



## RESEARCH ARTICLE

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# Sweet chestnut agroforestry systems in North-western Spain: Classification, spatial distribution and an ecosystem services assessment

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## Abstract

**Aim of study:** Agroforestry systems of *Castanea sativa* have specific forest structures, which are different from other ecosystems of sweet chestnut. They have provided several ecosystem services (ES) to local inhabitants for centuries including relevant pastoral use. However on present times, have isolated distribution ranges and declining trends. The chestnut trees are their main components but occur at low densities. They are cultivated by using different treatments to improve specific features and maximize different types of production.

**Area of study:** North-western of Iberian Peninsula.

**Material and methods:** We used a large database (>750 field plots) to classify *C. sativa* dominated-stands into different ecosystem typology (including traditional agroforestry systems), and to assess their most relevant ES. We used field data to define their spatial distribution and discriminant analysis to determine the classification accuracy. Finally we also defined a set of qualitative and quantitative ES indicators for different groups to compare different trends.

**Main results:** We successfully classified these ecosystems and found that the traditional agroforestry systems are of major importance in providing ES, as food provision or cultural services, but showed isolated distribution patterns. Moreover, other types of chestnut-dominated ecosystems, supply important ES such as biomass provision and climate regulation.

**Research highlights:** The relevance of the *C. sativa* agroforestry systems from ES point of view was pointed out in this work, but also their declining dynamic. Further analysis, based on temporal trends, could help to a better understanding of their status and to define conservation and management strategies.

**Additional keywords:** rural abandonment; *Castanea sativa* decline; cultural landscapes; multifunctional ecosystems and landscapes; National Forest Inventory.

**Abbreviations used:** AFS (agroforestry systems); dg (diameter of tree with average value of basal area of the plot); dgcs (diameter of *C. sativa* trees with average value of basal area of the plot); ES (ecosystem services); G (basal area); hdom (dominant height); hg (average height); hgcs (average height of the *C. sativa* trees); N (number of trees); Ncs (number of trees of *C. sativa*); NFI (national forest inventory); Pcs (percentage of chestnut trees in relation to the number of trees of the plot); V (volume).

**Authors' contributions:** JVRD, MBA and PAA analyzed the data. EMDV supervised the work. All authors wrote, read and approved the final manuscript.

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## Introduction

Sweet chestnut (*Castanea sativa* Mill.) is the only native species of the genus *Castanea* that occurs in Europe. Woodlands of the species cover more than 2.5 million hectares of land throughout Europe. In the NW

Iberian Peninsula, chestnuts grow under a wide span of climatic conditions, ranging from Mediterranean (with an annual rainfall of 600 mm and a marked drought during the summer) to Atlantic (with more than 1500 mm of precipitation per year). Although *C. sativa* is one of main tree species in the Iberian Peninsula, its

importance from an anthropological point of view is associated with the wide variety of products that it provides to society. The species has played a key role in Iberian forests during thousands of years (Costa *et al.*, 1998) and the importance of the NW Iberian Peninsula as a refuge for the species during the Last Glacial Maximum has been highlighted (*e.g.* Krebs *et al.*, 2004; Mattioni *et al.*, 2008; 2013; Rocés-Díaz *et al.*, 2018). Chestnuts have been an essential part of the diet of traditional communities for centuries, and the trees have provided timber for construction and firewood for energy. The distribution of *C. sativa* has thus been strongly modified by traditional human use. Although this species is frequent in many Mediterranean countries (Turkey, Greece, Italy, France and Spain, etc.), the cultivation methods were first developed and extended by the Greeks and Romans. During the Middle Ages, these techniques were introduced to different regions, thus increasing the importance of chestnut ecosystems and associated products (Conedera *et al.*, 2004). In the NW Iberian Peninsula, *C. sativa* often occurs below an altitude of 1,500 m, thus avoiding the coldest locations and occupying an environmental niche that overlaps with that of *Quercus robur* (Rocés-Díaz *et al.*, 2014b).

*Castanea sativa* is one of the most important multi-functional species in Southern Europe (Martin *et al.*, 2011). Several of the cultivars have been developed for the desirable traits of its products. In NW Spain, cultivars such as *Lemos* and *Portuguesa* produce large chestnuts, whereas chestnuts produced by the *Pareda* cultivar have valuable organoleptic properties and the trees also produce long straight branches that are used in rural construction (Pereira-Lorenzo *et al.*, 1996; Álvarez-Álvarez *et al.*, 2006). Traditional management of *C. sativa* woodlands has focused on production of chestnuts, timber (for construction) and firewood. These agroforestry systems (AFS) are usually considered to have played a multifunctional role in the traditional way of life of the inhabitants of the region.

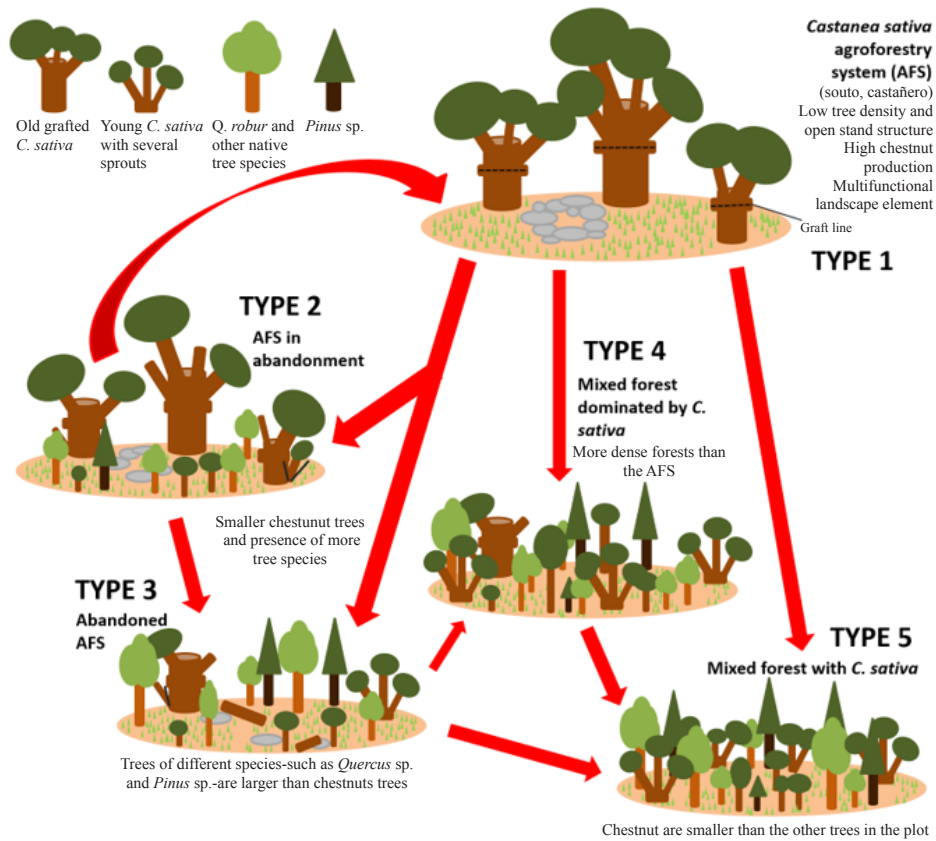
This multifunctional role can be observed and analysed from the perspective of ecosystem service (ES) provisioning. The ES concept has become increasingly important in environmental science and management during the last few decades because it demonstrates the relationships between biodiversity, ecological functioning and human well-being (MEA, 2005).

