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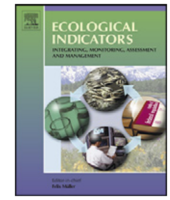

Short Communication

Indicator species of broad-leaved oak forests in the eastern Iberian Peninsula

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ABSTRACT

The degraded state, scattered distribution and substrate type of *Quercus pyrenaica* forests in eastern Spain make them a subject of particular interest, as well as a priority for conservation efforts. An extension of Dufrêne and Legendre's indicator value (IndVal) analysis was applied to one hundred relevés. This extension of the IndVal method allowed us, by considering the preference of species for combinations of relevé groups, to obtain those species that represent local, but also regional, characteristics (as a new practical use). Our objective was to identify the species that best indicate the main ecological features of these broad-leaved oak forests. The usefulness of our analysis was evidenced at two levels: local indicator species, showing the characteristic species of individual sites and including the presence of endemics in the area; and indicator species of combinations of two or more sites, reflecting the affinities or relationships between these scattered forests.

Most singular forests showed a higher number of local indicator species. The indicator species of each site combination represent the main ecological traits shared by these groups – such as proximity to the coast, land uses or postglacial migration pathways – thereby defining their relationships. Indicator value analysis with site group combinations (*Multipatt* function) proved to be a useful tool for the identification of different species that could serve both to determine the local forest conservation status and aid in its preservation, as well as contributing to an understanding of the life history of larger territories.

1. Introduction

The *Quercus pyrenaica* forests in eastern Spain are remnants of the broad masses that occupied the peninsula in cooler eras and are now found predominantly in the northwest. These forests are therefore unique examples of sub-Mediterranean broad-leaved forests in this area, with an additional special feature: their substrate, which comprises Buntsandstein sandstones and rodenas surrounded by limestone. This uniqueness makes them prime targets for conservation. In many cases, habitat fragmentation has gradually reduced the quality and extent of these scattered forests, mainly due to grazing and felling for charcoal manufacture or to favour other forest species such as pine (Calvo et al., 1999). The impact of these disturbances in eastern Spain has been particularly severe, as forest regeneration is not straightforward in this area (Pulido, 2002). Thus there is an urgent need for prompt action to understand their main ecological traits, together with the species range that best defines their particularities. Indicator forest species take on key interest when discussing the conservation status of forests, since they reflect their life history (MacNally and Fleishman, 2004). The close relation they show with the different aspects of the habitat makes them useful tools for a range of purposes, since they can be used as indicators of diversity, richness, and disturbance (McGeoch, 1998).

Today, there is an even greater need in both conservation and management for detailed knowledge of key species and their autecology (Rubio et al., 2011). According to Grumbine (1994), three of the main goals in ecosystem conservation and management are the maintenance of native species, the protection of representative examples of native ecosystems, and the adaptation of human activities to these principles. The identification of native species and ecosystems, community types and traditional land uses therefore becomes an issue of vital importance for the preservation of an ecosystem, especially when communities are isolated from each other and surrounded by a more or less hostile environment. In this regard, Dufrêne and Legendre (1997) developed a methodology to identify indicator species, assuming that for a species to be an appropriate indicator of a given target type (e.g. a habitat type, environmental state or a community type), most of its occurrences should be concentrated in the target type, as well as being present with a certain frequency. The aim of the present study was to determine a set of species that best indicated the different environmental influences or features of the ecological mosaic of territories, such as land use, scattered distribution, altitude or substrate type. Since we needed a method that made it possible to obtain this wide range of information, we chose a recent modification of Dufrêne and

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Legendre indicator species analysis (De Cáceres et al., 2010). This modification allows the determination – by analysing each site separately as well as in combination – of a set of both local and shared floristic indicators. The specific questions we addressed were: What are the indicator species of these *Q. pyrenaica* forests? What do they indicate? Which of them are common species to these scattered forests? As original *Q. pyrenaica* forests are described growing on purely siliceous soils, could this tool find species that indicate changes in substrate type?

