

Unveiling the conservation status of the sessile oak forest for their protection and management in the northeast of the Iberian Peninsula

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Abstract. The sessile oak forests found on the northeast of the Iberian Peninsula are ascribed to the *Lathyro-Quercetum petraeae* association and play a key role in understanding the ecology of this habitat, as this region represents its xeric limit. For this reason, we analysed the biodiversity patterns and current conservation status of the sessile oak forests in the region. To do so, we collected Braun-Blanquet inventories of 34 plots randomly distributed throughout the sessile oak forests. The results showed a relationship between the climatic conditions and the biodiversity variables. While the richness of the community increased with decreasing temperatures, the characteristic species found within the community decreased at these same temperatures. This result was due to the presence of most companion species in the cool zones at high elevations. Sessile oaks are found close to other communities, such as silver birches and Scot pine forests.

On the other hand, in the warm areas at low elevations, the sessile oak community was more established, with plants typical of this type of forest. These slightly warmer zones with sessile oaks are very important in terms of conservation and more vulnerable to climate change and the thermophilization of the community, as has been studied. As such, protecting and managing these forests is key to conserving this community. Nevertheless, as current protection measures do not safeguard most of these forests, it is essential to define a conservation strategy to preserve them. Using the conservation status, we have established criteria to improve the conservation strategy for sessile oak forest on the NE Iberian Peninsula.

Keywords. *Quercus petraea*; community ecology; indicators; prioritization.

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Introduction

The sessile oak (*Quercus petraea* (Matt.) Liebl.) is a very abundant deciduous tree that is widely distributed across Europe (Eaton *et al.*, 2016). On the Iberian Peninsula, the sessile oak reaches its southern-most distribution limit; however, there are some remarkable populations in the north, such as those in the Cantabrian range and Pyrenees. The NE Iberian Peninsula populations are an isolated case because the area is in the Mediterranean region, so this region represents the xeric limit of the species (Bou *et al.*, 2016). For this reason, the sessile oak forest is restricted to the cool and moist mountains of Catalonia, such as the Pyrenees or the Catalan Precoastal Range (Bou *et al.*, 2016), which provide refuges for the survival of this species (Vigo, 2011; Loidi, 2017). The forests on the NE Iberian Peninsula represent merely 0.38% of the total forest coverage in the region. This phenomenon is a consequence of both the Mediterranean climate's dry summer months, which curtail the development of this species in the lowlands, and a result of human activity transforming the landscape (Bou, 2019).

The warm conditions on the NE Iberian Peninsula are increasing due to climate change (Martín Vide *et al.*,

2016; Peñuelas *et al.*, 2016), which, in turn, represents a dire threat to the conservation of the sessile oak forest (Vayreda *et al.*, 2013); for example, these conditions can change the species composition of the community (Bou & Vilar, 2019a). The preservation of these forests at their xeric limit is very important because they are better adapted than the northern forests to these dry and warm conditions (Mátyás, 2010). Moreover, for centuries, the sessile oak forests have been intensively exploited, which has altered their distribution and structure (Eaton *et al.*, 2016). Nevertheless, during the 20th century, subsequent changes and the abandonment of forestry practices led to the expansion of forest coverage on the NE Iberian Peninsula (Vila, 1999; Boada, 2002; Gordi, 2009; Bou Manobens *et al.*, 2015), as was similarly reported for Montseny sessile oak forests, which have expanded and become more dense (Bou & Vilar, 2018, 2019b). As a consequence of this intensive exploitation in the past, there is now a significant lack of mature forests in Catalonia (Mallarach *et al.*, 2013), and only a few ancient and mature sessile oak forests remain (Bou, 2019; Bou & Vilar, 2019b). The same problem has been reported for sessile oak and pedunculate oak (*Quercus robur*) throughout Europe (Saniga *et al.*, 2014). Furthermore, the landscape

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has been changed because landowners have converted natural sessile oak forests into chestnut (*Castanea sativa* Mill.) plantations (Llobet, 1947; Panadera & Nuet, 1986). Moreover, these changes are ongoing because chestnut plantations are currently being replaced with stands of Douglas fir (*Pseudotsuga menziesii* (Mith.) Franco) (Broncano *et al.*, 2005; de Ribot Porta, 2016), an invasive plant that has been reported in sessile oak forests (Bou & Vilar, 2016, 2019a). Although the exploitation of sessile oak forests has decreased, there are still a few cases of intensive activity that are causing a number of severe impacts (Bou *et al.*, 2018).