Since the 19<sup>th</sup> century, the spread of ink disease (caused by *Phytophthora cambivora* and *P. cinnamomi*) and more recently chestnut blight (caused by *Cryphonectria parasitica*; Bouhier, 1979; Mansilla Vázquez *et al.*, 2000) has severely damaged chestnut stands. The chestnut gall wasp (*Dryocosmus kuriphilus*) has recently been detected in NW Iberian Peninsula and represents a new risk as it is a major pest of chestnut

forests. Changes in the traditional farming methods, such as the introduction of new agricultural crops, the abandonment of some cultural practices and establishment of plantations of fast growing species (*e.g.* *Pinus* sp. and *Eucalyptus* sp.) have also led to a marked decline in chestnut AFS (Díaz-Varela *et al.*, 2009). These processes are congruent with the loss of diversity detected in this area from a cultural point of view (Martinez *et al.*, 2010) and with an overall decline in traditional ES supply in Spain (EME, 2011). Some recent studies have analysed the status of this type of ecosystem. For example Díaz-Varela *et al.* (2011) used GIS and Remote Sensing data to establish relationships between forest variables and chestnut trees in these AFS. Analysis of spatial data corresponding to these AFS is essential to enable the development of management and conservation policies.

*Castanea sativa* woodlands have traditionally been managed by different regimes (Conedera *et al.*, 2001). Several types of ecosystems and AFS include chestnut trees as the main element but differ in relation to their productive aim. In this study, we mainly focused on the open stand AFS formed by grafted chestnut trees mainly destined for production of fruit but also forage for cattle, timber and litter and which represent an important element of the traditional landscape in NW Spain. These open stands (known in NW Spain as *soutos*, *castañeros* or *castañeos*) are found close to small villages and usually include very old, large chestnut trees (more than 150 years old and breast diameter more than 40 cm) growing at low densities (<400 stems/ha). Although man-made, these AFS are included in the Habitats Directive (Directive 92/43 Annex 1: “*Castanea sativa* woodlands”; EC, 1992) and show a high species richness for moderate intensity of use (Gutián *et al.*, 2011). Some coppice stands devoted to traditional chestnut production have been almost totally abandoned, and most stands were destined for production of high quality timber and biomass (Menéndez-Miguélez *et al.*, 2013). These pure chestnut forests are regenerated from adventitious and dormant buds and typically include a high density of stems per hectare. Finally, in abandonment (and abandoned) chestnut woodlands can be mixed with *Pinus* spp. (or other species as, for example, *Pseudotsuga menziesii*) in forest stands with higher tree density and high levels of productivity (Nunes *et al.*, 2013). These changes produce different types of forests depending on the intensity of management and the objective of the AFS (Fig. 1).

In this sense, we expect a scattered distribution pattern of *C. sativa* AFS on the study area, where most of the forest stands analyzed are abandoned/in



**Figure 1.** Description of different types of *C. sativa* ecosystems in the study area in relation to each other. AFS=Agroforestry systems.

abandonment. In addition, we also expect that these AFS provide a wider range of ES than the other ecosystems typologies, including cultural aspects related with their traditional management. Thus, specific objectives for this work were: i) to determine the spatial distribution of different typologies of ecosystems where *C. sativa* is the most relevant species –including traditional AFS–; and ii) to develop a preliminary assessment of ES provided by these different ecosystems.

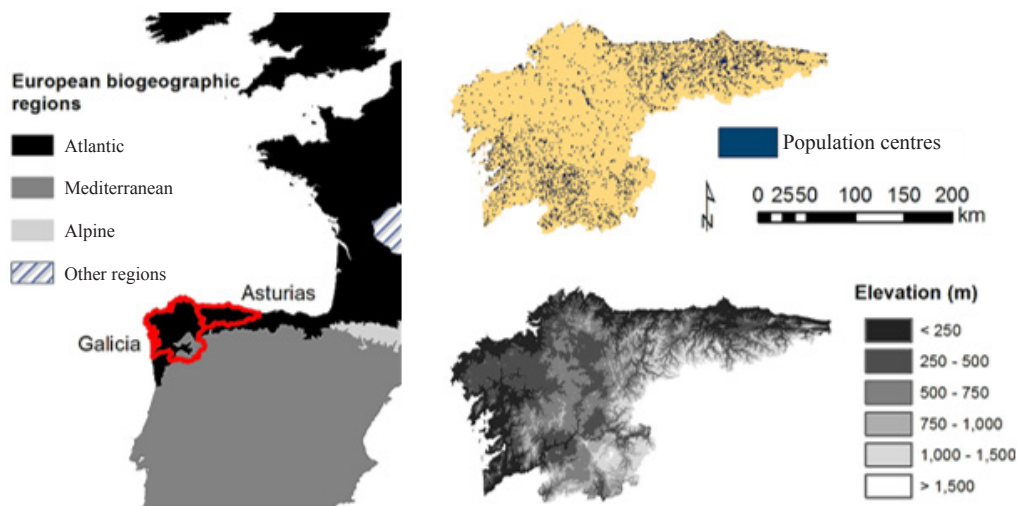
## Material and methods

### Study area

The study area encompasses the regions of Asturias and Galicia in NW Spain, which are included in the European Atlantic Region (EEA, 2011) bordering the Mediterranean Region (Fig. 2). The historical impact of woodlands on the NW Iberian Peninsula mainly occurred during the last two thousand years (Muñoz-Sobrino *et al.*, 2005). The climate in the most of the area is oceanic, with mean precipitation exceeding 1000 mm/year (Ninyerola *et al.*, 2005). Precipitation

decreases in summer in some areas, but physiological drought does not occur anywhere in the area. Part of the SW of the study area (covering an area of ~ 5,000 km<sup>2</sup>) is included in the Mediterranean Region and the climate is Mediterranean. This zone has a marked summer with drought and higher temperatures. The terrain is rugged and the elevation ranges from sea level to above 2500 m.

