Chapter

Pollard Forest of *Fraxinus angustifolia* in the Centre of Iberian Peninsula: Protection and Management

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Abstract

The activity of pollarding *Fraxinus angustifolia* L. is one of the most singular in the Guadarrama piedmont, Madrid. This treatment generates a patrimonial landscape of great interest and identity. The main aims of this work are to determine the surface covered by *Fraxinus angustifolia* L.; its conservation state and structure; the main variables that influence its distribution; and the elaboration of a typology. We start with the historical construction of these forests (from the eleventh century until the present moment). Some of them are excellent examples of pollard forests, thanks to the traditional regulations based on regional codes and byelaws and on a rational exploitation from some owners. Then, we analyse the physical determinants of this forest distribution. We establish a typology in which we consider the surface soil moisture, accompanying species, slope, morphostructural unit and type of property. *Fraxinus angustifolia* L. is, due to its narrow dependence of the existence of water, an indicator species of climate change and therefore vulnerable to the increase in temperatures and its consequences. Furthermore, its value as cultural heritage and the need for its conservation for its silvicultural values are highlighted.

Keywords: *Fraxinus angustifolia* L., silvopastoral system, pollard, cultural heritage, surface soil moisture

1. Introduction

Pruning and pollarding of tree species constitute an activity that has existed in European forests for centuries. Pruning and pollarding of tree species constitute an activity that has existed in European forests for centuries. Although pruning is still a frequent silvicultural practice, in some areas, some species are currently no longer pruned and there has been a decline in other uses that had been implemented in forests, which played a vital role in shaping their silvo-structures [1–3]. This pruning responded to different objectives, among these, production of wooden beams, charcoal, firewood, timber for ships, leaves for fodder, etc. All these activities were tightly controlled by traditional regulations [4]. These coppice forests present an "aerial" morphology [5]. In general terms, among the formations in which these practices were abandoned, we can highlight forests of oak (*Quercus pyrenaica* Wild., *Quercus robur* L.), birch (*Betula* ssp.), holly (*Ilex aquifolium* L.), and Holm oak (*Quercus ilex L. subsp. ballota* (Desf.) Samp.) [6]. Consequently, numerous tree species, generally deciduous ones, have been subjected to this traditional management regime.

In order to accurately interpret the evolution of European forests, especially in the south, anthropogenic disturbances, as well as the development thereof over time, must be taken into account. This can involve erroneous interpretations of the patterns and processes observed in forest ecosystems [7–9]. Specifically, pollarding has constituted a fundamental part of rural economies in much of Western Europe, and it also shapes a landscape of great cultural, aesthetic, and identity-related value that has lasted up to the present time as a result of the persistence of these practices [10–14]. Pollarding became widespread in many of Europe's forests and agricultural and rural environments, from the British Isles to Romania and from Scandinavia to the Mediterranean basin, and evidence of pruning in the different agro-forest landscapes can still be observed [5, 15–17].

Many studies on *Fraxinus* ssp. in Europe have been conducted in relation to the taxonomy and the ecological characteristics of *Fraxinus excelsior* L. [18–22] and to the role it plays in maintaining biodiversity [23, 24]. Nonetheless, few studies on *Fraxinus angustifolia* Vahl. have addressed the relevance of this species in the western Mediterranean's agro-forest landscape. The centre of the Iberian Peninsula houses one of Europe's densest formations of *Fraxinus angustifolia* [25]. These forests are currently conserved as *dehesas*, mainly presenting tree and herbaceous strata associated with secular livestock farming which to the present day still involves pollarding. It is precisely this *dehesa* landscape that characterises the formations of *Fraxinus angustifolia* in the Guadarrama mountains of Madrid. These dehesas formed mainly (sometimes exclusively by *Fraxinus angustifolia*) are really unique because of their main species and their territorial concentration and differ from the best-known dehesas of the South and West peninsular, usually populated by *Quercus suber* and *Quercus ilex*. Pollarding can be conducted twice during the year: in wintertime, less habitual and intended mainly for firewood production, and at the end of the hot season, when pastures are parched, in order to provide fresh fodder for the livestock immediately after pruning. This endows the tree with a unique appearance, with stems up to 2 m long which become wider at the top due to the scarring where they are cut. This pruning system gives rise to *dehesas*, dotted with old trees presenting a *cabeza de gato* (cat's head) morphology. Notwithstanding, this structure is not homogeneous because these large stands alternate with young stands and flooded areas. This agricultural landscape also comprises pastures growing in the herbaceous stratum. These formations exhibit a certain degree of variety based on gradients of moisture, with xeric species (dense, high-cover pastures dominated by *Poa bulbosa* L.), on relatively moist (pastures of *Agrostis castellana* Boiss. and Reuter) or temporarily flooded (moorlands of *Nardus stricta* L.) terrain [26, 27]. This whole mosaic, dominated by pollarded trees, makes up an open *dehesa* forest formation. It presents a high biodiversity of energy-rich pastures on flat or slightly sloped terrain and in turn constitutes one of the most emblematic traditional landscapes on the southern slopes of the Guadarrama mountains.

Interestingly, *Fraxinus angustifolia* plays a significant role in the areas close to the villages, known as *ruedos* in the Mediterranean world. This space mainly involves smallholdings delimited by stone walls and hedges, which are subjected to intensive cultivation; they are habitually irrigated and therefore permanently moist practically throughout the year. In this environment, the most common tree species is the ash (*Fraxinus angustifolia* L.). This landscape comprises hedgerows in which the trees and the ash in particular play a relevant role, both within and around the perimeter. It is a fragile landscape, endangered by intense processes, mainly urbanisation and the abandonment of agriculture and livestock farming, factors which cause the loss of much of these lands [28].

Furthermore, in these forests, many associated values are recognised, not only in relation to the biodiversity and the ecological elements they contain but also to the culture and identity-related values and those referring to aesthetics, perception, productivity, and history. Civil society promotes numerous initiatives emphasising the heritage-related values of pollarded landscapes or of unique examples of pollarding: the Woodland trust (http://www.woodlandtrust.org.uk/), the Veteran Trees Initiative (UK.), The centre Européen des trognes in France (http://www.maisonbotanique.com/centre-europeen-trognes.php), the Vetree European Project (Veteran Tree Network, https://vetree.eu/es/page/10/), etc. In Spain, we can highlight the initiative "Chopo Cabecero (Pollarded *Populus*). The Identity of a Landscape", implemented by the Centro de Estudios del Jiloca—the Jiloca Study Centre (http://www.chopocabecero.es/).

The present research aims to provide more in-depth knowledge of *dehesas* of pollarded *Fraxinus angustifolia* in the centre of the Iberian Peninsula and to elucidate the origin and genesis of these formations on the southern slopes of the Guadarrama mountains; to demarcate and map the area they occupy; to characterise and to establish the typology of the masses delimited and lastly, to identify their main values and the threats they face.