Currently, all these problems can be managed by new legislation and planning for the region's natural heritage and forest resources. This legislation is especially relevant because the majority of the NE Iberian Peninsula forests are privately owned (Terradas *et al.*, 2004) and the number of planned exploitations has increased in recent years (Anon., 2016). However, in an attempt to preserve the natural heritage of this region, 30% of land on the NE Iberian Peninsula falls under the protected areas network (Anon., 2016), and 49.80% of the sessile oak forest falls into this category.

The evaluation of conservation measures of the sessile oak forest on the NE Iberian Peninsula is an important issue, which needs to be addressed to develop efficient management planning to preserve this habitat. Conservation status depends on the composition, structure, and functions of habitats (Maciejewski *et al.*, 2016), but it is generally accepted that it can be based on measures of biodiversity or features as surrogates (Margules & Pressey, 2000; Cabeza & Moilanen, 2001; Yoccoz *et al.*, 2001; Carboni *et al.*, 2009). Although the threats and impacts on the sessile oak forest have been clearly analyzed and described (Bou, 2019), unfortunately, the conservation status of this habitat has yet to be thoroughly studied. Furthermore, the sessile oak forest is not a habitat of Community interest (Vigo *et al.*, 2005), so a standardized evaluation and monitoring program does not exist. To devise a conservation and management plan for this habitat, the existing sessile oak stands need to be prioritized according to their biodiversity indicators. There are two ways to do this: one is to use global biodiversity to identify possible hotspots, and the other is to use the biodiversity associated explicitly with particular habitats. While both approaches can be useful, the most important indicator is the community's characteristic flora because these are the elements that will define the community. Due to the lack of mature forests, perfect reference forests do not exist (Rodà *et al.*, 2009). Still, the large datasets available (Font, 2013) are a handy tool for identifying characteristic species that constitute the community in its known optimal state.

Therefore, this study aimed to evaluate the conservation status of sessile oak forests on the NE Iberian Peninsula to improve the management measures. We analyzed the relationship between conservation indicators and environmental conditions to understand how the conservation status changes between the different forest areas. We determined how efficient the

protected zone network was in safeguarding the habitat. We hypothesized that best preserved sessile oak forests are protected by high levels of protection on the NE Iberian Peninsula. Finally, this study aimed to use the conservation status to propose prioritization criteria for conservation actions and competent management.

Material and Methods

Study site

Our study covered the sessile oak forests found in the NE of the Iberian Peninsula, which inhabit the physiographic units of the Northern Pyrenees, the Precoastal Range and the Coastal Range, bordering the Mediterranean Sea and covering a surface area of 4825 ha (Carreras & Ferré, 2012) (Figure 1). The sessile oak forests span from 500 to 1800 m asl. Sessile oaks are only found in montane zones with high precipitation or, in some cases, with regional microclimates. The mean annual temperatures of the regions in this study range from 8 to 13°C, and annual precipitation ranges from 812 to 1035 mm (Table 1). The sessile oak forests grow on acidic lithology (Bou, 2019). In addition, human factors must also be included in these environmental conditions because, historically, many of these forests were exploited (a practice now abandoned), and they have also been included in different protected areas (Anon., 1996).

