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Monitoring Diversity Profiles of Forested Landscapes in the Mediterranean Spain: Their Contribution to Local and Regional Vascular Plant Diversity

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Abstract: Biodiversity monitoring is key for understanding the delivery of ecosystem functions and services. Mediterranean forests and woodlands harbor many characteristic species of the Mediterranean vascular flora, and hence, they are a good surrogate for detecting changes in biodiversity linked to global change. In this work, we present a database resulting from the study of vascular plant diversity in multi-scale plots of 0.1 ha, measured around the first decade of this century and located in Mediterranean forest environments. Diversity profiles are calculated from Hill numbers (0, 1 and 2) for local (α) and regional (Y) diversity, as well as a multiplicative calculation of differential diversity (β). The main Mediterranean forests sampled had a medium coverage of 51% and stand dominant height of 10.6 m, and they were monospecific in two-thirds of cases. Local diversity reaches its highest values (around 78 species per 0.1 ha) in Holm oak dehesas, with values below 50 species for the most productive forest stands dominated by species of the genus *Pinus*. As regards the contribution to regional diversity, broadleaf formations contribute the most, with stone pine forests and dehesas in an intermediate position, and pine forests contributing the lowest in species richness terms.

Keywords: typical and dominant species; coniferous and broadleaves tree species; forest management; hill numbers; local and regional richness



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1. Introduction

Biodiversity has long been considered integral to the sustainable development agenda [1], establishing its maintenance and/or improvement as a priority objective for reaching sustainable development “that meets the needs of the present while safeguarding Earth’s life-support system, on which the welfare of current and future generations depends” [2].

The measurement and monitoring of biodiversity at different scales is a seminal task for those involved in rural development [3], conservation planning [4] and evaluation of ecosystem services [5]. Biodiversity is a multidimensional term that involves not only genes, species and ecosystems [6] but also taxonomic, functional and phylogenetic approaches [7].

Biodiversity measurement is not as easy as it might seem, and although attempts to identify all the living beings that inhabit a certain ecosystem are not rare [8], it is more usual to focus on some surrogates or related ecosystem properties. Determining the taxonomic diversity of some well-known biological groups (plants, birds, bats, or butterflies) is one of these surrogates. Reiterative measures of biological diversity using a framework design [9] is necessary for understanding not only local but also regional biodiversity evolution and the main threats that affect it.

The measurement of biological diversity has been widely discussed in the literature and an almost endless number of indices and indicators have been proposed [10]. As diversity is a complex multidimensional property at any organizational level, viewing diversity through the lens of a single index is to project that multidimensional complexity onto a one-dimensional ordinal scale [11]. In this sense, an Ecology Forum [12] brought up the topic of the measurement of diversity. Almost all the authors in this Forum agreed upon using Hill numbers [13] or species equivalent numbers, instead of the classical diversity indices (entropies). The recent use of Hill numbers (qD) shows equivalences for $q = 0$, $q \rightarrow 1$, or $q = 2$ to classical species richness, the exponential of the Shannon index and the inverse of the Simpson concentration, respectively [14]. Having abundance data, the simultaneous use of these three indices, which take into account species richness, the typical species and the dominant species in each sample, enables us to build profiles of diversity that allow for a more accurate comparison between samples at different sites or samples taken on different dates. A diversity profile is a curve depicting the simultaneous values of a collection of diversity indices. Thus, the profile portrays the views of diversity from different vantage points simultaneously.

These diversity profiles can be applied to diversity at different scales from local or stand diversity (α diversity) to regional diversity (γ diversity) and to the differential diversity (β diversity), the latter being calculated either by additive or multiplicative methods. They are important tools for analyzing biogeographical regions and monitoring biodiversity in conservation plans [15,16].

The Mediterranean basin has been traditionally described as one of the hot spots for vascular plant species [17]. Mediterranean forest floras are richer than the contiguous temperate forest floras, not only in tree species but also in other forest species, as a result of the last glaciation, ancient and actual human land uses, and natural disturbance incidences [18]. Recently, scenarios of climatic change have had a medium to severe influence on Mediterranean species and ecosystems, deriving from the increase in temperatures and changes in the precipitation regime, including a reduction in the total rainfall and elongation of the dry season. The Iberian Peninsula is an important reservoir of European biodiversity [19] and is usually included in the “Mediterranean Region” hotspot of global biodiversity [20]. In this context, we propose in this study an overview and comparison of the diversity of forests in the Mediterranean, Spain, using surveys of vascular plants based on multi-scale plots carried out over a period of twelve years (2002–2013) and analyzing diversity profiles at the local and regional scale, considering the main dominant tree species on the stands. The data have been compiled from different projects and partly published in several papers [21–24].

