Social relations	0	4	4
D2. Cultural landscape	3	14	5
D3. Heritage	3	12	7
D4. Historical remains	1	1	4
D5. Sense of place/identity	2	7	3
D6. Aesthetic	0	2	2
D7. Landscape beauty	2	8	6
D8. Inspirational	0	0	0
D9. Recreation and eco-tourism	2	14	10
D10. Education and knowledge	3	14	8
D11. Well-being and health	2	7	4
D12. Traditional knowledge	2	15	10
D13. Spiritual and religious values	1	1	4
Total cultural ecosystem services	**21(5.3)**	**99(5.8)**	**67(5.2)**

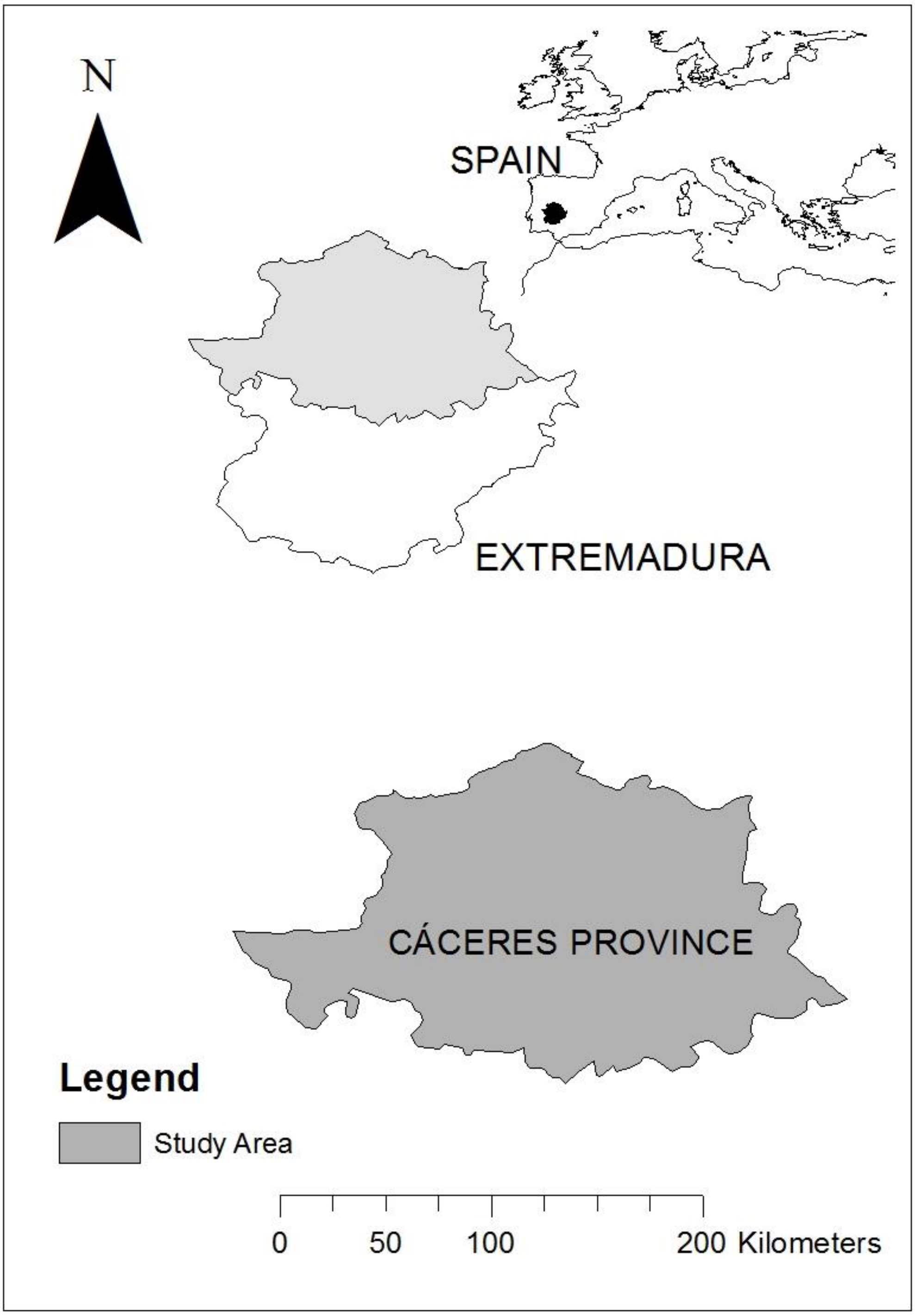

Figure S1. Location map of the study area