2. Materials and methods

2.1. Study area and data gathering

We focused our study on the *Q. pyrenaica* forests in the eastern Iberian Peninsula (see Appendix), and collected 100 floristic relevés (i.e. the list of species, along with an estimate of their cover values, found within an explicit plot, which in these forests is usually above 100 m^2) (Braun-Blanquet, 1932). Relevé data are normally presented in a relevé-by-species matrix, which we summarize in Table 1. Located at altitudes of between 950 and 1700 m, these oak forests persist in three different mountain ranges (see Appendix): the pre-coastal ranges of Sierra de Espadán (1) and Sierra de Prades (2), and the inner Sistema Ibérico range (including 4 localities: Penyagolosa (3), Albarracín (4) and Cuenca (5) (Boniches and Ranera) massifs. Each locality (site) is therefore represented by a group of relevés (Table 1).

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Although soils in the eastern part of the Iberian Peninsula are predominantly calcareous, our forests are mainly located on sites with a special kind of siliceous soil known as Triassic rodenas (Buntsandstein sandstones and argillites). As some influence of surrounding calcareous soils can be expected on the flora, data from forests growing on purely siliceous substrata (granite and gneiss) in the Sistema Central range (central Iberian Peninsula) were included, in order to control for floristic differences due to substrate type. We therefore considered two additional massifs (sites) – Ayllón (6), and Guadarrama (7) (see Appendix) – and their corresponding relevés, for this purpose.

2.2. Statistical analysis

We first used Principal Components Analysis (PCA) on the relevé-by-species matrix containing presence–absence values, in order to display the compositional variation among the *Q. pyrenaica* woodlands in the study area. Given a relevé-by-species matrix and a classification of the relevés into groups, the Indicator Value (IndVal) index was defined by Dufrêne and Legendre (1997) as the product of two components: A_{ij} and B_{ij}; where A_{ij} is a measure of species i specificity or positive predicting value as an indicator of the relevé group j; and B_{ij} is the probability of finding the species when the relevé belongs to the relevé group j (De Cáceres and Legendre, 2009). As ecological niches cannot normally be reduced to closed compartments, De Cáceres et al. (2010) extended the Indicator Value method to cope with the variation of species niche breadth. Specifically, they extended indicator value analysis by considering all possible combinations of relevé groups (i.e. combinations of sites in our case) and selecting the combination for which the species can best be used as an indicator. The analysis produces the set of indicator species significantly associated to each relevé group or relevé group combination. Among these, we selected those species with IndVal value greater than 0.5 (i.e. the most constant and specific species). Thus, only species which were frequent and also statistically significant were shown as representative of site or site combinations ("shared differential species", Willner et al., 2009).

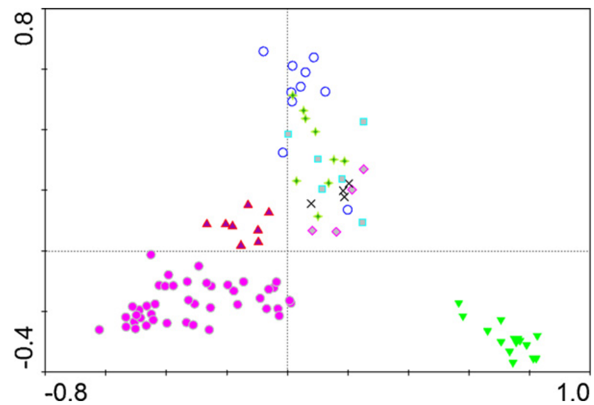

Fig. 1. Principal component analysis of eastern *Quercus pyrenaica* forests: Sierra de Espadán (downward triangles), Sierra de Prades (solid boxes); Sistema Ibérico: Penyagolosa (open circles), Albarracín Massif (stars) and Serranía de Cuenca: Boniches (X-marks), Ranera (diamonds); Sistema Central: Ayllón (upward triangles), Guadarrama (solid circles).