The current work allows us to explore systematically the similarities and differences in diversity measures among forests that grow in different areas of the Mediterranean, Spain. First, this extensive dataset can be a valuable tool for long-term monitoring plans to check changes in the diversity of vascular plants at different scales and in relation to the evolution degree of the forest stands under the influence of global change. To this end, two data matrices were built, one with the name, location, and description of the sampled plots and another matrix with a species/inventory format, where the identified species and their quantification appeared in the 143 sampled plots.

Second, we aim to conduct the following:

- (1) To describe and to compare the diversity profiles of vascular plants at the stand level (α diversity) for the main Mediterranean forests in Peninsular Spain.

- (2) To assess what the contributions of different typologies of Mediterranean forests to the regional diversity (γ diversity) are.
- (3) To infer the levels of intra-dissimilarity in species composition of the different types of forests in Mediterranean Spain (β diversity).

2. Materials and Methods

2.1. Data Collection

We have surveyed vascular plant species in a total of 143 multi-scalar plots of 0.1 ha along the Mediterranean climatic zone of Peninsular Spain. The location of these plots is not due to random sampling or a stratified one, but it is the result of twelve years (2002–2013) of a homogeneous sampling strategy conducted by a group of researchers and collaborators in the context of different research projects. The plots sampled are shown in Figure 1.