2. Methods and study area

2.1 Methods

The study was developed in four methodological phases in order to establish the area covered by *Fraxinus angustifolia*, to analyse its state of conservation and forest structure, to determine the main variables influencing its distribution and lastly, to establish a typology.

In the first phase, we conducted a search for bibliographic and digital information at different scales, and we analysed documentation in digital historical archives (Archivo PARES: http://pares.mcu.es/) and municipal archives. As sources of basic cartographical reference, we employed the Inventario Forestal de la Comunidad de Madrid—Madrid Regional Govt. Forest Inventory (Consejería de Medio Ambiente—Dept. of the Environment), the Mapa Forestal de España—Spanish Forest Map, the habitats considered in Directive 92/43/CE, and the Mapa de Terreno Forestal de la Comunidad de Madrid – Madrid Regional Govt. Map of Forestland. As complementary sources, we employed the MDE LIDAR (Instituto Geográfico Nacional—National Geographic Institute), the Madrid Regional Govt.'s available planimetry at a scale of 1:5000, the Catastro de Rústica—Rustic Land Registry (Dirección General del Catastro—General Land Registry Dept.), and the orthography at a scale of 1:5000 (IDE of the Madrid Regional Govt. available through WMS).

In the second phase, we established the criteria for identification, correction, and incorporation of enclosures containing ash trees. This enabled us to identify the ash forests that were not defined in the cartography to maintain the pre-existing ones and to eliminate those that could no longer be considered as such. We bore in mind:

- All the areas included in the Iberian Mediterranean Ash Forests of *Fraxinus angustifolia* and *Fraxinus ornus* 91B0 (Directive 92/43/CEE), eliminating riparian forests with excessively regular widths. In these areas, we verified in the field the absence of ash trees and excluded the areas dominated by riparian vegetation.

- The polygons classified as ash forests, ash tree *dehesas*, and a mixture of ash trees with deciduous species from the cartography of the Mapa de Terreno Forestal de la Comunidad de Madrid—Madrid Regional Govt. Map of Forestland. We also included polygons in which *Fraxinus* presented values of 30% or others coinciding with hedgerows and wood pastures.

- Riparian ash forests that presented continuity with larger masses or hedgerows with presence of ash trees.

- We did not take into account the riparian ash forests; however, we did establish criteria for differentiating them. For this reason, we employed the basic hydrographic network from the MDT 100 × 100 to define a 100 m buffer zone (Public Water System); we conducted an individualised review of the areas that remained within the buffer zone or those that were situated very close to it. This enabled us to include those that presented continuity with other polygons of ash forest or those that, although they formed part of the riparian vegetation, encroached uphill or had become meadows or plots of *dehesa* land.

The third phase consisted of designing different itineraries combining the orthography at a scale of 1:5000 and employing the LIDAR Digital Elevation Model (0.5 m) and the available forest cartography. We selected the tracks considering geographic area: Northeast, Centre and Southwest, and abiotic (physiography and lithology) and forest (type of forest structure) conditioning factors. These transects enabled us to rectify and incorporate new data into the cartographic information sources of reference.

In the final phase, we estimated the different variables intervening in the localisation of the ash forests, reducing these to three: slope, morphology of the terrain, and surface soil moisture. We obtained the slope directly from the LIDAR model, simplifying it in order to operate it in three categories (low: <5%; moderate: 5-10% and medium>10%). Curvature, derived from the MDE LIDAR, was classified into two categories: 1 (concave lands) and 2 (convex lands). Finally, for moisture, we differentiated three typologies: moist, semi-moist, and dry. In the latter case, we applied particular methodological criteria. We first analysed the images from Sentinel-2 in the months of May, June, and July (clear contrasts between moist and dry areas), choosing as the optimum image the one from July 3, 2015. We extracted data on surface soil moisture using the band combination that was proposed by EOS DATA ANALYTICS (2017) and reclassified into four intervals for subsequent vectorisation.

With the aim of establishing a valid typification, we analysed the three variables obtained and conducted a grouping process using the software ArcGIS 10.3 (ESRI) *Grouping Analysis* tool. We verified the reliability of the results by means of a stepwise or relational analysis with the *exploratory regression* algorithm of the same software. We calculated the results following the *euclidean distance* method, avoiding sub-algorithms, which provide excessive weight to geographic proximity. The information was simplified until four types were established. To this, we added the cohort of species accompanying each type (based upon the Madrid Regional Govt. Map of Forestland), differentiating: monospecific ash forests, with *Quercus pyrenaica* or *Quercus ilex subsp. ballota*, with different types of scrublands or mixed with different deciduous species. Finally, in order to provide an understanding of the distribution of *Fraxinus angustifolia* in the area, we intersected the types with the morphostructural units identified. In this case, as a reference we employed data from [29, 30] differentiating three groups: horst, tectonic basins and depressions and piedmont[1].

[1] Based on an initial classification in which 6 types were differentiated: massif horst and slopes, massif horst and summits, medium-sized horst and slopes, tectonic basins, depressions and piedmonts.

