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Exploring the Role of Management in the Coproduction of Ecosystem Services from Spanish Wooded Rangelands☆

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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 toward more intensified models. This paper assesses the coproduction 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 midsized 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 previously mentioned elements covary consistently, generating bundles of ecosystem services associated with each of three management models based on the intensity of management.

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 southwestern 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 and Oviedo, 2014).

The long-term interaction between these wooded rangelands and the people living among them is an archetype of coupled social-ecological systems (SESs), 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 et al., 2012), as they enhance biodiversity through low-intensity management (Mountford and Peterken, 2003; Fischer et al., 2010) and habitat diversity (Moreno et al., 2016).

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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, sheep, 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 (Moreno et al., 2013; López-Sánchez et al., 2016) and 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 (Stoate et al., 2009; Roellig et al., in revision). 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 monofunctional, 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 (ESs). 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 sociocultural dimension of ES provision is often neglected (Nieto-Romero et al., 2014; Fagerholm et al., 2016b). In addition, there is a need for a more thorough understanding of the complex relationships between ES, particularly 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 and Eastwood (2016) offered theoretical frameworks explaining how ESs are coproduced in social-ecological systems through the interaction between an ecosystem component and a social component. Here, we propose that the coproduction 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 coproduction, 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 vary across stakeholder groups (Oteros-Rozas et al., 2014; Villamor et al., 2014; Fagerholm et al., 2016a; Garrido et al., 2017). Sociocultural and biophysical factors, such as land tenure and property size, influence management decisions, perceptions, and perspectives (Huntsinger and Oviedo, 2014; Hausner et al., 2015; Malinga et al., 2016).

The main objective of this paper is to explore how management influences the coproduction 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.

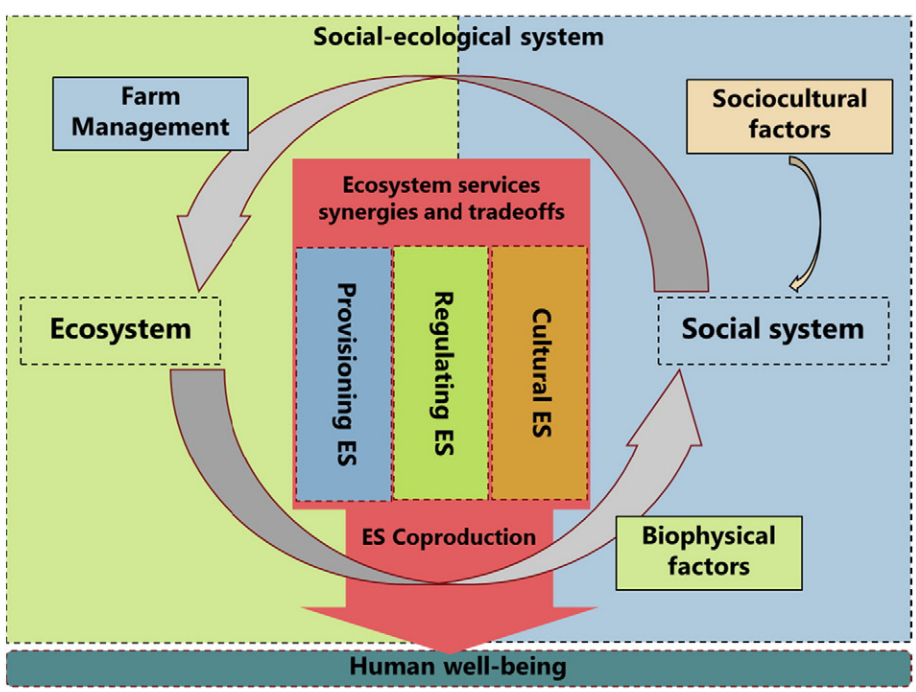

Figure 1. The two sides of the social-ecological system feed back into each other in the coproduction of ES. The social system shapes the ecosystem through management, while the ecosystem sets the boundaries and limits the management through biophysical factors. Sociocultural factors also influence the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

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We 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 (Schaich and Plieninger, 2013; Andersen et al., 2013; Hausner et al., 2015; Malinga et al., 2016). 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 their 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 coproduction. It is expected that greater diversity will deliver a broader range of ES, as has previously been observed in other studies (Raudsepp-Hearne et al., 2010; Lüscher et al., 2014; Andersson et al., 2015).