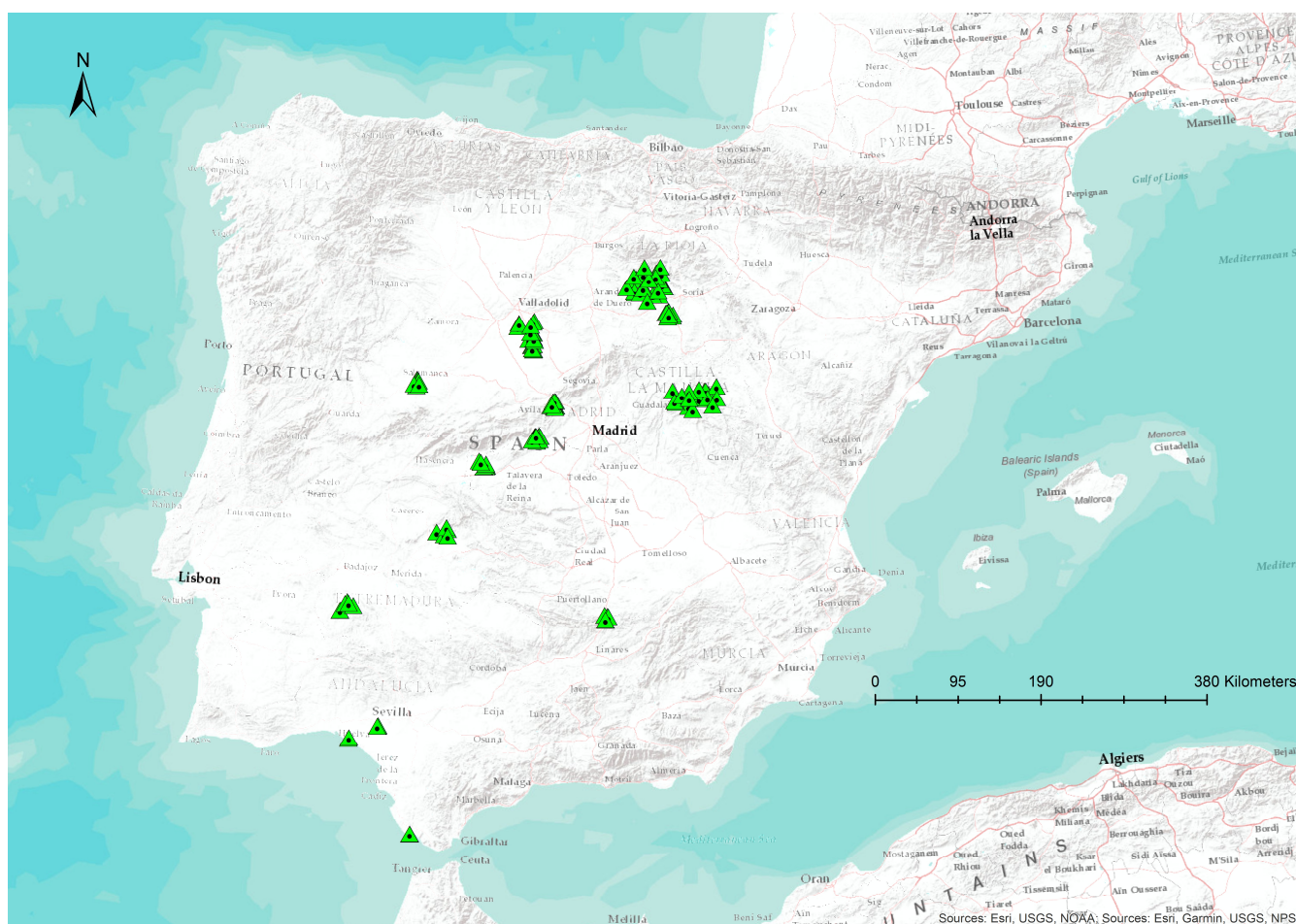


Figure 1. Location of 143 forests stands sampled during the 2002–2013 period.

The main plot variables recorded were the location (the X and Y coordinates of the upper right corner of each plot), canopy cover and dominant height of the plot, the average DBH—diameter at breast height of trees—the number and mean basal area of trees, forest typology, and the main and secondary (when it appeared) tree species. Then, the identification of vascular plant species was conducted at the species level following *Flora Iberica* [25] and *Anthos* (<http://www.anthos.es/> (accessed on 1 September 2024)). Species of doubtful determination were excluded from the database.

The presence and abundance of vascular plant species in each forest site were recorded in 1000 m² plots (50 m × 20 m), following Whittaker's multiscale plot design, modified by Stohlgren [26]. Detailed information of the plot design can be found in previous publications [18].

Plots were mainly located in the core ($n = 115$) of forested areas, at least 100 m away from the nearest forest edge, following the steepest slope to record major environmental variability but also in ecotones or forest edges ($n = 28$) for detecting species that frequently thrive in these local habitat conditions. Sampling within plots was nested as follows:

- (i) Ten subplots of $0.5 \text{ m} \times 2 \text{ m}$ (1 m^2) arranged equidistantly within the plot, with the outer border of each subplot lying on the perimeter of the plot. Within these subplots the abundance of herbaceous and woody plants was estimated according to 5 cover categories: (1) <5% of the total subplot area, (2) between 5% and 12%, (3) between 12.1% and 25%, (4) between 25.1% and 50% and (5) >50%.
- (ii) Two subplots of $2 \text{ m} \times 5 \text{ m}$ (10 m^2) in opposite corners of the plot, with their outer borders lying on the perimeter. Within these subplots, the abundance of woody species was estimated using the same categories of point (i).
- (iii) One subplot of $5 \text{ m} \times 20 \text{ m}$ (100 m^2) in the middle of the plot, without contact with any of the other subplots. Within this subplot, all tree individuals were measured (DBH and height) and the dominant height and dominant canopy cover were estimated.
- (iv) Finally, the complete plot, 1000 m^2 , was fully surveyed for species not found in the subplots of 1, 10 and 100 m^2 , and a minimum abundance rate was assigned to these species.

Fieldwork was carried out in late spring, May and June, which was considered the optimal phenological state for species identification in a unique visit per plot. Only one annual visit for sampling is a limiting factor for detecting all species growing throughout the year but not for the comparison between samples taken in the same way.

2.2. Data Analysis

Descriptive statistics and basic relationships between forest structural properties (EP) and diversity indexes were calculated on Statistica 6. Figure maps were made using ArcGis 10.8.

As diversity indices, we calculated diversity (qD) as effective number of species (qSp_E) following Hill [13], $q = 0$, $q \rightarrow 1$ and $q = 2$ (see Tuomisto [27] for details).

$${}^qD = \left(\sum_{i=1}^s p_i^q \right)^{1/(1-q)}$$

The parameter q defines the kind of used mean. Increasing the value of q gives more weight to the most abundant species and less weight to the rarest ones. 0D (diversity with $q = 0$) is based on the weighted harmonic of the p_i values and its numerical value is the same as that of the species richness (R). 1D is based on the geometric mean and equals the exponential of the Shannon entropy, and 2D is based on the arithmetic mean and equals the inverse of the Simpson concentration.