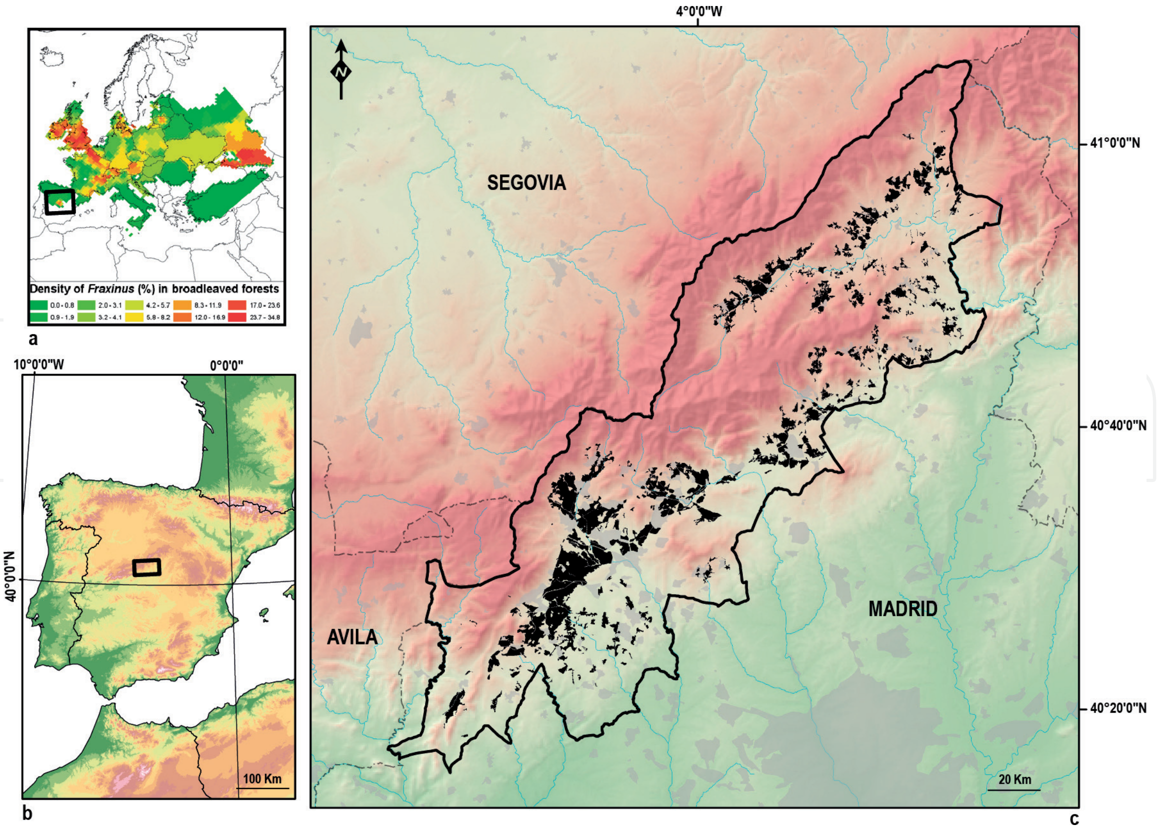

Figure 1.
a) Fraxinus angustifolia density in Europe according to [25]. b) Localisation of the study area on the Iberian Peninsula. c) Distribution of the Fraxinus angustifolia forests in the study area. Own design.

2.2 Study area

The area chosen is located on the southern slopes of the Guadarrama mountains, where *Fraxinus* exhibits one of its finest and southernmost representations in Europe and in the Iberian Peninsula (**Figure 1**). Specifically, we studied 49 municipalities presenting a total area of 198,300 ha. In this sector, the morpho-structural guidelines condition the layout of the relief, which is based on a tectonic system running in the northwest-southeast direction [29–31]. The physiography is characterised by horst (at approx. 2000 m) and graben (from 900 to 1000 m). Lying within the latter, both on the periphery and between summits are tectonic basins and depressions. The dominant materials comprise granitoids and metamorphic rock fields occasionally interrupted by calcareous-marly outcrops. The climate is continental Mediterranean, characterised by hot and dry summers, an average precipitation slightly higher than 650 mm annually, concentrated in autumn and winter, and average temperatures ranging from 12 to 14°C. In this sector, *Fraxinus angustifolia* L. occupies 20,591 ha of the more accessible zones containing tectonic basins, depressions and gentle slopes, on soils with little or no surface hydric deficit. These morpho-hydrological conditions give rise to the aforementioned rich pollarded livestock-farming silvosystems that are highly appreciated for their productivity.

3. Evolution, origin, and historical background

3.1 From the forest mass to the initial uses (eleventh to fourteenth centuries)

The gradual sedentarisation and growth of settlements during the reconquest against Islam (mid-twenty-first century) gave rise to the first production-oriented forest management based on pruning. Specifically, the location of settlements in valley bottoms occupied by ash forests facilitated the exploitation thereof, with the appearance of the first pollards. At that time, there was generally abundant regulation of uses in the shape of Royal Decrees, Regional Codes, and Byelaws. This regulatory framework enforced within a series of incipient territorial identities (the *Real de Manzanares*, the *Sexmo de Casarrubios,* and the *Comunidades de Villa y Tierra* of *Buitrago* and of *Segovia*) lasted almost five centuries [4, 6, 7, 8, 28, 32–34, 36, 37].

3.2 The coppice forest of *Fraxinus angustifolia* and the first enclosures (fourteenth to eighteenth centuries)

The population increase in the mountain areas and the progressive appearance of new settlements caused a growing need for pastures, charcoal, firewood, and timber. This entailed obvious risks and consequences: transformation of the ash forests into coppices and their delimitation as municipally property. In the High Middle Ages, a period of regulation was initiated [32], in which these delimitations were decisive: *las fresnedas son acotadas y defesadas restringiendo sus mejores vuelos y herbajes para el engorde de bueyes de labranza (the ash forests are delimited and "defesadas" (protected), restricting their best crowns and pastures in order to fatten beasts of burden)*. It was precisely this need that caused the continual modification of byelaws governing forestry uses [33–37]. Numerous examples exist of different municipal byelaws, highlighting the importance of protecting these forests from the depletive uses that were becoming generalised outside these estates. For instance, in the case of El Escorial, the Royal Decree dated September 3rd, 1565, prohibits introducing *"...ningún género de ganado mayor ni menor, ni de noche ni de día..." (any class of large or small livestock, whether by night or by day), and forbids "... sacar ni cortar ninguna leña verde ni seca del heredamiento de la fresneda..." (extracting or cutting any green or dry wood from ash forests)*. These circumstances generally applied, with few exceptions, to the whole piedmont of the Guadarrama mountains. At this time, there were two models of exploitation of the ash forests. On one hand, the *dehesas boyales* (common-use pastures), subjected to a higher degree of regulation and protection, used for livestock farming, in which one could find examples of pollarding. On the other, there were the common and private ash forests, the exploitation of which involved coppice forests exploited for charcoal and firewood.

3.3 Genesis of pollarded forests (eighteenth to nineteenth centuries)

Once the Court of Madrid has become consolidated, the increased demand for charcoal and timber determined the management model of the ash forests (eighteenth century). As from this time, the population growth gave rise to an exponential increase in the need for fuel (firewood and charcoal) and meat [38]. This demand for fossil fuels is the commonplace in the rest of Europe and has serious consequences for the forest formations [39, 40]. For example, [41] state that in Europe, wood was habitually extracted from coppice forests to make charcoal and they consider that at least 15% of this came from wood pastures. This rise in consumption of forest resources called for State intervention by means of the 1748 Royal Byelaws, which were intended to protect and increase the area of forests and plantations. During the eighteenth and ninteenth centuries and within this reference framework, the State attempted to tax these resources, conducting as many as three inventories, see [42–44]. Analysis thereof enables us to determine the presence of three different typologies associated with forestry uses in general and of ash forests in particular: coppice forests used for production of charcoal and firewood and seedling forest used for production of timber for construction and pollards in enclosed pastures intended to provide grazing for beasts of burden.