Methods

Study Area

The study area is located in Llanos de Trujillo, part of the region of Extremadura, in southwestern Spain (39°31′50′′ N, 5°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 600 mm. The population density is rather low (12.8 inhabitants/km^2) and is mostly concentrated in urban areas. Since the 1970s, 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 past decades to the tertiary sector, with tourism playing an important role. Three main groups of tourists exist: 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 toward 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.

The landscape is composed of annual grasslands (38%), holm oak wood pastures (dehesas) (33%), shrublands (16%), and extensive cereal crops (11%) (see 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 (van Oudenhoven et al., 2012; Reyers et al., 2013; Fischer and Eastwood, 2016; Palomo et al., 2016). Indicators must be comprehensive, informative, and consistent at different scales (van Oudenhoven et al., 2012; Mouchet et al., 2014). 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 (Nieto-Romero

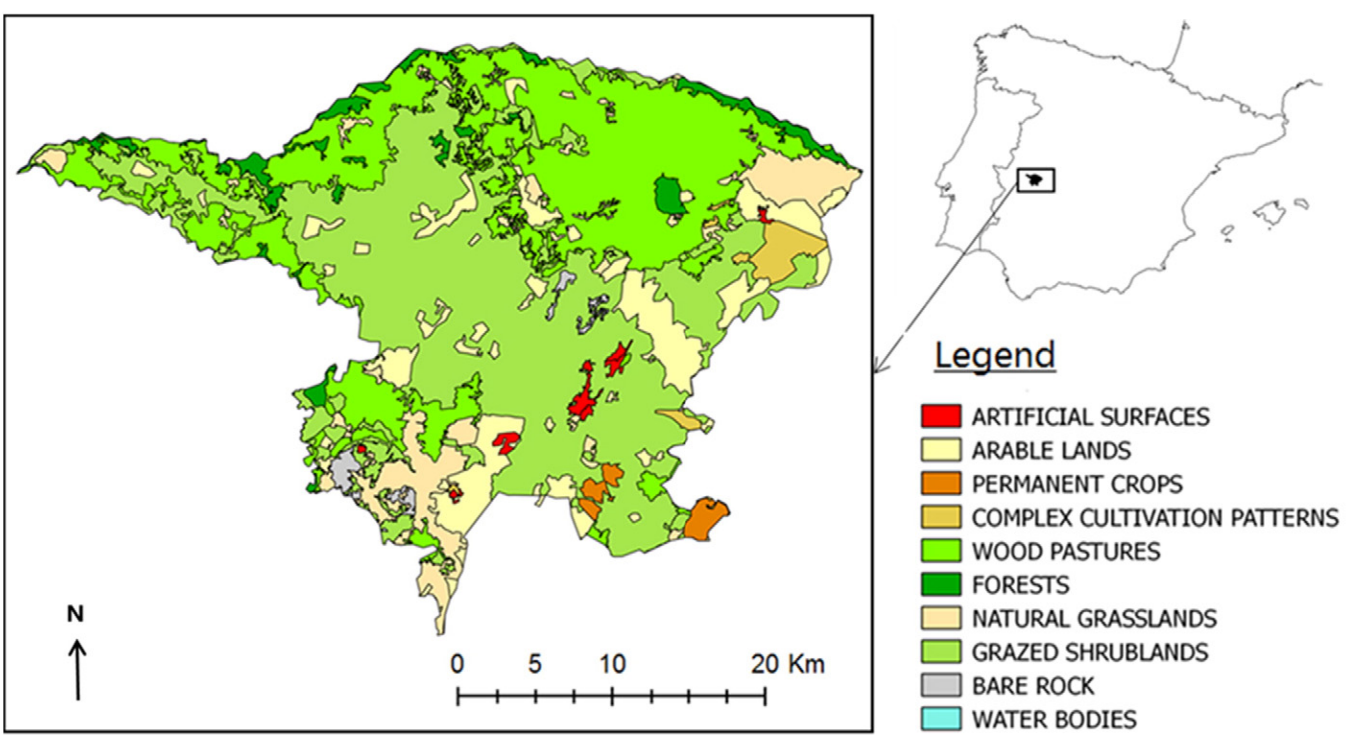

Figure 2. Location of the study area within the Iberian Peninsula and land cover map, according to CORINE 2012 data (EEA, 2016).

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et al., 2014; Plieninger et al., 2015; Modernel et al., 2016; 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. 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 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 semistructured 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 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 minimize the dispersion within each new cluster. As variables, we included all management indicators and sociocultural and biophysical factors (see 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., 2014, 2017; 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

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	Herzog et al. (2012); Maes et al. (2012); Andersen et al. (2013); Lüscher et al. (2014); Andersson et al. (2015)
Cereal production	Ha cultivated for cereal per year/total ha	Continuous	Cereal production	Raudsepp-Hearne et al. (2010); Maes et al. (2012); Andersen et al. (2013)
Firewood production	Tons of firewood per year/total ha	Continuous	Firewood production	Maes et al. (2012); Andersson et al. (2015)
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	Andersen et al. (2013); Turner et al. (2014); Andersson et al. (2015)
Visitor frequency	Frequency of on-foot visitors (1-5)	Categorical	Outdoor activities	
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		

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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 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).