We calculated qD values for local diversity (α) and regional diversity (γ), aggregating different plots of the species/inventory's matrix using different parameters as follows:

- The location of the sampled plot (core or ecotone);
- The tree species composition of the canopy (monospecific or mixed canopy);
- The main tree species in the canopy.

EstimateS 9.1 software [28] was used for calculations of diversity at different aggregation levels. Species-sampled curve and richness estimators, Abundance-based Coverage Estimator—ACE—[29] and Chao 1 [30] were calculated as well. Finally, we calculated beta diversity using a multiplicative approach.

$${}^qD_\gamma = {}^qD_\alpha \times {}^qD_\beta$$

When ${}^qD_\gamma$ or gamma diversity is the total diversity found in the aggregation level of interest, this can be expressed as the mean effective density of species per effective com-

positional unit (${}^qD_\alpha$) multiplied by the number of effective compositional units obtained (${}^qD_\beta$).

3. Results

Data matrices ICIFOR_forest_sites_data and ICIFOR_forest_species_data, in XLSX format, are available in the following repository: <https://saco.csic.es/s/KXqbjxSrGRdENJX> (accessed on 1 September 2024).

The sampled forests included open woodland and dehesas and close canopy forests (averaged coverage $51.5 \pm 21.9\%$) with monospecific (100 plots) or mixed (43 plots) tree species canopies. The stand dominant height was on average 10.6 (± 4.6) m. In relation to the main tree species, in 80 cases, the dominant species belonged to the genus *Pinus* L., in 51 cases, it belonged to the genus *Quercus* L., and in the remaining 12 cases, it belonged to the another genus. Significant negative correlations were found between canopy coverage (Fcc) and dominant height (H_0) with α diversity indices (see Table 1) but not between other structural variables and local diversity.

Table 1. Statistics of lineal regression between ${}^qD_\alpha$ and two structural variables Fcc (canopy cover) and H_0 (dominant height).

Diversity Index	${}^qD_\alpha$	Coefficients	Typical Error	T Statistic	Probability	R	R ²
0D	Intercept	68.3178	4.5386	15.0525	0.0000	0.222	0.049
	Fcc	−0.2227	0.0824	−2.7030	0.0077		
1D	Intercept	21.6049	1.6435	13.1456	0.0000	0.423	0.179
	Fcc	−0.1652	0.0298	−5.5377	0.0000		
2D	Intercept	12.9140	1.0515	12.2815	0.0000	0.419	0.175
	Fcc	−0.1045	0.0191	−5.4730	0.0000		
0D	Intercept	73.8569	4.4551	16.5782	0.0000	0.326	0.106
	H_0	−1.6299	0.3980	−4.0956	0.0001		
1D	Intercept	19.9343	1.7309	11.5167	0.0000	0.333	0.111
	H_0	−0.6494	0.1546	−4.2001	0.0000		
2D	Intercept	11.4216	1.1196	10.2016	0.0000	0.296	0.089
	H_0	−0.3684	0.1000	−3.6836	0.0003		

Diversity at local and regional scale.

The averaged local richness of species per plot (${}^0D_\alpha$) was 57.03 ± 21.6 . The total number of species (0DY) detected in 143 plots was 1019 (28 were finally rejected because they were not determined at the species level), with an accumulated mean coverage per plot of 105.93% and standard deviation of 45.7%. The expected 0DY calculated by the ACE was 1111, and that calculated by Chao1 was 1199 species. The number of species found accounted for over 15% of Spanish vascular flora and near 25% of Peninsular Spain vascular flora [31].

The data of the Hill numbers ($D = 0, 1$ or 2) for alpha or local diversity at different aggregation levels of plots, following structural or compositional criteria, are shown in Table 2. The tree species considered were as follows: *Pinus halepensis* Mill. (d1, e1, f2), *Pinus nigra* subsp. *salzmannii* (Dunal) Franco (d1, e2, f4) *Pinus pinaster* Aiton (d1, e1, f1), *Pinus pinea* L. (d1, e1, f2), *Pinus sylvestris* L. (d1, e2, f3), *Pinus uncinata* Ramond ex DC. (d1, e2, f3), *Quercus faginea* Lam. (d2, e4, f7), *Quercus ilex* L. (d2, e3, f5, f6), *Quercus petraea* (Matt.) Liebl. (d2, e4, f7), *Quercus pyrenaica* Willd. (d2, e4, f7), *Quercus suber* L. (d2, e4, f7), *Fagus sylvatica* L. (d3, e5, f8), *Castanea sativa* Mill. (d3, e5, f8), *Fraxinus angustifolia* Vahl (d3, e5, f8), *Juniperus oxycedrus* L. (d3, e5, f8), *Juniperus thurifera* L. (d3, e5, f8), *Arbutus unedo* L. (d3, e5, f8), *Eucalyptus camaldulensis* Dehnh (d3, e5, f8), and *Ilex aquifolium* L. (d3, e5, f8).