Despite the attempt of local councils to conserve forests and *dehesas*, in the nineteenth century, deforestation and overexploitation were noteworthy. This can be seen in [45]: *"Se observa bastante monte de roble, quejido y fresno aún en los terrenos labrados, lo que hace suponer que en su antigüedad estuvo cubierto de uno muy espeso y que las necesidades de cultivo y la industria del carbón, juntamente con la presión de combustible para hacer fuego los habitantes del país, han dado lugar a que sólo exista dos terceras partes o la mitad propiamente de esta clase de terreno en los alrededores de la población…" (One can observe common oak, lusitanian oak and ash forest remaining on the cultivated land, which leads one to believe that in the old times it was covered with dense forest, and the need to cultivate, together with the charcoal industry and the inhabitants' firewood requirements, has led to a situation in which only two thirds or one half remain of this kind of land in the surroundings of the village).*

Unlike other European countries, such as the United Kingdom [3], where pollarding fell into decline as from the year 1900, in our study area, it became consolidated over time and is actively practiced at present.

3.4 Generalisation of the current forestry model applied to ash forests (nineteenth to twenty-first centuries)

As from half-way through the nineteenth century, there occurred a gradual decrease in the multifunctionality of forests, with the consequent decline in their exploitation for charcoal and firewood. This change in the model was confirmed in the twentieth century, and a new production system became consolidated and has come to dominate in the pollarded ash forests: extensive livestock farming [46]. In this context, many farmers began to breed fighting bulls and from the start of the nineteenth century supplied animals for Madrid's bullfighting festivities [4]. Additionally, in view of the low profitability of bull breeding, many owners began to produce quality meat by means of imported breeds (Limousin and Charolais), autochthonous ones (Negra Serrana), or a mixture of both.

There is currently clear evidence of ash forests mainly associated with livestock farming, which presents a high degree of silvo-structural diversity. Nonetheless, the best ash forests are maintained as functional pollarded open woodland, and the marginal lands are progressively becoming pluri-specific forestland with thickets.

4. Types of pollarded ash forests and their values

4.1 General characteristics

Fraxinus angustifolia occupies 20,590.80 hectares, representing 10.4% of the study area and approximately 3% of the Madrid Regional Autonomy. These formations run parallel to the predominant reliefs in this sector of the Guadarrama mountains (**Figure 1**). Their highest degree of concentration and continuity is seen in areas presenting very specific geographic and environmental features: high moisture levels, gentle slopes and altitudes ranging from 800 to 1350 metres on granitic and metamorphic lithologies. These silvo-structures present an appearance of open woodland with pollarded trees, and they represent one of the most characteristic landscapes on the low slopes and in the valley bottoms.

Almost 80% of the ash forests mapped present a fraction of canopy cover of between 10 and 70%. Furthermore, very few are included in very dense forest

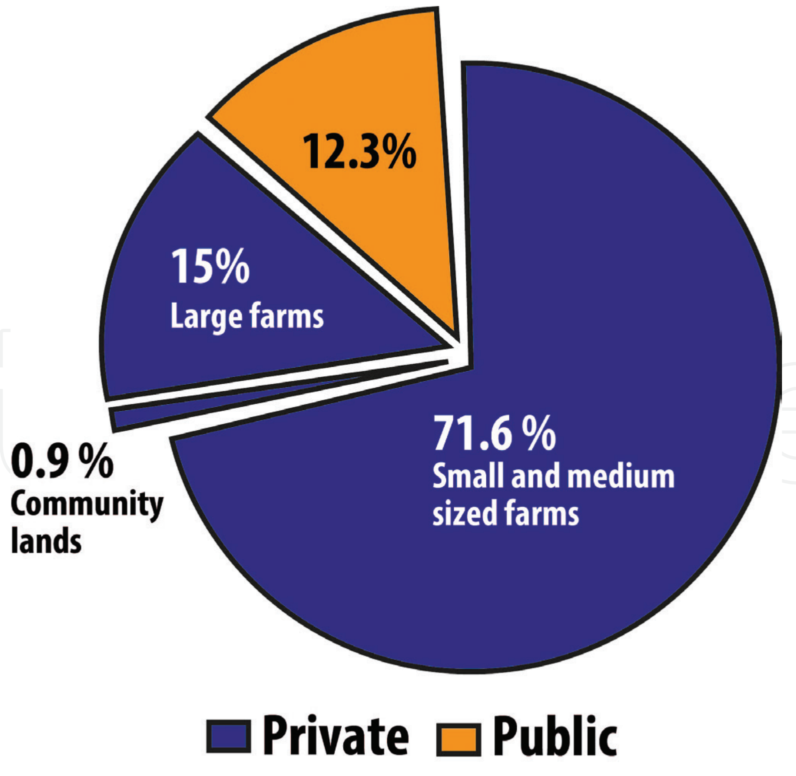

Figure 2.
Ownership of the ash forests. Own design based on the Madrid Regional Govt. Map of Forestland (2009).

formations (2.34%). The remaining 20% are integrated within meadows or pastures with dispersed trees, showing no continuity.

As for ownership (**Figure 2**)[2], there is a clear relationship between the ash forests and private property, as over 85% (18,346.85 ha) are privately owned. In particular, there is a predominance of private estates (86.70% and 18,141.21 ha), and in this category, the representativeness of neighbourhood associations falls to 0.98% (205.64 ha). Among publicly owned lands, we can highlight town councils (8.47%; 1771.80 ha), compared with 3.86% belonging to the Madrid Regional Govt., the State, and the *Confederaciones Hidrográficas* (Water Boards). Lastly, with regard to the type of property, there is a predominance of medium- and small-sized private estates (71.6%, 14,986.34).

4.2 Types of ash forests

We defined four typologies of ash forests in relation to moisture, slope, morphology of the terrain, and accompanying species (**Figure 3**, **Table 1**). As can be seen in **Table 1**, the variable moisture constitutes the most influential conditioning factor of these four types. The factors relating to slope and accompanying species are secondary and are represented in all the types and at all thresholds. In relation to the latter variable, the species and categories selected were monospecific ash forests; ash forests with *Quercus pyrenaica*; with *Quercus ilex subsp. ballota*; with different types of scrubland and with a mixture of different deciduous species. As can be observed in **Table 1**, the mixed formation of *Fraxinus angustifolia* and other deciduous species is almost insignificant in

[2] There is a discrepancy between the total area considered as ash forest and the area of variables associated with ownership (2924.69 ha) due to the inclusion of some ash forests situated outside what is considered as "Forestland" on the Madrid Regional Govt. Map of Forestland (municipal green spaces, on occasions considered as urban land, etc.).