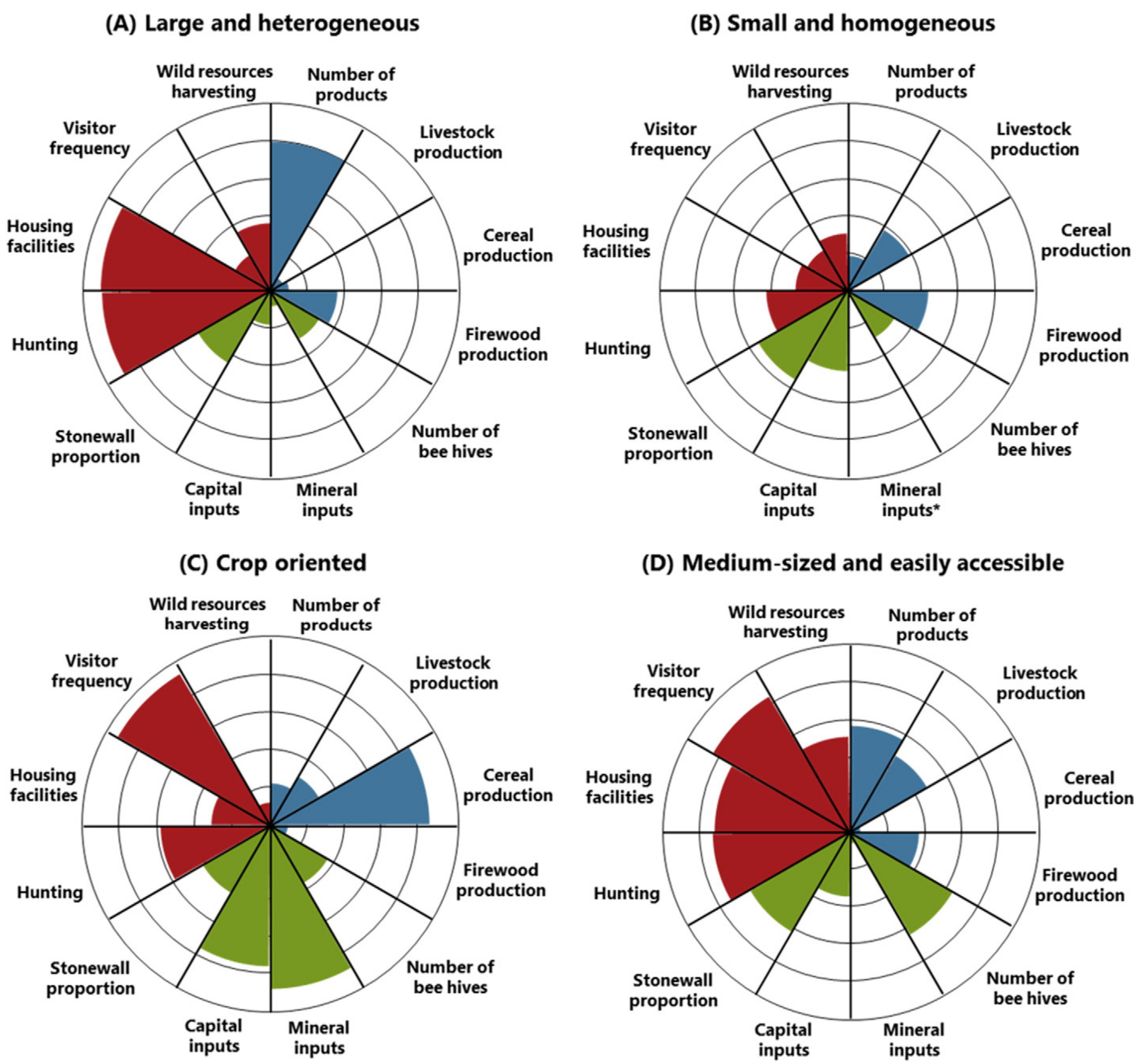

Figure 3. Flower diagrams illustrating the quantification for each management indicator by petal length. Each flower represents one of the clusters identified in the hierarchical cluster analysis (HCA). Colors of the petals refer to the ES category with which the management indicator has been associated (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.

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Table 2
Factor loadings derived from the principal component analysis. 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

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 2). 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 previously mentioned HCA (see Fig. 3A). On the negative side we found properties from the second cluster class (see 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 (see Fig. 4), which is also associated with rented properties and properties in the third cluster from the HCA (see 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 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 previously mentioned HCA (see Fig. 3D).

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 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.

Discussion

Dehesa Characterization

The clustering process shows that properties are differentiated on the basis of the intensity of management and orientation of production (see 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 among 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; midsized to large-sized operations focused on crop production; and midsized properties that are easily accessible via public paths that enhance the recreational use of the dehesa.

The first group (see Fig. 3A), called “large and heterogeneous” based on its main traits, included operations with mixed and multifunctional management in terms of both production, with a higher number of products on average than the rest of the dehesas, and recreational use of the property, with a high number on average of nonwood 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 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 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). Sociocultural 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 (see 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 and 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 toward 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 toward “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