The study region covers an area of 40,200 km<sup>2</sup> of which ~ 40% comprises forest land. The area is one of the most densely forested regions in Spain (MAPAMA, 2013). During the last century, human activity has greatly transformed the most accessible areas at low and medium elevations (< 1000 m). Much of the low-lying land is used to grow fast growing species such as *Eucalyptus* spp. and *Pinus* spp. for timber production. Although remnants of natural forests are relatively more abundant than in nearby areas, they are commonly scattered amongst habitats associated with livestock use (meadows and heathlands). In the montane areas, forests are more abundant, although fragmented, and the timber line is represented by deciduous forests which rarely occur above an elevation of 1700 m (Díaz & Fernández-Prieto, 1987).



**Figure 2.** Location of the study area (limited by the red line), description of the relief and the population centres. Sources: EEA (2011); IGN (2013); MAPAMA (2014).

## Data sources

Field data was obtained from the Spanish National Forest Inventory database (NFI; MAPAMA, 2013) where plots with a minimum tree cover of 5% were sampled. Thus, all the forest areas of Spain are prospected in this database. For this inventory, data were collected within a regular grid of 1 km × 1 km covering the entire forested territory. For each node of the grid, the NFI provides information about the tree species including their size in circular plots georeferenced with geographical coordinates.

The number of stems per hectare (N), basal area (G), dominant height (hdom, defined as the mean height of the 100 thickest trees per hectare) and average height (hg) were calculated from the tree variable measurements. Appropriate tree expansion factors were used for this purpose, as the Spanish NFI design of the field plot is based on concentric subplots where the selection on sampled trees depends on their diameter. The expansion factor can be defined as the relationship between the reference area (1 ha) and the area comprising the subplots and the values of the number of sampled trees are adjusted to a per hectare value (Álvarez-González *et al.*, 2014). We finally obtained a database including more than 11,000 plots, to be managed using a Geographic Information System (ArcGIS 10.2; ESRI, 2011, Redlands, CA, USA). The data were used to spatially locate the *C. sativa* plots, to characterize the plots and to differentiate between different types of *C. sativa* ecosystems. In addition, information from technical reports that describe the *C. sativa* ecosystems and their characteristics in NW Spain (Fernández-López, 1984; Fernández-López & Pereira-Lorenzo, 1993; Álvarez-Álvarez *et al.*, 2000)

the different management and restoration options were used to complete the database. Information from Digital Elevation Models (DEM) was also used to characterize the terrain in the *C. sativa* plots.

## Types of ecosystem services analysed

We used the Common International Classification of Ecosystem Services - CICES V4.3 (Haines-Young & Postchin, 2013) as a guideline for defining services. This system has several points in common with the Millennium Ecosystem Assessment (MEA, 2005). These classifications are probably the most commonly used in ES analysis. The different type of data compiled here were related to some of the services defined in this classification system (Table 1) and service supply was analysed.

## Classification of *C. sativa* ecosystems and data analysis

The classification method was based on the information available in the study area for sweet chestnut woodlands. Two criteria were considered: i) the type of woodland in relation to tree density (cleared stands <400 trees/ha derived from traditional management for fruit production, and dense stands ≥ 400 trees/ha derived from abandonment of the previous type); and ii) the type of dominant trees in the stand (in relation to diameter and height). The values of these variables, shown below, were chosen on the basis of recent studies characterizing *C. sativa* coppice stands in the area (Menéndez-Miguélez *et al.*, 2013; 2014). As the target ecosystem of the present study was the *C. sativa* agro-ecosystem, we restricted our investigation to those stands in which this species



**Table 1.** Main variables analysed, their sources and the associated ecosystems services (ES). NFI=National Forest Inventory.

Data Source	Associated ES	Variable	Level of provision	Range of values
NFI	Provision of materials	dg (cm)	Very low	<15.7
			Low	15.7-21.2
			Intermediate	21.2-26.9
			High	26.9-37.1
			Very high	37.1-166.4
		G (m <sup>2</sup> /ha)	Very low	<10.8
			Low	10.8-19.9
			Intermediate	19.9-29.8
			High	29.8-40.1
			Very high	40.1-126.3
	Energy provision; Climate regulation	V (m <sup>3</sup> /ha)	Very low	<47.8
			Low	47.8-98.9
			Intermediate	98.9-148.8
			High	148.8-215.9
			Very high	215.9-556.3
Erosion regulation	Cov_tree; Cov_tot (%)	Very low	<20	
		Low	20-40	
		Intermediate	40-60	
		High	60-80	
		Very high	80-100	
Technical reports and others	Traditional knowledge	Cultural elements (n°)	Very low	1
			Low	2
			Intermediate	4
			High	6
			Very high	>6
	Landscape valuation and recreational uses	Expert criterion	Expert criterion based on scientific and technical reports about ES for forest and woodlands in the study area	
			Food provision	Chestnut production