Table 2. Species richness (${}^0D_\alpha$), typical species (${}^1D_\alpha$) and dominant species (${}^2D_\alpha$), at the plot level, grouped by different criteria. Standard error in brackets. The variable Agr expresses the level of aggregation (initial letter) and the significance of the comparison between the means (same number for members of the same group).

	Agr	n_Plots	${}^0D_\alpha$	${}^1D_\alpha$	${}^2D_\alpha$
All plots	a	143	57.03 (21.7)	13.23 (8.4)	7.62 (5.4)
Core plots	b1	115	55.14 (21.1)	12.05 (7.4)	6.87 (4.6)
Ecotone plots	b2	28	64.79 (22.7)	18.05 (10.5)	10.69 (7.1)
Monoespecific plots	c1	91	55.76 (21.3)	12.86 (8.6)	7.35 (5.6)
Mixed plots	c2	52	59.25 (22.3)	13.87 (8.3)	8.08 (5.0)
<i>Pinus</i> spp.	d1	80	47.39 (18.2)	10.60 (7.0)	6.37(5.1)
<i>Quercus</i> spp.	d2	51	70.18 (18.5)	17.22 (8.8)	9.54 (5.3)
Other species	d3	12	65.40 (24.3)	18.80 (9.6)	7.72 (5.6)
Mediterranean pines	e1	51	47.84 (18.9)	11.34 (7.7)	6.82 (5.6)
Mountain pines	e2	29	46.59 (17.3)	9.30 (5.5)	6.15 (4.06)
<i>Quercus ilex</i>	e3	35	72.17 (18.6)	18.86 (8.9)	10.52 (5.5)
Other <i>Quercus</i> spp.	e4	16	65.81 (18.0)	13.62 (7.6)	7.40 (4.3)
Other species	e5	12	65.40 (24.3)	18.80 (9.6)	7.72 (5.6)
<i>Pinus pinaster</i>	f1	25	45.33 (17.4)	8.05 (3.6)	4.62 (1.9)
<i>Pinus pinea</i> ^	f2	26	51.27 (19.9)	14.07 (9.1)	9.04 (6.9)
<i>Pinus sylvestris</i> *	f3	19	45.37 (20.2)	9.24 (6.4)	5.61 (5.1)
<i>Pinus nigra</i>	f4	10	48.90 (10.2)	9.41 (3.6)	5.55 (2.0)
<i>Quercus ilex</i> dehesas	f5	12	77.83 (15.0)	23.83 (7.4)	13.92 (5.0)
<i>Quercus ilex</i> forests	f6	23	69.22 (19.8)	16.27 (8.7)	8.75 (4.9)
Other <i>Quercus</i> spp.	f7	16	65.81 (18.0)	13.62 (7.6)	7.40 (4.3)
Other species	f8	12	65.40 (24.3)	18.80 (9.6)	7.72 (5.6)

^ Includes two plots dominated by *Pinus halepensis*. * Includes one plot dominated by *Pinus uncinata*.

Along with the expected differences for all indices between core plots and ecotone plots (b level), a significant difference was observed between the plots dominated by *Pinus* spp. and the rest of the species—*Quercus* spp. and other species—(d level). The aggregation between pine species due to their main location in Mediterranean mountain habitats (*P. sylvestris*, *P. nigra* and *P. uncinata*) and more typically Mediterranean habitats (*P. halepensis*, *P. pinea* and *P. pinaster*) did not show significant differences. In the last level of aggregation, the plots dominated by *P. pinea* were significantly more diverse (the pine group), and the dehesas dominated by *Q. ilex* were in turn more diverse at the aggregation level where the rest of the species were grouped.