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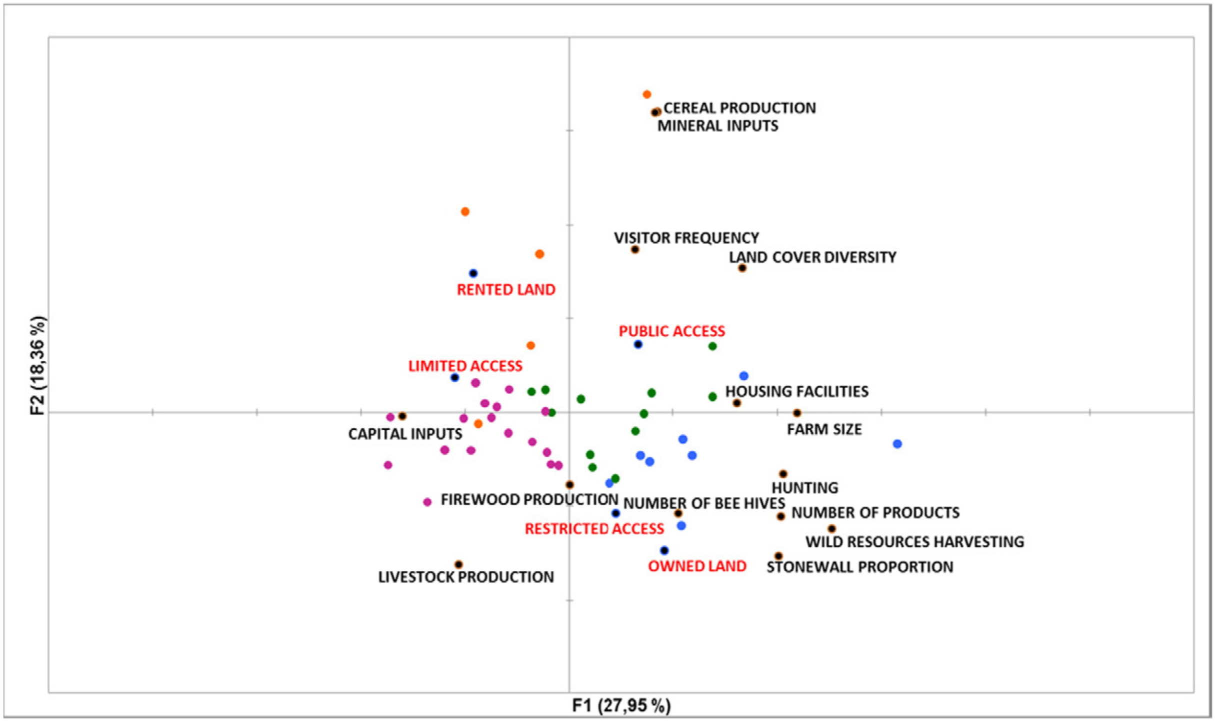

Figure 4. Biplot of the first two components in the principal component analysis. Percentage of explained variation for each axis is given in brackets. Active variables labels (management indicators and biophysical factors) are represented in black. Supplementary variables labels (sociocultural factors)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

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 multidimensional 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,” in which animal production plays a secondary role while cereal production dominates (see Fig. 3C). These dehesas also have a clear tendency toward 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” (see Fig. 3D), reflects an intermediate situation between the large and 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 it 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 toward 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., 2009a, 2016), 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