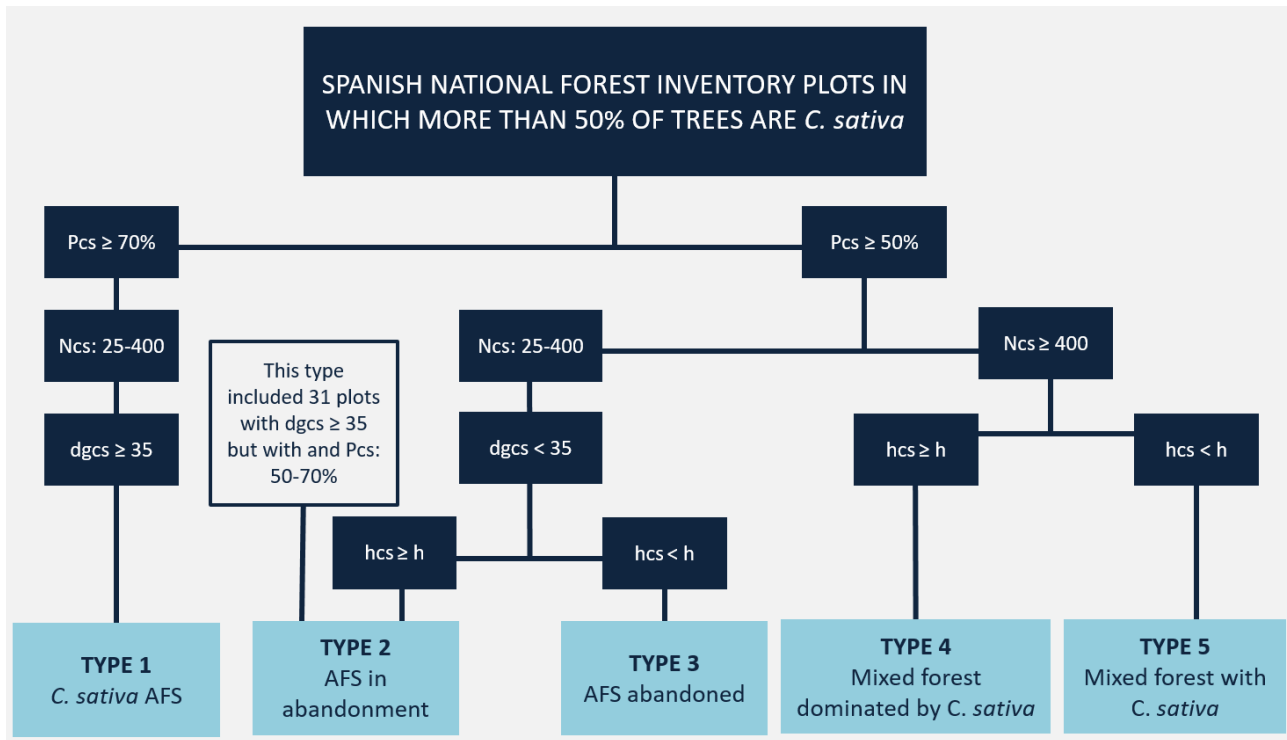
was the most common tree. Thus, 776 plots in which *C. sativa* represented more than 50% of the trees were considered for further analysis. This proportion was considered in order to restrict the analysis to stands produced by traditional management (*i.e.* for fruit and materials provision) where the main element was sweet chestnut trees (often grafted). It was also considered important to identify those stands with the highest likelihood of representing the sweet chestnut AFS *sensu stricto* - *i.e.* closest to complete dominance of the species. From the initial set of plots, we therefore selected stands with more than 70% of *C. sativa* trees (see Figs.1 and 3).

The following variables were used to characterize and analyse the *C. sativa* AFS: Pcs, percentage of chestnut trees in relation to the number of trees of the plot (%); N, number of trees/ha; Ncs, number of trees

of *C. sativa*/ha; dg, diameter of tree with average value of basal area of the plot (cm); dgcs, diameter of *C. sativa* trees with average value of basal area of the plot (cm); hg, average height (m); hgcs, average height of the *C. sativa* trees (m); hdom, dominant height (m); G, basal area (m<sup>2</sup>/ha); Gcs, basal area of the *C. sativa* trees ((m<sup>2</sup>/ha); V, volume (m<sup>3</sup>/ha); Cov\_tree, soil cover of trees in the plot (%); Cov\_tot, vegetation soil cover (trees, shrub, etc.) in the plot (%).

The plots were classified into five types of ecosystems on the basis of some of the previous variables:

- **Type 1.** *C. sativa* AFS characterized by plots with Pcs  $\geq$  70% (where practically all the trees were *C. sativa*); Ncs = 25-400; and trees of dgcs  $\geq$  35cm. The tree density values were chosen considering the traditional *C. sativa* AFS, in which the open structure maximizes the amount of light reaching the trees. The



**Figure 3.** Description of the classification process used to define the five types of *Castanea sativa* ecosystems.

density of coppice stands of this species is therefore > 400 trees/ha (Menéndez-Miguélez *et al.*, 2013). The diameter (dg) of sweet chestnut in the coppiced stands in the study area ranges between 9.56 and 30.98 cm (Menéndez-Miguélez *et al.*, 2013; 2014), while in plantations of this species younger than 25 years, the diameter is < 35 cm (Álvarez-Álvarez *et al.*, 2010).

• **Type 2:** Recently abandoned *C. sativa* AFS. Plots in which  $Pcs \geq 50\%$ , chestnuts tree density, 25 to 400 trees/ha,  $dgcs < 35$  cm and the average height of chestnuts trees is higher than the plot height ( $hcs \geq h$ ). Mean height was included because it provides a better representation of the stand structure than dominant height, which is more closely related to site quality. *C. sativa* is the main species in the vertical structure of the plot. Type 2 also includes 31 plots with  $dgcs \geq 35$  and  $Ncs = 25-400$ , which were not considered Type 1 because the  $Pcs$  is <70%.

• **Type 3:** Abandoned *C. sativa* AFS. As Type 2 but  $hcs < h$ . The chestnut trees in the stand are not the dominant part of the ecosystem and they are in decline.

• **Type 4:** Mixed forest dominated by *C. sativa*. The tree density is higher (>400 trees/ha);  $Pcs \geq 50\%$ ; and  $hcs \geq h$ . *C. sativa* trees are dominant in the stand. Sometimes coppice stands of *C. sativa*.

• **Type 5:** Mixed forest with *C. sativa*. As type 4, except  $hcs < h$ . *C. sativa*. The trees density is higher (>400 trees/ha);  $Pcs \geq 50\%$ ; and  $hcs < h$ . These are sometimes coppice stands of *C. sativa*. This type is similar to type 4, but the chestnuts trees are not dominant in the forest structure.

It should be noted that 34 of the plots, in which  $Pcs \geq 50\%$ , were omitted from the analysis because the density of chestnut trees was < 25 trees/ha. Finally, we used some data limited only to a few of *C. sativa* ecosystem plots that include information about the following:

- Chestnut fruit production ( $kg/m^2 \cdot year$ ): in two different years for an AFS plot (type 1) vs. an abandoned plot (type 3).

- Cultural: amount of elements and processes involved in traditional harvesting of the AFS ( $n^\circ$ ; source: Álvarez-Álvarez *et al.*, 2000).