The contribution of the different forest plots aggregated based on the main species showed three groups (Figure 2a) in terms of the regional richness of species (0Y). Similar results appeared when the analysis was limited to the grouping with the lowest number of samples applying rarefaction (Figure 2b). The accumulation curves showed greater gamma

diversity for *Q. ilex* forests, Other *Quercus* spp., and the group called Other species (upper zone). The lower area of the figure gathers the curves of most of the pine species, reaching the lowest values of regional diversity. Finally, the accumulation curves for the *Q. ilex* dehesas and the *P. pinea* formations showed intermediate gamma diversity.

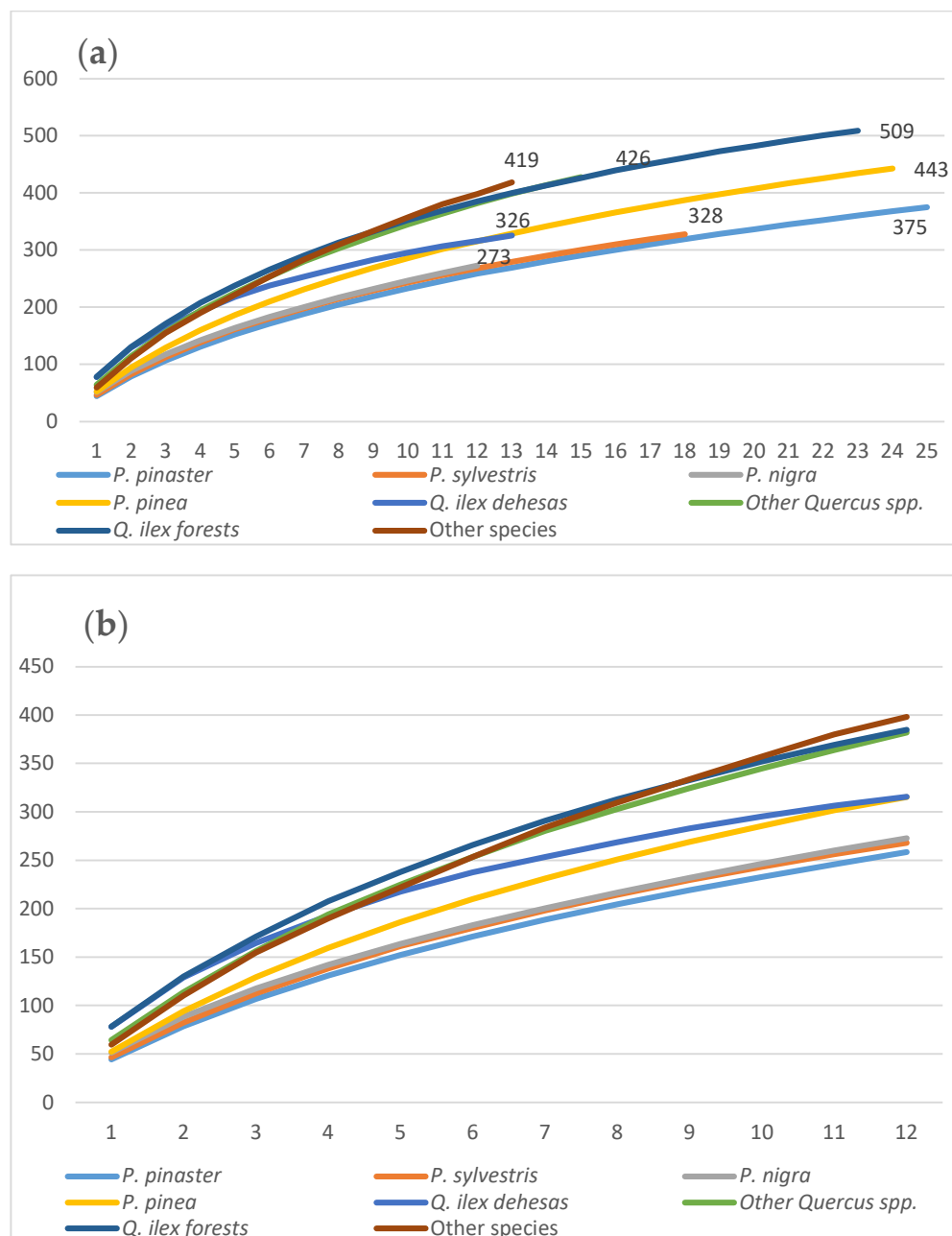


Figure 2. Accumulation curves for species richness (${}^0D_\gamma$) for groups considering main tree species (X axis number of plots, Y axis number of species). (a) All samples with the gamma value superimposed by group (the numbers at the end of each curve are the values of the accumulated richness for each formation); (b) 12 samples' rarefaction by groups.