Data collection

To evaluate the current conservation status of the sessile oak forests, we carried out 34 inventories of the plant community using a modified (Bou & Vilar, 2019a) Braun-Blanquet method (Braun-Blanquet, 1964) to measure only the abundance in 100 m² plots. Using the available habitat cartography of Catalonia (Vigo *et al.*, 2005), we determined the distribution of the sessile oak forest in the study area, where we randomly distributed the plots. The raw data that were collected are available at figshare (Bou & Vilar, 2020a). Different sessile oak forest communities have been described on the NE Iberian Peninsula, but here, we focus on the dominant sessile oak community, *Lathyro montani-Quercetum petraeae* (Lapraz 1966) Rivas-Mart. 1983, which is synonymous with *Teucrio scorodoniae-Quercetum petraeae* (Lapraz 1996) O. Bolòs 1983, which includes different sub-associations (Bolòs, 1983; Vigo, 1996). To achieve the proposed objectives, the sub-associations of the chestnut plantations and Scots pine plantations on the Coastal and Precoastal Ranges were discarded, so in this study, the concept of sessile oak forests refers to the typical oak habitat (CORINE 41.5611 Xero-mesophile, acidophilous *Quercus petraea* forests, sometimes with *Betula pendula* of the Pyrenees and the northern Catalanidic territory).

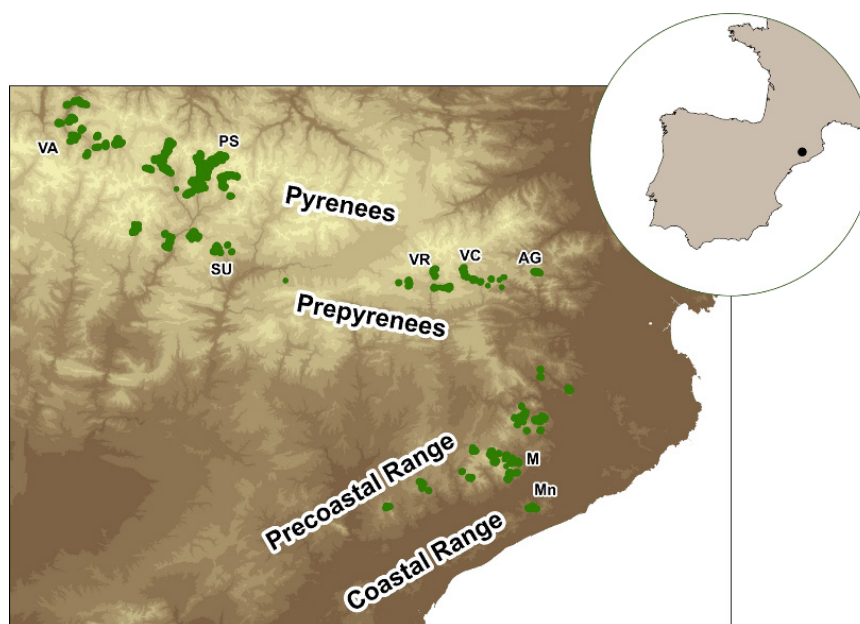


Figure 1. Sessile oak forests (green) on the NE Iberian Peninsula. Subregion abbreviations: VA (Vall d'Aran), PS (Pallars Sobirà), SU (Alt Urgell), VR (Vall de Ribes), VC (Vall de Camprodon), AG (Alta Garrotxa), M (Montseny), Mn (Montnegre).

Table 1. Localities studied (region) with meteorological characteristics of sessile oak forests. Climatic variables were estimated using a georeferenced model (Ninyerola *et al.*, 2000). Abbreviations are: Invs., inventories; malt, mean altitude; P, mean annual rainfall; T, mean annual temperature; Tmax, mean maximum annual temperature; Tmin, mean minimum annual temperature.

Region	Invs	malt (m asl)	P (mm)	T (°C)	Tmax (°C)	Tmin (°C)
Pyrenees	22	1255.23	943.41	8.74	14.56	2.96
Pre-Pyrenees	4	1110.75	1042.83	9.53	14.88	4.30
Precoastal Range	6	1050.75	973.25	10.10	14.58	5.75
Coastal Range	2	652.50	942.95	12.60	17.00	8.25

In each plot, we recorded the orientation, elevation, and coordinates. Using this information, we estimated the meteorological data (precipitation, mean temperature, minimal temperature and maximal temperature) using georeferenced models of the NE Iberian Peninsula (Ninyerola *et al.*, 2000).