We used discriminant analysis (Fisher, 1936) to evaluate the accuracy of the classification procedure. This is a multi-variant statistic technique in which the main objective is to describe differences between a set of groups (in this study, the five types of ecosystems) based on a series of observed variables (the stand variables of the plots). This enables prediction of a response variable that depends on the values of the classificatory variables. For this purpose, a set of discriminating functions and some related statistical parameters were calculated. The statistics indicate the significance of each of the functions and also the amount of variability explained by each. Finally, the predictions (the type of ecosystem predicted with these functions) were compared with the observed values. The analysis was performed using STATGRAPHICS Centurion XV software.

The variables used to define the different types of chestnut ecosystems were associated with the corresponding ecosystem services for which they

constitute a proxy. The variables, their sources and the associated services are shown in Table 1. Using the available information, provision of a set of seven ecosystem services was pre-evaluated using categories ranging from null to very high level of provision. This is common procedure in ES analysis (defined as Matrix method by Burkhard *et al.*, 2010; 2012). Each range of variables was divided into five class (quintiles) according to their relationship with the ES evaluated. In addition, radial graphs including the different ES assessed and the levels of supply level of the five types of ecosystems are shown (see Results).

## Results

### Ecosystem types classification

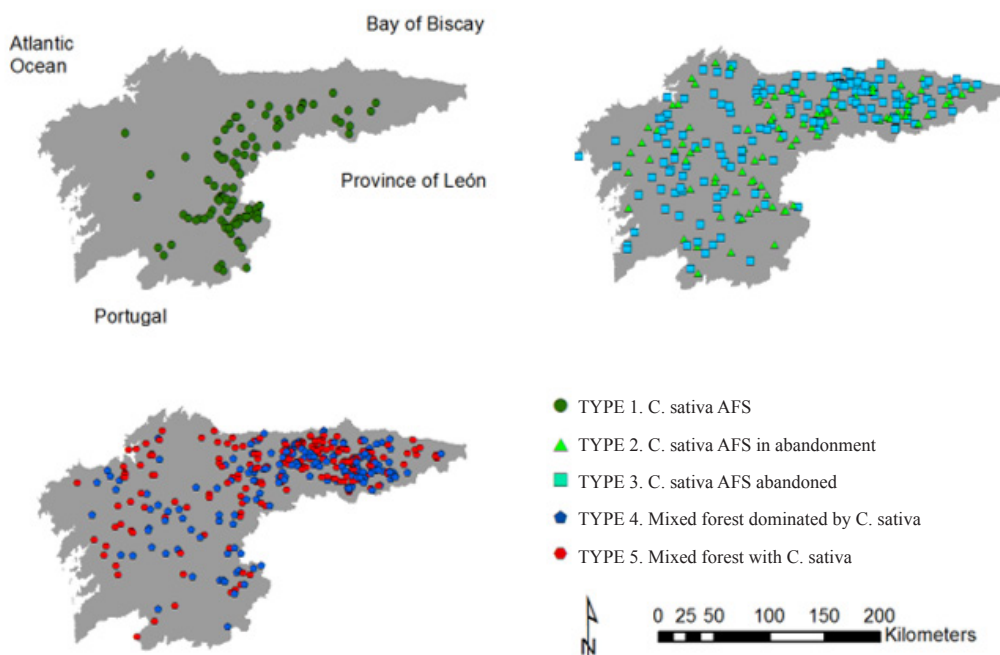
The spatial distribution of the different *C. sativa* ecosystem types found in the study area is shown in Fig. 4. *C. sativa* AFS type 1, characterised by large chestnut stems (diameter > 35 cm) at lower densities (< 400 stems/ha) was the least extensively distributed of the five types (only 102 plots). These plots are located in mountainous areas in the central and eastern half of the study area and none are close to coastal zones. AFS type 2, characterised by recent abandonment had a similar geographic distribution as type 1 and was identified in a similar number of plots (106). However, some of the plots classified as type 2 were closer to the coast and were more widely spread

in the western zone. AFS type 3, which represents totally abandoned areas, was identified in 157 plots. This type is distributed across the whole study area, including coastal zones. Ecosystem types 4 (180 plots) and 5 (197 plots) are characterised by forest stands that are very different from the original AFS, with higher densities and smaller trees. These types are distributed throughout the study area, with some clusters of plots in the eastern half of the study area.

The discriminant analysis revealed four different discriminating functions (Table 2). Functions 1 and 2 are associated with the highest Eigen values or canonical correlations and together explained 81.82% of the variability of the data.

The results of the discriminant analysis confirm those of the previous classification method based on the characteristics of the dominant tree layer. The spatial representation of discriminant functions 1 and 2, showing the different types of *C. sativa* ecosystems are shown in Fig. 5. The points corresponding to agroecosystem type 1 show low values for function 1 and high values for function 2. The other four types are influenced by different degrees of abandonment, from early stages (type 2) to mixed forest where *C. sativa* is not the dominant structural element (type 5). This differentiation is shown on clusters of points in Fig. 4. Agroecosystem types 2 and 3 have lower values of function 2 relative to type 1. Finally, ecosystem types 4 and 5 show similar values but are clearly differentiated from the other types.

The percentages of plots successfully (and unsuccessfully) classified using the original criteria



**Figure 4.** Spatial distribution of different types of *Castanea sativa* ecosystems in NW Spain. AFS=Agroforestry systems.

**Table 2.** Statistical parameters of the discriminant functions.

Discriminant function	Eigen value	Relative percentage	Canonical correlations	Wilks			
				Lambda	Chi-Squared	DF	p-value
1	1.7852	47.73	0.8006	0.0894	1768.18	48	0.00
2	1.2749	34.09	0.7486	0.2491	1017.86	33	0.00
3	0.5179	13.85	0.5841	0.5668	415.81	20	0.00
4	0.1622	4.34	0.3736	0.8604	110.11	9	0.00

and the predicted classification with the discriminant functions are shown in Table 3. On average, 76.68% of the plots were successfully classified.