Indicator value analyses were performed using the '*multipatt*' function of the R package 'indicspecies', using IndVal as the statistical index. To control for the effects of using relevé groups of unequal size, the sum of the mean overall groups in its *A* component was included, following the recommendations of De Cáceres and Legendre (2009). Only presence–absence values were used in these analyses. The use of presence/absence data implies that the indicator species obtained are specific and frequent, but not dominant, and are diagnostic on their own "not only when exceeding a certain cover value" (Willner et al., 2009). The low weighting of rare species that characterizes IndVal is also reduced with presence–absence data (De Cáceres and Legendre, 2009). In our indicator value analyses we assumed that initial groups (sites) were floristically homogeneous. In order to check that the compositional variation within each site was not excessively high, we calculated the beta diversity of its corresponding group of relevés, using the beta-diversity index suggested by Legendre and Peres-Neto (2005). Specifically, we transformed our values using the chord transformation (Legendre and Gallagher, 2001), and then calculated the overall variation for each group of relevés. Multivariate centroids were also calculated in order to confirm the floristic proximity between sites.

In this paper we suggest using the number and identity of the indicators to determine how different geographical locations could be related, and the autoecology of the representative species of site combinations to identify shared environmental characteristics.

3. Results

Together, the first two PCA axes explained 22.1% of the total variance (Fig. 1). This low percentage can be understood in terms of a wide ecological gradient, thus indicating the floristic heterogeneity of the relevé data. The first axis separated the pre-coastal relevés with the lowest altitudes in the whole set – Sierra de Espadán (downward triangles) – in the most positive part of the diagram, from the rest. Sistema Central relevés – Guadarrama (solid circles) and Ayllón (upward triangles) massifs – are in the negative part, whereas the remaining relevés are in the middle. The second axis separated the Guadarrama massif (solid circles) and Sierra de Espadán (downward triangles) in its negative part, whereas the rest of the eastern relevés appeared in the positive part. Thus, the first PCA axis could be interpreted as a continentality gradient, with relevés from the central Iberian Peninsula as the most continental;

Table 1
Summary of locations studied. For every location the information presented is: the number assigned to every locality in Fig. 1 (Num.), Abbreviation (Abbr.), Spanish political division (Province), distance to the coast (D. coast), altitudinal range (Altitude), data gathering (N. relevés), and percentage of exclusive species per forest (% excl. spp.).

Num.	Abbr.	Locality	Province	D. coast	Altitude	N. relevés	% excl. spp.
1	E	Espadán	Castellón	35 km	900–1106	15	43.94
2	Pr	Prades	Tarragona	27 km	950–1050	6	40.31
3	P	Penyagolosa	Castellón	58 km	1250–1500	10	26.26
4	Al	Albarracín	Teruel	235 km	1500–1700	9	28.77
5	B	Boniches	Cuenca	170 km	1000–1200	4	15.38
	R	Ranera		120 km	1280–1380	4	20.45
6	Ay	Ayllón	Guadalajara	430 km	960–1350	8	17.07
7	G	Guadarrama	Madrid	480 km	1170–1500	43	47.65

while the second axis could be related to a summer humidity gradient, with the relevés with shorter or compensated summer drought located in the positive part.

3.1. Site indicator species

The *multipatt* function produced, on a first level, the species which are representative of individual sites (see Appendix A):