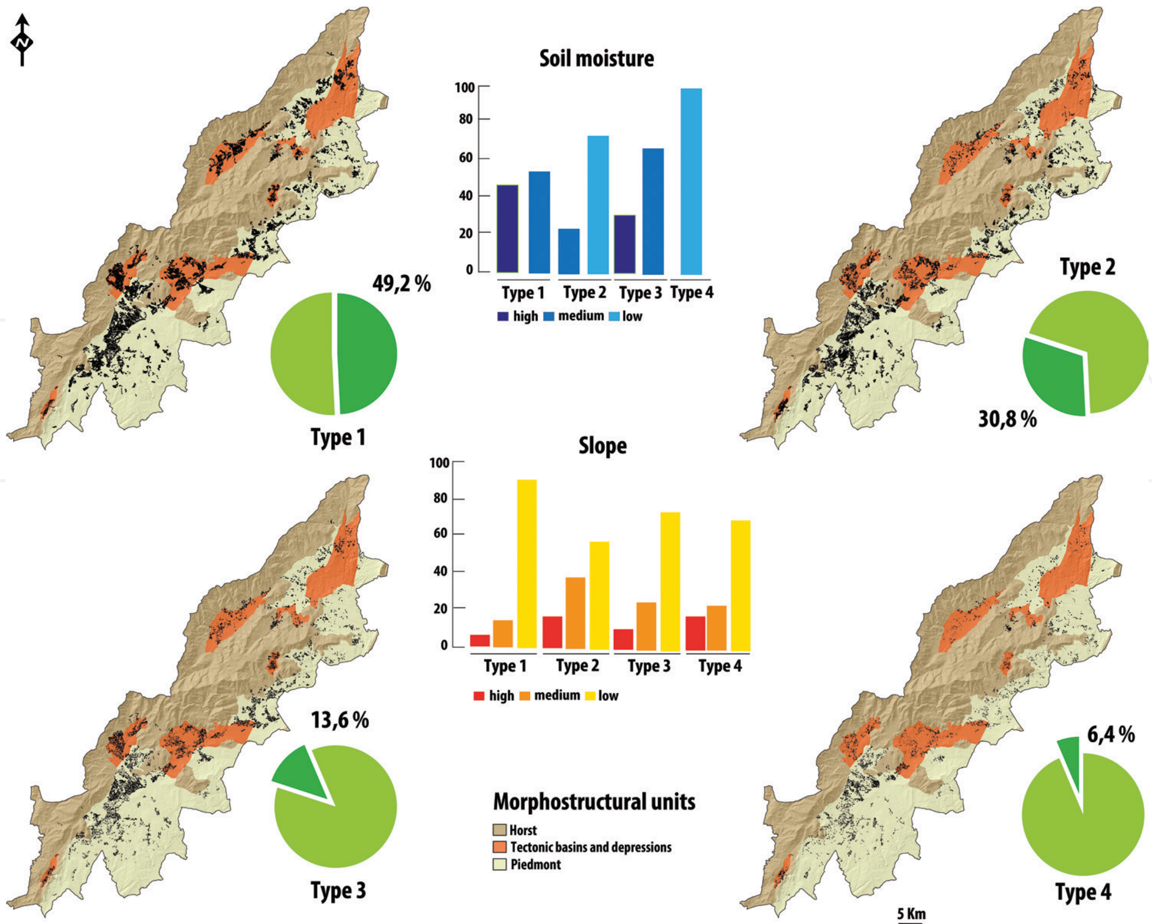

Figure 3.
Types of Fraxinus angustifolia forests.

the four types obtained, ranging from 0.56 to 0.77% (155,59 ha). The facies of *Fraxinus angustifolia* with scrubland is an indicator of the possible process of abandonment of these formations in the study area. The most habitual species involves dense thorny thickets of blackberry (*Rubus ulmifolius*), hawthorn (*Crataegus monogyna*), and wild rose (*Rosa* ssp.). The percentages are very similar in the four types obtained, ranging from 9.48 to 10.67% (a total of almost 2000 ha). Therefore, the most characteristic accompanying species involves *Quercus ilex subsp. ballota* and *Quercus pyrenaica*, which would appear to indicate transitions toward different bioclimatic belts. The presence of *Quercus ilex subsp. ballota* accompanying *Fraxinus angustifolia* is associated with the upper horizons of the Mesomediterranean and the lower horizons of the Supramediterranean, with more xeric edaphic conditions. Specifically, this formation appears in over 3195 ha and has its maximum representation in type 2 (20.03%). The main plurispecific formation therefore involves *Fraxinus angustifolia* accompanied by *Quercus pyrenaica*. In this case, it is associated with the Supramediterranean belt, with soils exhibiting a higher level of surface moisture. This formation occupies over 6400 ha, and type one concentrates over half, representing 32.48% of the area. *Fraxinus angustifolia* disappears when conditions relating to stoniness, xericity, and thermicity become more favourable to *Quercus pyrenaica* with increased altitude.

The various different types of *Fraxinus angustifolia* forests are described below. The extension and main characteristics are mentioned for each typology.

Type 1. These are mainly monospecific formations occasionally sharing the forest cover with *Quercus pyrenaica*. They are located on flat topographies, gentle and

		ha	%	ha	%	ha	%		ha	%	ha	%	ha	%
		1	1	2	2	3	3		1	1	2	2	3	3
Type 1 (10135.39 ha - 49.22%)	**Moisture**			**5645.06**	**55.7**	**4490.33**	**44.3**	**Type 2 (6340.89 ha - 30.79%)**	**4792.72**	**75.58**	**1548.17**	**24.42**		
	fa+qi			1225.61	12.09	129.54	1.28		998.86	15.75	270.91	4.27		
	fa+scr			514.81	5.08	446.09	4.4		462.14	7.29	140	2.21		
	fa+qp			1098.1	10.83	2193.67	21.64		1438.98	22.69	539.2	8.5		
	fa+od			10.87	0.11	67.2	0.66		41.86	0.66	7.07	0.11		
	fa			2795.67	27.58	1653.83	16.32		1850.89	29.19	590.99	9.32		
	Slope	**8779.95**	**86.63**	**984.89**	**9.72**	**370.56**	**3.66**		**3344.01**	**52.74**	**2237.6**	**35.29**	**759.28**	**11.97**
	fa+qi	1338.38	13.21	14.14	0.14	2.63	0.03		683.65	10.78	473.49	7.47	112.63	1.78
	fa+scr	866.44	8.55	69.31	0.68	25.14	0.25		290.54	4.58	207.9	3.28	103.7	1.64
	fa+qp	2486.65	24.53	586.31	5.78	218.81	2.16		819.65	12.93	795.67	12.55	362.86	5.72
	fa+od	51.02	0.5	16.42	0.16	10.63	0.1		17.52	0.28	23.06	0.36	8.34	0.13
	fa	4037.45	39.84	298.71	2.95	113.34	1.12		1532.64	24.17	737.49	11.63	171.74	2.71
Type 3 (2795.96 ha - 13.58%)	**Moisture**			**1885.76**	**67.45**	**906.56**	**32.42**	**Type 4 (1318.55 ha - 6.4%)**	**1318.55**	**100**	**0**		**0**	
	fa+qi			314.02	11.23	25.3	0.9		232.15	17.61				
	fa+scr			172.52	6.17	106.67	3.82		140.73	10.67				
	fa+qp			366.66	13.11	453.14	16.21		323.11	24.51				
	fa+od			3.45	0.12	17.78	0.64		7.36	0.56				
	fa			1029.1	36.81	307.3	10.99		615.19	46.66				
	Slope	**1874.67**	**67.05**	**650.06**	**23.25**	**271.23**	**9.7**		**867.14**	**65.76**	**266.56**	**20.22**	**184.85**	**14.02**
	fa+qi	252.07	9.02	67.47	2.41	19.79	0.71		148.73	11.28	50.38	3.82	33.04	2.51
	fa+scr	210.72	7.54	49.9	1.78	18.57	0.66		81.85	6.21	26.18	1.99	32.71	2.48
	fa+qp	424.72	15.19	260.45	9.32	134.63	4.82		136.99	10.39	96.3	7.3	89.83	6.81
	fa+od	13.05	0.47	4.25	0.15	3.93	0.14		3.2	0.24	2.66	0.2	1.51	0.11
	fa	974.11	34.84	267.99	9.58	94.31	3.37		496.38	37.65	91.05	6.91	27.77	2.11