Heterogeneity inside Groups

The beta diversity profiles (ratio between regional diversity and local average diversity) for the three calculated indices showed that the most heterogeneous groups for every index are those formed by "Other species" and *Other Quercus* spp., followed by *P. pinea* pine forests (Figure 3). It can be interpreted that both the species in the pool that constitutes the

richness and the typical and dominant species are quite different between some samples and others, which corresponds to assemblages dominated by different tree species growing in different habitats. It is also remarkable that the beta diversity profile of the Holm oak dehesas, being the lowest in species richness (${}^0D_\beta$), exceeded the values of typical species and dominant species in pine forests. Finally, *P. sylvestris* forests were shown to be the most homogeneous, with a reduced number of typical species and dominant ones in relation to the rest of the forests studied.

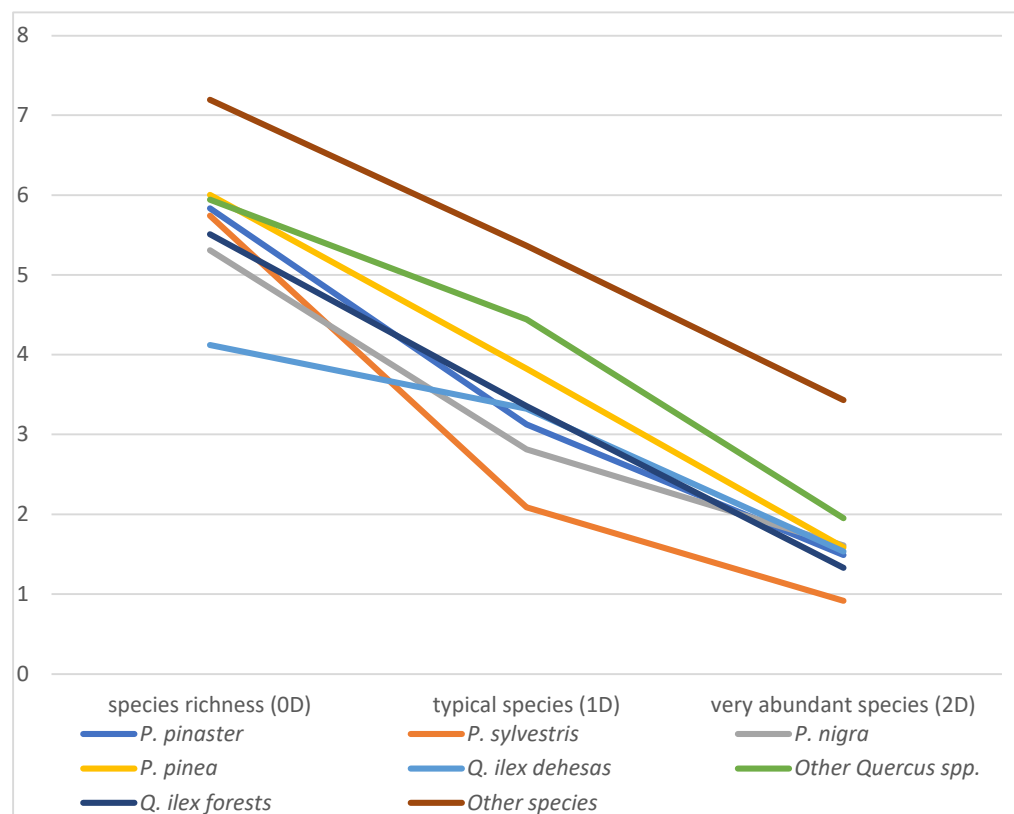


Figure 3. Diversity profiles for multiplicative beta diversity (${}^qD_\beta$) grouped by main species using rarefaction data (12 samples per group). (X axis Hill numbers (0, 1, 2), Y axis multiplicative beta diversity value).

4. Discussion

We analyzed the local and regional vascular plant diversity for different forests and woodlands in Peninsular Mediterranean Spain surveying 143 0.1 ha multiscale plots throughout the first decade of the 21st century. In general, stands dominated by pine species presented lower diversity for their “Hill numbers” (richness, typical species and dominant species), both at a local and regional scale, than those dominated by *Quercus* spp. and other tree species. We also confirmed that two stand variables were negatively related with diversity scores, namely canopy cover and the dominant height of the main tree species.