### Analysis of stand variables

The variables analysed in this study revealed differences between the five types of chestnut AFS identified (Table 4). The number of trees per hectare (N) was lower for type 1 (169) than for types 2 (195) and 3 (319) and much lower than for types 4 (1157) and 5 (1187). The dg was much higher for type 1 (61.88 cm) than for the other AFS types. This variable is lower in those plots where the chestnut is not totally dominant (types 4 and 5; 18.63–20.93 cm) than in others representing different stages of abandonment (types 2 and 3; 24.71–31.61 cm). For similar reasons, G was also higher for type 1 than for the other types. However, the high density of trees in types 4 and 5 implied higher values of G than for types 2 and 3. Tree height was similar in all AFS types considered, although it was slightly higher in AFS type 1. The V per plot also differed, and the highest values were observed in the closer-to-forest-structure types (4 and 5; >179 m<sup>3</sup>/ha) and attributed to the high density of trees per hectare. The mean V in AFS type 1 (133.91 m<sup>3</sup>/ha) was higher than in the other types (<103.12 m<sup>3</sup>/ha). Regarding with the total vegetation cover and the tree cover in the stands, the values were similar in all AFS types, with tree cover ranging between 40.54% and 49.21% and total vegetation cover ranging between 64.46% and 76.66%.

Regarding fruit production, the data only applies to plots of AFS type 1 and 3. Chestnut production was higher in the year that sampling was carried out

in the AFS (1.478 kg·m<sup>2</sup>) than in the abandoned type (1.207 kg·m<sup>2</sup>).

In relation to elements of traditional and cultural knowledge, AFS type 1 was characterised by several exclusive treatments and processes. For example, different grafting methods were used to maintain or add to the ecosystem trees with certain characteristics. Thus, more than 140 cultivars of this species have been identified in the study area (Furones-Pérez & Fernández-López, 2008; 2009). Other treatments such as pruning to maximize fruit production are also important. Some traditional elements were also found in these stands, such as the circular stone structures (height 0.5 m) used to store and preserve chestnuts.

### ES assessment

Finally, we used the different variables described in the previous section to classify ES provision. For this purpose, we used the ranges of values shown in Table 1 for each variable and the mean values for each ecosystem type (Table 4). The results of this assessment for the seven ES are shown in Fig. 6. Thus, for example, type 1 produced more chestnuts than the abandoned systems and thus food provisioning service is higher. This type of AFS also provides large dimension timber (diameters > 60 cm) that can be used for construction and thus is also associated with a high level of materials provisioning. The abandoned AFS (types 2 and 3) showed an intermediate level of the seven services considered. Ecosystems types 4 and 5 were associated with low levels of materials and food provision and traditional knowledge but high levels of energy provision, mass

**Table 3.** Number of plots and percentage agreement (underlined) and disagreement between the original plot classification and the discriminant-based classification

Observed	Predicted				
	Type 1	Type 2	Type 3	Type 4	Type 5
Type 1	<u>79 (77.45%)</u>	13 (12.75%)	2 (1.96%)	8 (7.84%)	0
Type 2	1 (0.94%)	<u>89 (83.96%)</u>	8 (7.55%)	3 (2.83%)	5 (4.72%)
Type 3	1 (0.64%)	20 (12.74%)	<u>129 (82.17%)</u>	0	7 (4.46%)
Type 4	0	11 (6.11%)	1 (0.56%)	<u>135 (75.00%)</u>	33 (18.33%)
Type 5	0	3 (1.52%)	14 (7.11%)	43 (21.83%)	<u>137 (69.54%)</u>



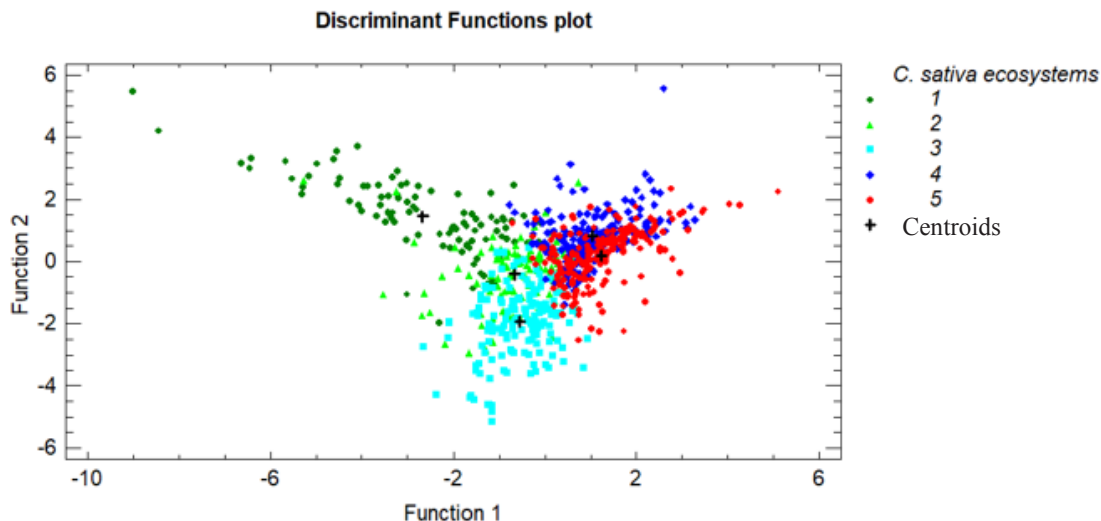


Figure 5. Representation of the values of functions 1 and 2 for all of the plots included in the study.