- Sierra de Espadán: this site obtained the highest number of indicator species in the whole set. Its northwest-southeast orientation favours the retention of rainfall associated with easterly (Levante) winds, producing summers with reduced drought. Its proximity to the coast also causes warm winters, and allows the inclusion of frost-sensitive species. These factors have permitted the development of a *Q. pyrenaica* forest in altitudes that are generally not suited to this species in the Iberian Peninsula. The indicator species that best characterize this forest are endemics such as *Minuartia valentina*, some of which – like *Biscutella calduchii* – are silicicolous, and others – such as *Helianthemum marifolium* subsp. *molle* – are calcareous. Serial thermophilous shrubs such as *Ulex parviflorus* subsp. *parviflorus* are also significant indicators of this locality, while *Quercus suber*, a tree that forms part of the canopy layer, was also appointed as indicator species.
- Sierra de Prades: this was the northernmost locality studied, and had the highest percentage of species with a temperate distribution. Twelve species were selected as indicators, with *Euphorbia amygdaloides* and *Campanula persicifolia* as the most important, both of which are common species in beech forests. In contrast, heliophilous herbs (*Anthriscus sylvestris, Festuca marginata*), and serial shrubs such as *Cistus salviifolius* which were extracted as significant, highlight the open character of these forests.
- Sistema Ibérico: on one hand, the Boniches massif in the Serranía de Cuenca showed a mixture of silicicolous and calcicolous indicators (i.e. *Quercus faginea*, see Appendix A), due to the favourable conditions of the Buntsandstein substrate (López, 1976), in addition to endemics (*Thymelaea subrepens*). In contrast, the Ranera massif, also in the Serranía de Cuenca, is the only locality where annual and highly competitive species such as *Urtica dioica* appear as the main indicators, giving an idea of the degraded state of the forest.

In contrast, the Albarracín massif was represented by typical mountainous species, and also by plants with preferences for stony land such as *Leontodon hispidus* (see Appendix A). The Penyagolosa massif – the coldest location in its area – was represented mostly by temperate species such as *Geranium sanguineum*, and also by species typical of temporarily flooded substrates such as *Rubus caesius*.

- Sistema Central: the main indicator species of these forests were typical plants of the herb layer such as *Holcus mollis* or *Melica uniflora*, in addition to some shrubs such as *Cytisus scoparius*; all of them show a distribution in the north-western area of the Iberian Peninsula, where granite and schist are the most common substrata in this type of forest. The second massif, Ayllón, showed a lower number of indicator species, including humid grassland species, indicating its typical management as open forest (Fuente, 1985), but also suggesting the particular moisture supply of this area.

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3.2. Indicator species of site-group combinations

The second kind of information obtained from the *multipatt* function concerned the species that are not specific to a single site but are associated to combinations of two or more sites that share ecological characteristics (see also Appendices B and C).

We present these results in combinations of two sites, three sites, and so on, in consecutively combined sites (Table 2). The highest number of shared species appears at the level of two combined sites, with Prades and Boniches as the two sites which appear most frequently in combinations.

Prades was also the site with the highest degree of indicator species in its combinations with other sites. It shared a large number of indicator species mainly with Espadán, Penyagolosa and Albarracín (see Appendix B), thus showing a high degree of relationship with these sites. These indicators express three main patterns in Prades: (1) the influence of the Mediterranean Sea (at approx. 27 km from the coast) represented by thermo-Mediterranean species in the combination Prades-Espadán, which are the most coastal massifs; (2) the moderately continental character of species corresponding to the combination Prades-Penyagolosa; and (3) the mountainous character of species selected in the combination Prades-Albarracín, also characterized by mesophytic grassland and typical species from the northern Sistema Ibérico.

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The second site most frequently appearing in two-site combinations was Boniches (Table 3). Its floristic composition related this site to its geographically closest site, Ranera, through perennial and calcareous species belonging to pioneer communities (*Conopodium arvense*); but also to calciphilous species that have a central-European optimum, and link it with the Penyagolosa massif (*Cephalanthera rubra*, *Inula salicina*). Forest fringe shrubs, such as *Genista florida* – in what is probably its easternmost location – related Boniches with the Guadarrama massif.

Combinations of more than two groups were represented by no more than 32 species that generate a real division of the data. Based on our objective, we established three types of site combinations

Table 2
Number of combinations of each site inside each combinatory level and total number of combinations of each site group. Abbreviations in Table 1.