Moisture	1: low; 2: medium; 3: high	
Slope	1: <5%; 2: 5-10%; 3: >10%	
Accompanying species	fa+qi	*Fraxinus angustifolia* + *Quercus ilex* subsp. *ballota*
	fa+scr	*Fraxinus angustifolia* + scrubland
	fa+qp	*Fraxinus angustifolia* + *Quercus pyrenaica*
	fa+od	*Fraxinus angustifolia* + other deciduous
	fa	*Fraxinus angustifolia* (monospecific ash forests)

Table 1.
Types of ash forests according to moisture, slope and accompanying species.

very gentle slopes (<5^0), fundamentally in depressed areas. A total of 49.22% falls within this group (10135.39 ha).

Type 2. This type comprises formations always presenting low or medium moisture levels, with no moist ash forests. The principal accompanying species are *Quercus pyrenaica* and, to a lesser degree when the surface is very dry, *Quercus ilex subsp. ballota*. They are located on medium and gentle slopes (<5–10^0) and on depressed terrain. They occupy 30.79% (6340.89 ha).

Type 3. Comprises the semi-moist formations and, to a lesser extent, the moist ones. There are no ash forests with low surface moisture. Almost 50% are monospecific and are situated on medium and gentle slopes. A total of 13.58% of the ash forests fall within this type (2795.96 ha).

Type 4. Comprises the dry monospecific ash forests on dry flat and sloping topographies. Only 6.4% falls within this category (1318.55 ha).

The definition of the typologies reveals the localised nature of the ash forests. As shown by **Figure 3**, the distribution of the different types in the territory studied does not clearly respond to patterns of geographic distribution because the variables influencing their localisation are present in most of the study area. For this reason, they intersected with the large morphostructural groups of the Guadarrama range. Results show that 61.09% (12,579.72 ha) of the ash forests lie on piedmont, 31.72% (6531.88 ha) on tectonic basins and depressions, and 7.18% (1479.20 ha) upon horst and its gentle slopes. We now indicate the main features of the morphostructures and the percentage distribution in hectares of each typology of ash forest in relation to the total area occupied by ash forests.

4.2.1 Piedmont

In these spaces, the predominant landscape exhibits a gentle slope, with visual basins opening up toward the Tagus or Torrelaguna river basins, with the Guadarrama mountains forming a backdrop.

At the foot of Guadarrama's main reliefs lies large areas gently sloping towards the Tagus River Basin or smaller areas sloping towards interior basins such as that of Buitrago (**Figures 4** and **5**). Their morphology generally presents broad ramps that gradually disappear, sinking below marls and gypsum formations. The readjustment tectonics have determined the current configuration and layout, favouring the entrenchment of the rivers and their entombment in the more fractured areas.

Type 1 is most relevant in the piedmont: 28.87% (5943.64 ha). Its most representative elements are located in the granitic piedmont of El Escorial-Alpedrete-Guadarrama (south-western sector). In these areas, fracturing has favoured the presence of depressed sectors of different sizes where accumulation of surface and hypogeous water is relatively common. The micro-topographical conditions, particularly on the rockier piedmont, give rise to different transition facies in which the remaining minority types are included. Type 2 (20.17%, 4153.71 ha) is associated with granite rocks or more continuous outcrops. In certain discharge sectors, type 3 (7.97%, 1641.23 ha) is associated with local fractures or surface runoffs and type 4 (4.09%, 841.14 ha) colonises marginal sectors on gentle slopes or structural thresholds.

As for ownership, in this context, the large estates (generally rare), together with the small- and medium-sized ones, play a vital role.

4.2.2 Tectonic basins and depressions

This landscape presents a combination of large tectonic basins between mountains, such as the Lozoya Valley, together with small depressions, presenting rounder forms and alveolar weathering basins. In both cases, the landscapes are closed, exhibiting compartmentalised configurations, as well as a strong identity.

Tectonics plays a fundamental role in this unit (**Figures 6** and **7**). The graben is characterised by constituting large sectors with irregular morphology, delimited by a well-defined tectonic scheme along all its margins. They are mostly

Figure 4.
Panoramic view of the El Escorial piedmont.