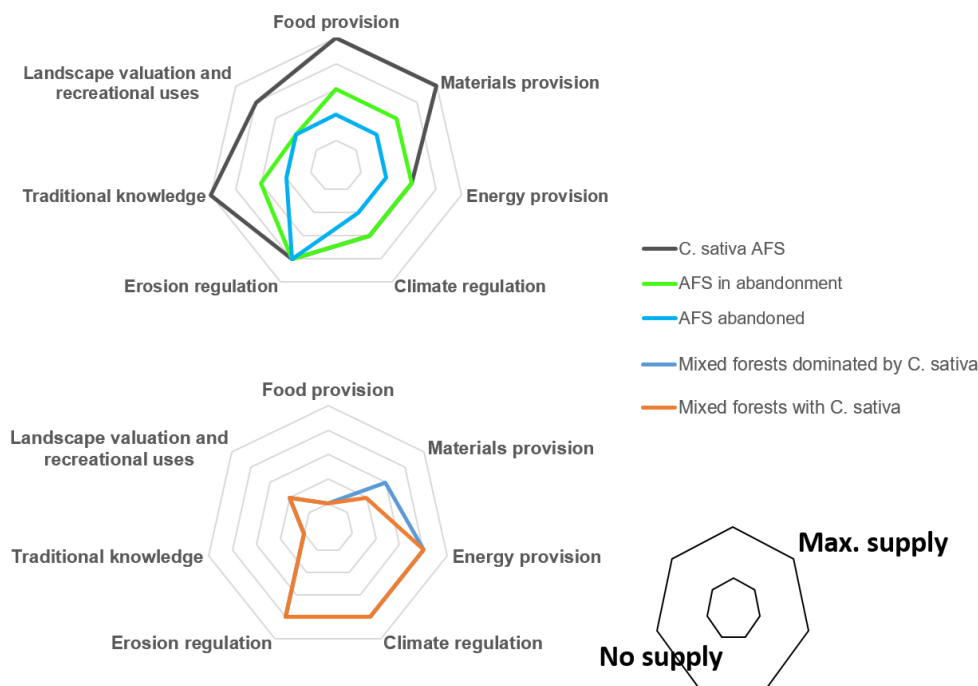


Figure 6. Representation of the supply of the different ecosystems services (ES) assessed in this study on the basis of different sources of information.

flow and climate regulation, all of which are related to the large amounts of biomass (170 m<sup>3</sup>/ha for types 4 and 5 and less than 135 m<sup>3</sup>/ha for the remaining types).

## Discussion

### AFS dynamics and perspectives

The results of the present study were obtained by integrating spatial databases and other types of data providing information about the forest structure in

the AFS. This classification enabled to classify the different types of AFS considered and identification of the relationships between the forest structure and condition and its capacity to provide services. This classification was supported by the results of the discriminant analysis. The combined consideration of both of these aspects led to an important finding: the *C. sativa* AFS shows a clustered distribution in mountainous areas (Fig. 4), which do not represent the best ecological niche for this species (Roces-Díaz *et al.*, 2014b). Nevertheless, this AFS is traditionally cultivated and managed in such environments in

**Table 4.** Mean values and standard deviation (SD) of the stand variables for the five types of chestnut AFS identified. dg (diameter of tree with average value of basal area of the plot); dgcs (diameter of *C. sativa* trees with average value of basal area of the plot); G (basal area); Gcs (basal area of *C. sativa* trees); hg (average height); hgcs (average height of the *C. sativa* trees); hdom (dominant height); N (number of trees); Ncs (number of trees of *C. sativa*); Pcs (percentage of chestnut trees in relation to the number of trees of the plot); V (volume); Cov\_tree (soil cover of trees in the plot (%)); Cov\_tot (vegetation soil cover (trees, shrub, etc.) in the plot (%)).

Variables		Type 1	Type 2	Type 3	Type 4	Type 5	Total
N	Mean	168.85	294.78	319.42	1156.92	1185.93	728.43
	SD	119.49	190.27	175.76	626.64	654.94	653.90
Ncs	Mean	155.87	200.83	213.69	983.87	994.50	598.04
	SD	105.04	120.50	104.51	579.39	619.86	589.33
G	Mean	41.27	22.87	15.80	35.47	29.39	28.69
	SD	24.58	19.84	11.18	19.89	13.84	19.59
Gcs	Mean	40.35	18.41	8.14	32.20	21.72	23.48
	SD	24.38	17.17	6.59	20.48	14.05	19.94
hg	Mean	13.05	12.82	12.59	12.05	12.50	12.53
	SD	3.31	3.61	3.16	2.65	2.90	3.08
hgcs	Mean	12.94	13.21	11.00	12.45	11.77	12.14
	SD	3.32	3.67	3.16	2.76	2.88	3.18
hdom	Mean	13.74	14.43	15.30	14.85	17.27	15.37
	SD	3.58	4.26	4.53	3.20	5.09	4.41
dg	Mean	61.88	31.61	24.71	20.93	18.63	28.27
	SD	25.50	16.27	6.53	8.44	5.81	18.94
dgcs	Mean	62.67	34.97	20.78	21.46	17.16	27.77
	SD	25.35	21.38	7.26	8.89	6.27	20.44
V	Mean	133.91	103.12	92.67	179.29	179.32	143.85
	SD	91.71	86.42	77.02	87.24	90.70	94.41
Pcs	Mean	94.49	72.29	70.12	85.44	83.61	81.08
	SD	8.92	19.38	14.22	16.12	14.25	17.05
Cov_tree	Mean	40.54	42.74	40.96	48.19	49.21	45.04
	SD	33.78	36.39	36.32	37.13	36.65	36.21
Cov_tot	Mean	76.66	67.22	64.46	69.97	72.51	70.26
	SD	38.87	44.76	45.98	43.89	42.31	70.26

the study area, probably driven by socio-economic factors. Conversely, in a priori more suitable areas, the species mainly occurs in abandoned AFS or mixed forests. This has important implications for the conservation of chestnut forests (e.g., as a habitat listed in Annex I of Habitat Directive 9260-‘*Castanea sativa* woods’; EC, 1992), and which can be observed from two points of view: 1) preservation of an AFS to maximize the capacity for provision of ES bundles (see following sections), relying heavily on active management and traditional knowledge outside the natural ecological range of the main species;

and 2) evolution towards preference of the typical ecological niche, but with strong competition from other naturally occurring species and/or intensively planted exotic species.

*Castanea sativa* AFS are important from cultural and historical points of view in different areas of the Mediterranean and Atlantic European regions (Pardo de Santayana *et al.*, 2007; Aumeeruddy-Thomas *et al.*, 2012). Although cultural elements of the landscape in these areas show a general decline (Martinez *et al.*, 2010), studies of their current status are scarce (Díaz-Varela *et al.*, 2009; 2011). Thus, the combined use

of different data sources, such as those that enable differentiation of different stages of change in the ecosystem (due to abandonment) may be of interest.