Mediterranean environments are characterized by low potential forest productivity [32], caused mainly by a short vegetative period (due to cold winters and summer droughts). In these circumstances, forests and woodlands have more frequently delivered protective functions rather than productive ones, relegating wood production to a secondary place in many cases and promoting other non-wood products such as acorns and pastures in the dehesas [33], pine seeds in the *P. pinea* open forest [34] or resin in *P. pinaster* forests [20]. These environmental and management restrictions have promoted monospecific canopies, with structural diversity directly related to their use or alternatively its abandonment degree [35].

Diversity at Local and Regional Scale

Although local diversity values for this type of sampling have certain limitations for comparison (e.g., single sampling or several occasions of resampling in a year in the same plot), some references can be useful to locate the relative value of our measurements. For Mediterranean environments, the highest values of local richness that we found in the literature occurred in pastures and dehesa systems. Díaz [36] cited values of 179 species per 0.1 ha in Monte Gilboa (Israel) [37] and 135 in Sierra Morena (Spain) [38]. Other authors [39] measured richness in other Mediterranean habitats of the Aljibe Mountains (Spain), obtaining values between 50 species per 0.1 ha (*Quercus coccifera* Shrublands) and 95 (*Quercus suber* woodland). They also collected data in other Mediterranean environments throughout the globe, with average values close to 40 species per 0.1 ha in California and France and slightly above 80 in Israel [40] and Spain. Obviously, these values were highly dependent on the studied habitats, their location in the territory and the number of plots analyzed. That is why our research provides valuable data for different habitats with a significant number of surveys.

We observed significant differences between core habitats and ecotones both for species richness and for typical and dominant species. This fact has already been highlighted in a previous publication [18] where the species density, percentage of unique species, and alpha diversity per plot were significantly higher ($p < 0.05$) in linear elements (ecotones) than in core habitats. Other authors in different environments [41,42] documented high diversity in ecotones, although other investigations [43,44] did not detect significant differences at the local level (core–ecotone–core transects).

Referring to the dominance trees of the canopy, there is a clear tendency towards monospecific stands (almost two out of three). Either this may occur due to the non-natural origin of some stands, i.e., plantations that were thoroughly conducted from the middle of the previous century [45], or due to the management legacy where single species stands have been traditionally prioritized [46]. In any case, we found no significant differences in diversity indices between sites dominated by single or multiple species at the local level or at the regional one. There was only a slight difference in species richness in favor of mixed stands (local 59.3 versus 55.8 and regional 674.4 versus 648.8 for rarefied data), but this lacked statistical significance.

We found the greatest difference between pine forests and the rest of the formations (dominated by *Quercus* spp. or by other species) when diversity based on the dominant type of tree species was considered. Pine stands had significant lower values for richness and typical species. This fact is well known for forests in temperate and boreal climates [47], but in Mediterranean landscapes, other factors may be involved, like the interval from the last disturbance and the phase within the forest succession [48,49]. For these authors, the existence and abundance of plants considered non-strictly forest-related are the differential fact of every forest with higher richness figures. Therefore, they consider that a structural state closer to maturity leads to a lower total number of species, which are mainly considered forest specialists. Regardless of the management circumstances, the sampled pine forests host fewer non-forest species due to their great dominant height and extensive canopy cover than forests dominated by other species (except for *Fagus sylvatica* stands).

Our sampling of vascular plant forest diversity has highlighted the extensive presence of pine forests in Mediterranean environments in Peninsular Spain. Although the contribution of pine forests to local and regional diversity is lower than that found in other forest species, many of these pine forests are located at the so-called forest limits, either due to the high altitude in the Mediterranean mountains or degraded/unfavorable areas, in which other species hardly thrive. In these cases, the forest canopy provides local conditions that in turn favor the development of other woody and herbaceous species, leading to a secondary succession that prevents land degradation and extreme conditions that are occurring more frequently due to global change. With respect to the other forest species, those of the *Quercus* genus are the most widely dominant. These species are found in an extensive environmental range, where altitude and summer rainfall determine their

dominance and development, as well as ancient and recent management. Their remarkable contribution to local and regional vascular plant diversity is essential for maintaining sustainable Mediterranean landscapes. In this way, the abandonment of traditional uses can provoke a state of threat in relation to fires, changes in land use or extreme meteorological events, which would lead to a significant loss of diversity, with the replacement of forest structures by scrubland and other stages of vegetation degradation.

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