Combinatory level	E	Pr	P	Al	B	R	Ay	G	Total indicator species
2 sites	3	6	3	4	6	3	5	4	32
3 sites	4	8	6	4	4	8	4	4	16
4 sites	3	4	7	6	4	4	5	3	9
5 sites	0	3	3	3	1	2	2	1	3
6 sites	0	2	2	1	2	2	2	1	3
7 sites	0	1	1	1	1	1	1	1	1
Total no. of combinations	10	24	22	19	18	20	19	14	

Table 3
Results extracted from Multipatt analysis. Lower left part: number of combinations between pairs of sites. Upper right part: distances between site-centroids. Abbreviations in Table 1.

	E	Pr	P	Al	B	R	Ay	G
E		0.90	0.94	0.96	0.97	0.98	1.06	0.95
Pr	4		0.70	0.73	0.87	0.78	0.84	0.72
P	4	13		0.70	0.79	0.84	0.83	0.71
Al	2	10	13		0.81	0.86	0.78	0.73
B	4	7	9	7		0.88	0.89	0.84
R	3	12	9	8	10		0.89	0.83
Ay	2	8	8	9	5	9		0.65
G	1	7	7	4	4	4	9	

(Appendix C) according to the best differentiated groups in the PCA: combinations of any sites that occur with the Sistema Central, those that occur with Espadán, and those that do not relate to either:

- Species associated to combinations of the Sistema Central and other site groups and were typical of dense cool oak forests such as *Poa nemoralis* or *Cruciata glabra*; open forest but with iberoatlantic preferences such as *Arenaria montana, Dactylis glomerata*; or those with their optimum in the temperate biome such as *Viola riviniana.*
- Species associated to combinations of Espadán and other site groups were thermophilous, in addition to those with humid atmosphere requirements such as *Hedera helix*, or calcareous requirements such as the Mediterranean shrub *Teucrium chamaedrys*, *Viola alba* or *Prunus spinosa.*
- Species associated to site combinations that did not include any of the former two sites tended to be representative of serial or degraded stages. Examples are species belonging to anthropogenic grasslands and meadows on deeper Eurasian soils such as *Arrhenatherum elatius* and *Trifolium pratense*. Prades, Penyagolosa and Albarracín include areas still in use for livestock feed. They are the most frequently combined sites in the whole set (see Table 3), indicating the high floristic affinity between these sites. Moreover, eastern relevés were more frequently combined with each other than with the Central or Espadán massifs. As seen in Table 3, the greater the number of combinations, the higher the floristic relationships among sites. The distance between multivariate centroids was generally in accordance with the results of *multipatt* function, but not always. Less frequently combined groups were not always the most distant in the species compositional space. An example of this is Ranera or Ayllón, which were the most distant from Espadán but obtained more significant combinations with it than with Guadarrama, which was much closer.

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Above the level of four combined sites (Table 2) the number of statistically significant indicator species was considerably reduced, and due to their singularity some cases, such as Espadán, did not generate any combinations. Indicator species of more than four site combinations were species often related to land use or forest species present in the herb layer (nemoral species). This was the case of typical oak-forest or forest-edge species such as *Poa nemoralis* or *Clinopodium vulgare*.

4. Discussion

This study presents a new and interesting pratical use of indicator value analysis with combinations of relevé groups to study the floristic affinities between sites. Indeed, the use of the *multipatt* function in our dataset showed the wide variety of ecological traits that define or characterize each site through its indicator species (including local endemics or anthropogenic influences) but also gave an idea of its floristic affinities with other sites. These affinities can be interpreted environmentally and geographically as the result of common present (or past) shared ecological features between sites. Each site has shown its particular indicator species, including the presence of local endemics, or anthropogenic influences.

In the comparison between eastern and central forests, all the indicator species of the Sistema Central were mostly silicicolous plants. Species with more stringent requirements for moisture, and thus with north-western preferences, were also relegated here, and comprised mesophyllous vegetation occurring in the east (Cuenca, Espadán).