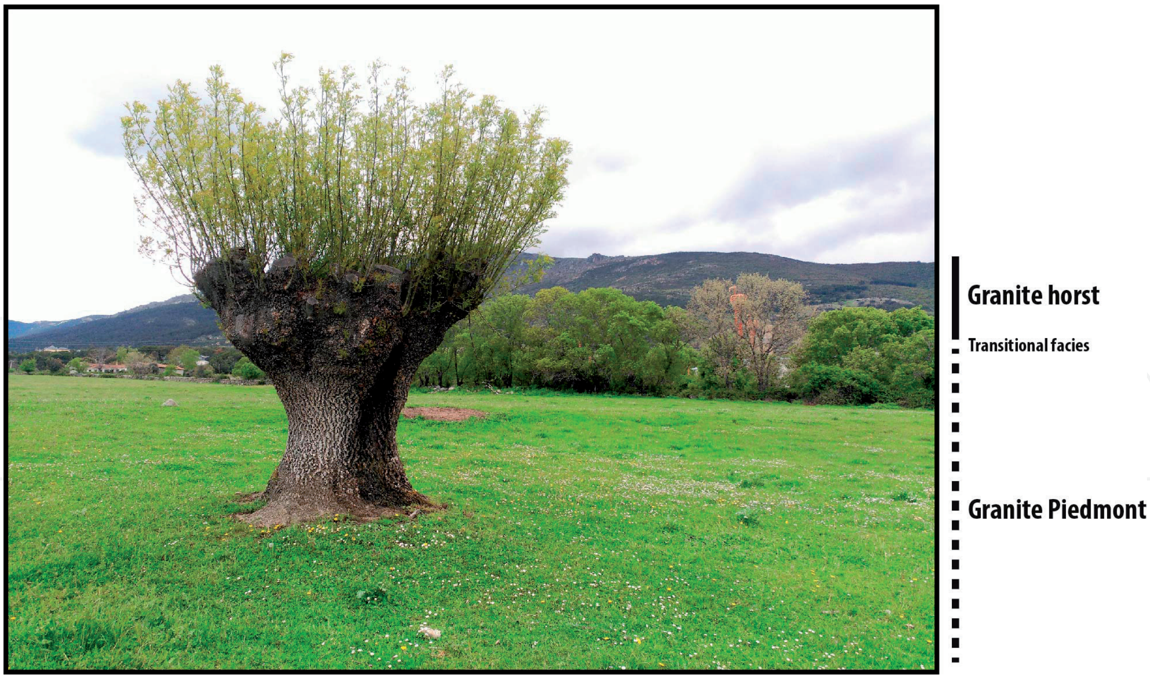

Figure 5.
Pollarded specimen in the El Escorial piedmont.

Figure 6.
An example of depression (arroyo del Valle, Bustarviejo).

Figure 7.
Group of pollarded trees (Valle del Lozoya).

situated at the foot of large horst. In the case of the depressions, the configuration adheres to fractures, presenting a certain degree of linearity and river valleys well-defined at one end (i.e., Robledo de Chavela, Manzanares el Real). It is often difficult to differentiate between types, as they can display mixed morphostructures.

Within this morphostructural unit, type 1 constitutes the most dominant one in the flatter sectors (17.52%, 3606.58 ha). Characteristic examples are the central sector of the Lozoya Valley or the depressions in the form of large alveolar weathering basins, like the arroyo of the Bustarviejo Valley. Type 2 is localised in the marginal areas in the rock fields in interior of the unit (7.97%, 1641.35 ha). Lastly, types 3 and 4 are hardly represented herein (4.46%, 918, ha and 1.78%, 365.95 ha, respectively) and are situated in marginal sectors coming into contact with the gently sloping horst.

4.2.3 Horst

They constitute the nucleus of Guadarrama's summits and slopes (**Figures 8** and **9**). Their current morphology derives from the effects of the postalpine tectonic readjustment that gave rise to a succession of horst at different levels. This unit extends from the summit erosion surfaces to where they come into contact with tectonic basins and depressions. Continuity is maintained along the axis Siete Picos-Carpetanos-Cuerda Larga, and marginal sectors are maintained in La Cabrera and in the displaced horst of Cerro de San Pedro.

Within this morphostructure, the ash forests are not very representative, appearing in the lower slope areas. Types 1 and 2 are the ones that occupy the largest area (2.84%, 585.18 ha and 2.65%, 545.82 ha, respectively). They are represented by formaciones finícolas (peripheral formations, that is, ones living at the edge of their range) that become installed in the flat areas occurring on steep slopes (i.e., Canencia) or in arroyos with stepped slopes (i.e., La Acebeda, Miraflores, Navacerrada). The presence of types 3 and 4 is not significant, as they barely reach 1.69% of the total (348 ha).

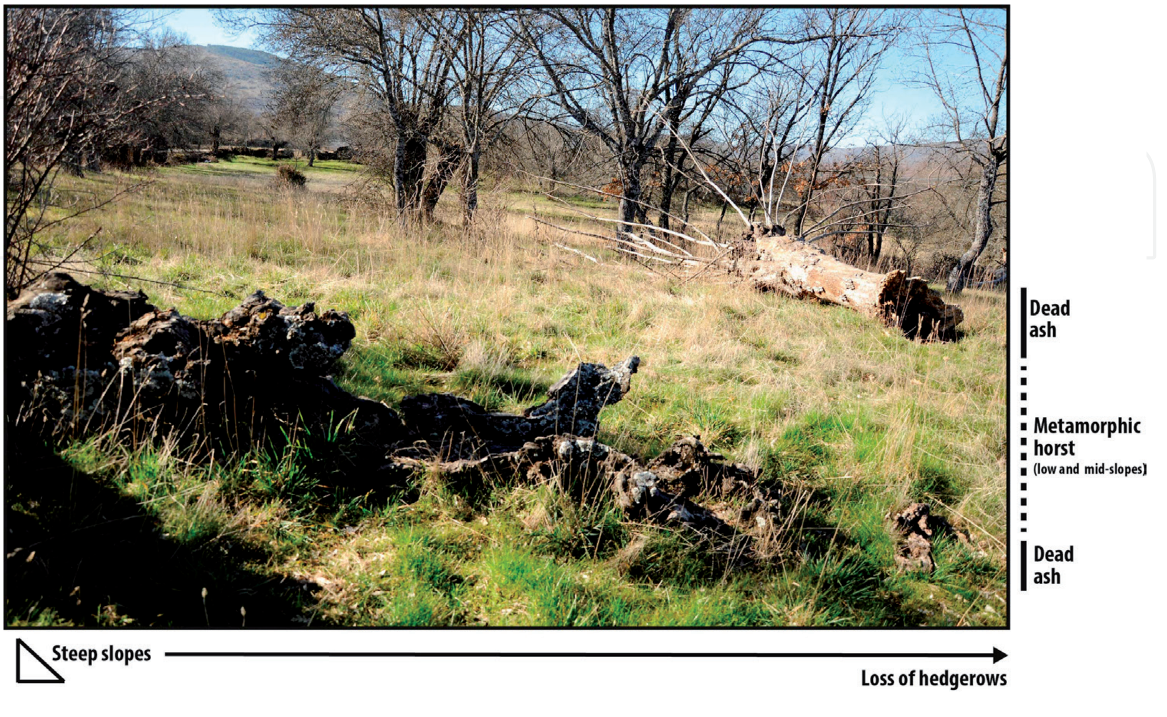

Figure 8.
Abandonment of hedgerows and dead ash tree (Canencia).