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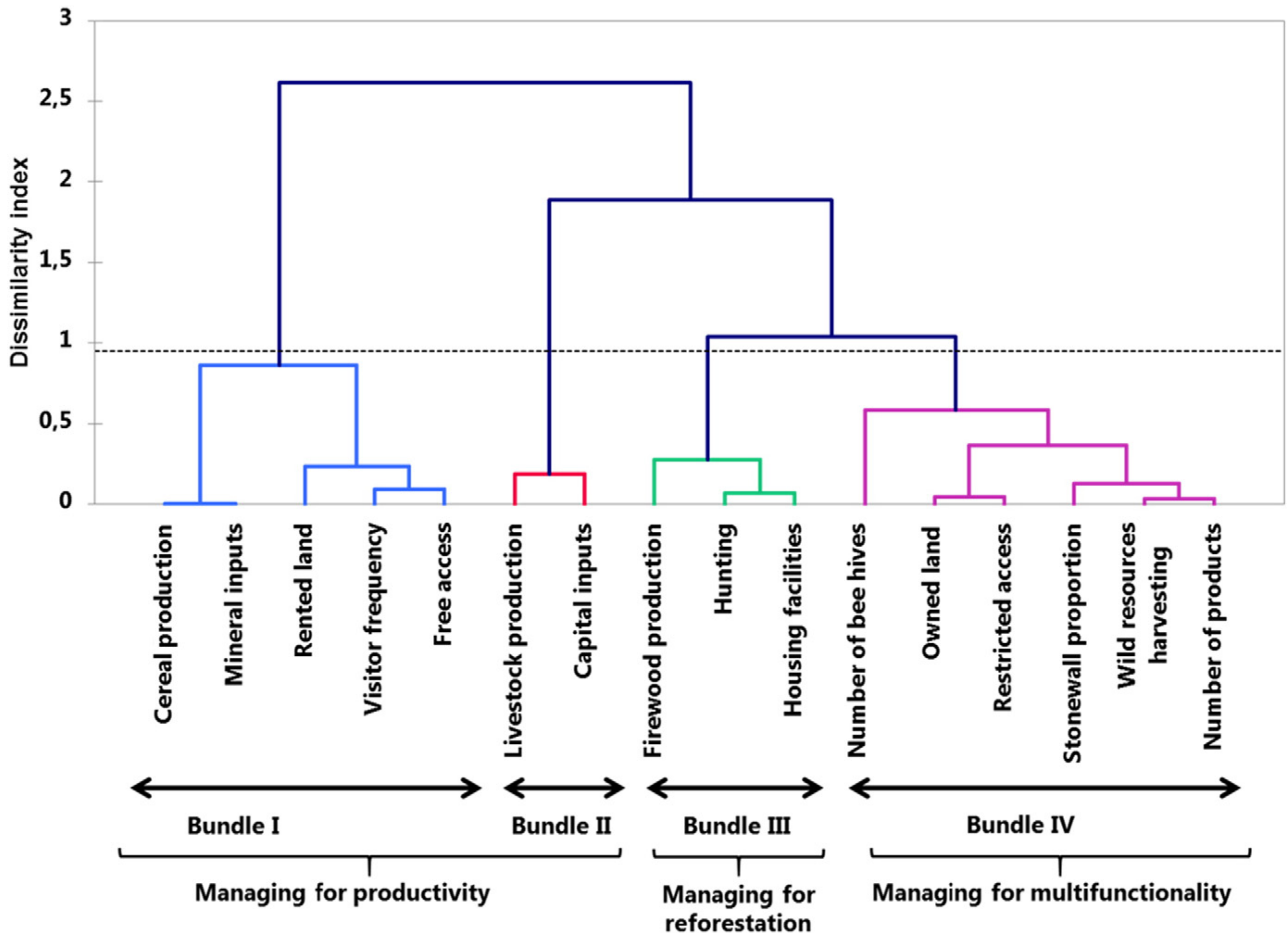

Figure 5. Dendogram of the hierarchical cluster analysis. The dendogram shows bundles of management indicators and sociocultural factors. Bundles are shown in different colors for the sake of clarity.

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 coproduction, 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 (see Table 2, 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 (Raudsepp-Hearne et al., 2010; Andersson et al., 2015; Butterfield et al., 2016). 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 coproduction are related to the intensity of crop (see Table 2, F2) and animal production (see Table 2, 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 (see Table 2, F4). Our study confirms that public access is the main factor driving recreational use (Brown et al., 2014; Hausner et al., 2015; Fagerholm et al., 2016a). 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 (Turner et al., 2014; Queiroz et al., 2015). 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 ES coproduction of the system (see 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 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 (see 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 (see Fig. 5):

- Management oriented toward 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 toward 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 that are in line with Queiroz et al. (2015) in a study based on a Swedish forested landscape.
- Management oriented toward 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 focus on 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 toward 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 coproduced in dehesas. Accessibility is conditioned by Spanish institutional history, characterized by 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 horseback 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 monoproductive due to lack of economic flexibility and low productivity of the typical dry and poor soils. Within the past 10 years, > 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, as well as both landowners and land workers.

Recent studies have highlighted the need to understand how social and ecological interactions are connected with ES coproduction (Fischer and Eastwood, 2016; Palomo et al., 2016; Mouchet et al., 2017). In this study we explain how biophysical and sociocultural factors shape the tradeoffs and synergies of ES coproduction as determined 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.

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