Different types of results gave different types of information:

a) *Number of indicator species* – A high number of indicator species for a given site gave an idea of its degree of uniqueness. A high number of indicator species relating a combination of sites may indicate that the ecological traits these species share is especially important as a descriptor of these sites, and also helps to distinguish these sites from others.
b) *Number of combinations* – The more floristically distinct a site is, the fewer indicator species were obtained for combinations of this site with others. The least frequently combined site was Espadán, precisely the only one that has a meso-Mediterranean character and a greater maritime influence, with species forced to adapt to post-glacial changes. At the other extreme was Prades (Catalan pre-coastal range), with twenty-four indicator species related to combinations of this site with others, showing the multiple influences that are grouped in this area, including land use and frequent fires. Most of its combinations occur

with Penyagolosa and Albarracín (Sistema Ibérico); these are the three sites with the highest degree of floristic affinity. Several authors point to the role of these three mountain ranges as migratory vegetation routes in the postglacial period, highlighting Albarracín as a connection between the Iberian and Catalan pre-coastal ranges (de Bolòs, 1989). These affinities were also observed in the PCA (Fig. 1), with a differentiated set of relevés in the upper part (Penyagolosa, Albarracín and Prades), and also with the Espadán set standing in isolation at the right, in accordance with its specific character.

4.1. Implications for conservation

Espadán and Boniches were the locations with the highest number of endemics as indicator species, half of which are included on European red lists. The protection of species with restricted distribution is crucial, and these sites should therefore be preferential areas for conservation. Five of the seven sites also obtained indicator species included on lists of ancient forest species (Hermy et al., 1999). The presence per se of these species is not directly correlated with the degree of conservation of the forest, but indicates the vulnerability of the set due to the species' limited dispersal rate and their low competitive ability. Hermy et al. (1999) noted the difficulty of these species to regenerate, since many of them do not form a persistent seed bank. Furthermore, the isolation of these eastern forests – mainly of their temperate species – may hinder the complete recovery of the community, even in the case where the arboreal mass can be recovered. Pollen flow is quite low between isolated populations of small sizes, thus isolation decreases the genetic diversity of forest species, and consequently reduces their capacity to adapt to change (Honnay et al., 2005). The effect of anthropogenic disturbances on these forests is therefore more damaging, and makes their recovery harder.

We have shown different degrees of conservation, with grazing as the main land use observed. At least half the study sites have typical pastureland species in common (various authors confirm this use; Barrera (1983) also confirms the existence of peat lands in Albarracín), even though some are included in protected areas. Gómez-Aparicio et al. (2004) indicated herbivory as a major limiting factor of deciduous forest regeneration, given the preferential predation of these phanerophytes over evergreens. Hence control of herbivory in these locations would be of particular relevance to improving their forest quality and regeneration. Ranera is the most degraded site, with annual and highly competitive species as its main indicators. As *Q. pyrenaica* forests are typically closed formations, a high number of nemoral indicator species could represent areas which continue to be more densely forested: Guadarrama, Prades and Boniches.

5. Conclusions

Determining species habitat preferences may be an objective in itself, but it is also a tool for achieving a better understanding of habitat ecological information (Dufrêne and Legendre, 1997). We emphasize the usefulness of indicator species analysis with site group combinations, not only for a better and more thorough understanding of our study areas, but also to make decisions about which sites should be preferential for conservation efforts. Furthermore, we have shown the wide variety of traits in the set of sites, which enables identification and preservation of the maximum amount of variability within this type of forest, as suggested by Mandelik et al. (2010). This is an important point in relict forests such as these, which are unique and especially vulnerable to any change in climate and in management.

Through the chorology of their main indicator species, we have found the various traits that define each area (calcareous (Boniches, Ranera), thermophilous (Espadán) and sub-Mediterranean species (Penyagolosa, Albarracín, but also Prades)). In addition, floristic affinities (shown by the number of indicators related to site combinations) confirmed the differentiation of east–west Pyrenean oak forests defined by the siliceous character and high-Atlantic influence of the central group, and the entry of limestone species with a greater or lesser mesophilic character in the eastern forests.

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