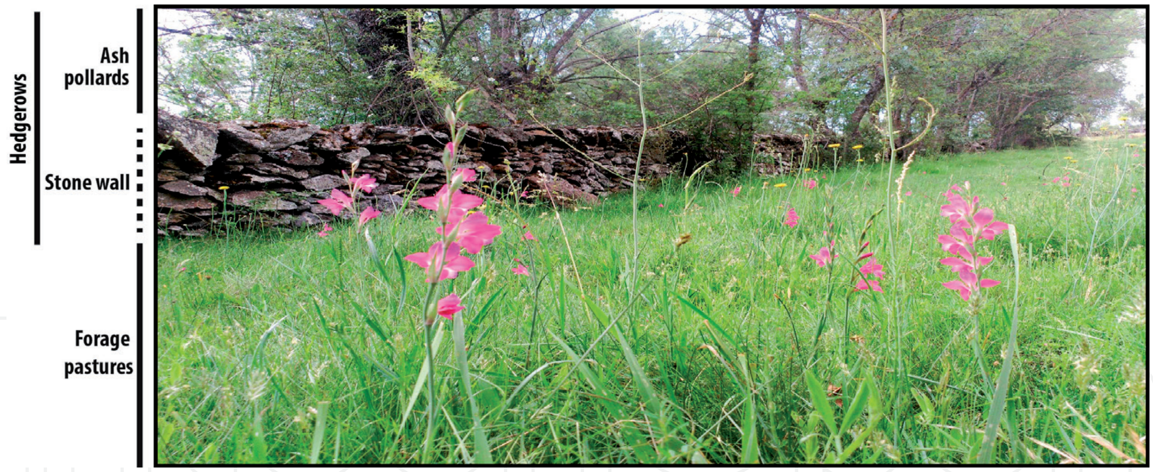

Figure 9.
Hedgerow and grazing pastures with Gladiolus communis (Lozoyuela).

	Values	Threats
Ecological and Biological	• High entomological biodiversity (saprophytes, lepidopters…) • Bird reserve • Well-conserved forest masses • Unique specimens	• Loss of entomological biodiversity associated with absence of livestock farming • Loss of traditional practices • Absence of pruning (hyper-development of crowns, risk of extreme climate phenomena, mortality…). • Intensification of, and changes in, production systems • Disappearance of stone walls • Closure of estates • Disappearance of pollarded ash trees due to the spread of urbanisation
Cultural and identity-related	• Livestock farming and pruning practices presenting a high ethnographic value • Robust identity and emotional link with these formations • Unique specimens	
Aesthetic and perceptive	• Patches of a certain extension in high-visibility environments (piedmonts and graben) • Intense annual phenological variety • Cultural image associated with artistic expression	
Productive	• Pastures with a high livestock-farming value • Estates and farms used for breeding fighting bulls. Use for firewood and timber • Apiculture • Tourism resource	
Historical	• Forms inherited from old byelaws • Conservation of stone walls and dry stone walls • Maintenance of common-use municipal estates • Presence of charcoal furnaces	

Table 2.
Values of, and threats facing, the ash forests in our study area.

4.3 Heritage values of the ash forests

Apart from characterising these ash forests, we also describe in depth the multiple values they present (**Table 2**). Among the most notable of these, habitually indicated, are the ecological and biological values, with emphasis upon the entomological biodiversity; the productive ones because, as a result of the secular livestock farming activity, the pasture formations present a high value. Moreover, cultural and identity-related values, referring to pruning practices that present a high ethnographic value, establish a close association with the resulting landscape. Finally, we describe the aesthetic-perceptive values and the historic values, both deep-rooted in the villages where these formations appear [11, 15, 17, 47, 48].

Of note is the value reached by some trees of *Fraxinus angustifolia*, not only as masses or formations but also as unique specimens due to certain features they display, such as longevity, shape, localisation, etc.

Finally, the biggest threats facing these forest landscapes refer to the disappearance thereof as a result of a radical change of uses, for example, urbanisation, with a change from rustic land to land zoned for development. Furthermore, other serious threats involve the disappearance of the key elements shaping this landscape, such as pruning, walls, enclosures, etc. We must also highlight changes in land uses, such as the intensification of livestock farming, which alters and depletes the floristic composition of pastures that are adapted to an extensive management regime involving livestock rotation.

5. Conclusions

The present study achieved its main objective: mapping, typifying and characterising the ash forest on the southern slopes of the Guadarrama mountains. From an historical perspective, they can be said to constitute formations shaped by secular uses of the canopy and of the land. As the formations were located in the areas closer to the villages, the Byelaws and Regional Codes of the *Comunidades de Villa y Tierra* (communities) or of the councils constituted an instrument for regulating uses. These regulations, which still exist in many cases, have been decisive with regard to shaping the current forest structure. Results show that the ash forests presenting the highest values due to their surface area or state of conservation are the ones located in the rocky piedmont and in the lower areas in tectonic basins and depressions. Nonetheless, it is their current localisation in the more accessible sectors that poses the main threat facing these agro-landscapes, as a result of urbanisation, with villages expected to grow in the future.

Another characteristic of these ash forests involves the traditional pollarding method, a land use described in the historical documentation from the end of the eleventh century. This practice constitutes one of the most significant identity-related values of traditional highland culture in Madrid's Guadarrama mountains. As a result of the notable changes that have taken place in these sectors, a process we have already described in previous studies [49, 50], they should be considered as endangered landscapes. A specific figure of protection should therefore be proposed for these forest formations (i.e., cultural landscape); this status should be reinforced through inclusion in the regional and local planning.

Additionally, results confirm that *Fraxinus angustifolia* depends strongly upon moisture and sub-surface water accumulation and, to a lesser degree, on slope. Within a scenario of higher temperatures, with less hydric availability and greater evapotranspiration [51], the presence of water proves to be determinant in relation to the vulnerability of this species in a future context of climate change. This fragility ought to constitute a priority line of future research, addressing the species within a broader framework as an indicator of change at regional level. In turn, there is a need for models and implementation strategies adapted to the new climatic scenarios; these should involve the collaboration and support of the different stakeholders.

In conclusion, there is a need to question the current state of affairs and to propose management criteria for Guadarrama's ash forests. The latest initiatives developed relating to pollarded ash forests (Seminars on pollarded ash forests organised by Madrid's Politécnica University in November 2017 and by the Autonoma University of Madrid in November 2018) have focussed on detecting the dynamics and threats involved and on putting forward proposals to promote future maintenance of these formations. These potential guidelines are based upon three axes: establishment of regulations on pruning methods by the regional administration involving the participation of all the stakeholders (especially in terms of the interaction between forest rangers and landowners); promotion of research and knowledge in order to provide better management and actions for dissemination, awareness, and revitalisation of pollarding and of pollarded forests.

Acknowledgements

This research was funded by the Madrid Regional Govt. via a call for environmental activities and projects (Order 3326/2017), through the Project "Mejora de la cartografía del Hábitat de Interés Comunitario 91B0 Bosques de Fresnedas de *Fraxinus angustifolia* y *Fraxinus ornus* en el territorio de la Comunidad de Madrid". ("Enhancement of the cartography pertaining to the Habitats of Community Interest 19B0 Ash Forests of *Fraxinus angustifolia* and *Fraxinus ornus*") within the territory of the Madrid Regional Autonomy".

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