## Chestnut (Agro) Ecosystem Services

### Food provision

This ES is probably the most important, at least from a historical point of view, of the services provided by this AFS. This ES is generally supplied at local scale (García-Nieto *et al.*, 2013; Rocés-Díaz *et al.*, 2015) and is one of the reasons for the typical location of this AFS close to the population centres. The *C. sativa* AFS was traditionally managed to maximize fruit production, using low tree density to enhance light exposure and grafting process to obtain high quality chestnuts. As a consequence, many diverse cultivars of this species have been identified in the study area (Fernández-López & Pereira-Lorenzo, 1993) and other similar areas (Furones-Pérez & Fernández-López, 2008; 2009). This complex management scheme yielded high levels of fruit production, which was responsible for the spread of the species through the AFS since the Middle Ages (Conedera *et al.*, 2004) in a wide range of environmental conditions. The fruit production data for AFS types 1 and 3, which represent two of the ecosystem types with a limited temporal range, show very high production in the traditional *C. sativa* AFS. In the last few decades, the study area has undergone changes that have led to a decline in cultural ecosystems and landscapes (Moran-Ordoñez *et al.*, 2011; 2013), and the importance of ES associated with traditional management (provision of food in chestnut AFS) has also declined (EME, 2011). Thus, the current low presence of type 1 in comparison with other types can be considered an indicator of this process.

### Provision of materials

Provision of materials from the chestnut AFS was important for the traditional way of life of this area, although the stands representing this AFS have a smaller amount of biomass than those of other stages. Some cultivars of *C. sativa* (e.g. 'Paredé') produce straight branches of more than 8-m to 10-m long above the graft line (Álvarez-Álvarez *et al.*, 2006), and the use of this species for traditional construction is widely documented (Bouhier, 1979; Fernández-López, 1984; Pereira-Lorenzo & Fernández-López, 1997). Use of the material is increasingly important and different studies have analysed the mechanical properties of this species for construction (Vega *et al.*, 2012; 2013). The trees in AFS type 1 are generally larger than in the other types, and this is important in relation to use of the material for construction purposes (to produce pieces of large dimensions).

### Energy provision

In the traditional agricultural and forestry systems in the study area, energy provision was less important than provision of other services. The low density of chestnut wood in comparison with other species (*Quercus* spp., *Fagus sylvatica* and *Fraxinus excelsior*) may be related to the lower importance of this species as firewood. However, there is a growing interest in the use of *C. sativa* for energetic purposes as a result of the higher levels of biomass production (Menéndez-Miguélez *et al.*, 2013). AFS types 4 and 5 (high density of trees in coppice stands) represent the stages of the AFS with the highest potential to supply this increasingly important ES (Nunes *et al.*, 2013).

### Climate regulation

Climate regulation is generally interpreted as the contribution made to the global climate functioning by carbon storage and is thus globally one of the most important types of ES. The *C. sativa* AFS are some of the most important in the study area (Castaño-Santamaría *et al.*, 2013). Biomass was highest in AFS types 4 and 5 (179 m<sup>3</sup>/ha of wood in comparison with < 135 m<sup>3</sup>/ha in the other types) and therefore higher levels of carbon are accumulated and supply of this ES is highest of the ecosystems analysed. In addition, mixed stands with *C. sativa* combined with other species as *Pinus* spp. or *P. menziesii* show high in this area high productivity values (Nunes *et al.*, 2013). Future studies analysing the spatial location (often close to villages) of the different ecosystems and their role in regulating the climate conditions (such as wind, temperatures, etc. at local level) may be of interest.

### Erosion regulation

This ES is associated with the protection of vegetation against erosion and similar processes. In the study area and similar steeply sloping areas, the risk of this type of process is high and the ecosystems have a key role (National Erosion Inventory of Spain; MAPAMA, 2015). The vegetation cover in the different types of ecosystems analysed here were similar and provision of this ES is therefore also similar.

### Traditional knowledge

Within the context of a decline in cultural and traditional landscapes in the last few years (EME, 2011), the cultural-type ES provided by this AFS is very important (Calvet-Mir *et al.*, 2012). Several authors have highlighted the role of *C. sativa* and their AFS from a traditional point of view (Pardo de Santayana *et al.*, 2007; Díaz-Varela *et al.*, 2009). Management of AFS type 1 depends on several types of traditional knowledge (including the aforementioned capacity for preservation of the species outside of its optimal distribution area) but also the use and conservation

of different cultivars (used in this area during several centuries) of this species supplied this type of ES more than the rest of types. In our opinion this is one of the most important services provided by the AFS, but is also the most severely threatened.

### **Landscape valuation and recreational uses**

Finally, in addition to the ES of traditional knowledge, relevance of *C. sativa* agroecosystems from esthetical and recreational points of view was highlighted by different authors (e.g. Díaz-Varela *et al.*, 2009; EME, 2011). For this reason ecosystems of type 1 show a higher level of supply of this specific ES.

## **Conclusions**

The *C. sativa* AFS are the result of human use and management during centuries focused on maximizing chestnut production. However, because of the wide range of ES supplied by these systems, they are considered as multifunctional landscape elements. Indeed, the possible role of chestnut plantations as multifunctional ecosystems has been highlighted (Martins *et al.*, 2010). Social and demographic changes in the last century are associated with the loss of traditional cultural ecosystems (Morán-Ordóñez *et al.*, 2011), landscapes (Martínez *et al.*, 2010) and services (EME, 2011) in this geographical area. The constrained distribution of the AFS type 1 relative to the species distribution is consistent with this idea. As a consequence, the loss of ES such as food provision (chestnuts) and cultural services will probably continue, while others such as energy provision and climate regulation may increase in the near future.

The combination of forest and spatial data considered in this study enabled assessment of the current state of the *C. sativa* AFS in NW Spain. A small number of plots were characterized as AFS relative to other forest ecosystems in which chestnut is the dominant tree. The classification procedure, based on different forest variables, describes the different stages of *C. sativa*-dominated ecosystems in the study area and was supported by the results of discriminant analysis. *Castanea sativa* AFS are typically formed by low densities (<400 stems/ha) of large grafted trees. The grafting was performed high up on the trees to enable other uses of the AFS (such as for grazing cattle). The decline in use and management of this traditional AFS has led to the development of different types of AFS according to the degree of abandonment and in which the chestnut trees also appear in coppice stands. However, spatial and temporal data on the stand variables in this important AFS should be combined for analysis of the

forest dynamics and also to obtain information about the population and other related parameters.

The ES provided by the *C. sativa* AFS (mainly provision of food and cultural services) are very different from those provided by other types of AFS. Although the traditional AFS shows a high potential capacity to provide a bundle of ES (*i.e.* a set of closely related services), the other AFS types mainly provide one or two services (mainly provisioning services). Consequently, changes in the AFS transforms the capacity of the landscape to provide services. This has important consequences for the multifunctional, sustainable management of forest landscapes in NW Iberian Peninsula beyond the mere conservation of chestnut forest as a habitat.

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