Using the coordinates of the plots, we also assessed the level of protection over all the sampled stands in the Catalan System of Protected Natural Zones (Anon., 2019) using three categories to classify the natural areas: non-protected, Natura 2000, and Natural Park areas. Non-protected areas are not included in this protected zone network; these areas can undergo forest management planning, but no special conservation laws apply. The first degree of the protected network is the Natura 2000, where the European Habitats Directive (Anon., 1992) must be applied; in Catalonia, this degree of protection is used to imply the PEIN (Generalitat de Catalunya, 1993), which applies in all related cases of this study. This protection is a basic degree of protection that entails a conservationist policy. All zones with high degrees of protection overlap with this basic degree of protection. The following degree in the network is

special protection zones, such as natural parks and natural reserves. The natural parks have specific laws that entail preserving the natural and cultural heritage of the zone and bringing a body of its managers for each zone. Natural reserves are also one of these special protection zones, but they have the highest level of protection in Catalonia. These zones have restricted human activity, and their only goal is the preservation of natural heritage.

Data analyses

There is no standardized method to evaluate the conservation status of habitat or a broad approach that is widely used; normally, these methods are designed for large-scale analysis with low resolution. Moreover, traditionally, the conservation status of forests has been analysed from the structural point of view, as the main topic of forest conservation used to be mature forests (Comas *et al.*, 2013; Mallarach *et al.*, 2013; Moya & Moya, 2013), and currently, ecosystem services are used as an approach to conservation status and interest (Banqué *et al.*,

2016). Ultimately, important studies from the community ecology point of view that focus on phytosociological and habitat approaches are lacking. These studies use both biodiversity and the composition of the community to define the conservation status (Rodà *et al.*, 2009; Carreras & Ferré, 2013; Bendali & Nellas, 2016). For this reason, we developed a new proposal using the state of the plant community as our approach to establishing the conservation status of the sessile oak forest. The biodiversity index and composition of the community were used as indicators in our proposal.

We used two different biodiversity indicators: the plant species richness, or the number of species (S), and the Shannon diversity index (H') (Shannon and Weaver, 1949). Species richness is the most commonly applied indicator and has been chosen because it is a simple measure of species diversity (Colwell, 2009) and can be easily interpreted. On the other hand, the Shannon diversity index is slightly more complex and brings additional information, as this index combines richness and evenness in a single measure (Colwell, 2009). It is very useful to use the two indicators because while richness shows the differences in rare species, the Shannon diversity index shows the changes in dominant species (Magurran, 2004). Therefore, the two parameters are interesting for evaluating the biodiversity and conservation status of the sessile oak community.

However, to focus clearly on how well the forest is conserved, we also used a compositional indicator, which shows how well established the sessile oak forest is. With this type of indicator, we used a checklist of plants present in the plots to establish the richness of the typical species expected to be found in the community for each plot. We used two approaches to identify any typical plants: phytosociological criteria and the CORINE criteria. With the phytosociological criteria, we considered the characteristic plants that different studies (Vigo, 1968, 1996; Bolòs, 1983, 1988; Carreras *et al.*, 1997) have identified for the association *Lathyro montani-Quercetum petraeae* (Lapraz) Rivas-Mart. 1983, the alliance *Quercion robori petraeae* Br.-Bl. 1932, the order *Quercetalia robori-petraeae* R. Tüxen 1932, and the class *Quercu-Fagetea* Br.-Bl. (1931) 1932. On the other hand, we used the CORINE criteria following the abundant plants that Vigo *et al.* (2005) described in CORINE 41.5611 Xero-mesophile, acidophilous *Quercus petraea* forests,

sometimes with *Betula pendula* of the Pyrenees and the northern Catalanidic territory. The list of those species that we considered typical plants is available in Bou & Vilar (2020a).

We use general linear models (GLMs) to assess how the environmental data affected the conservation indicators. The compositional and biodiversity indicators were the dependent variables in the GLM, the climatic (precipitation and temperature) and topographical parameters (elevation and orientation) were the independent variables, and the Gaussian distribution and identity link functions were used. We fitted one model for each environmental data type, and we selected the one with the lowest Akaike information criterion (AIC) value. We also performed ANOVA tests to detect any differences in the conservation indicators between the protected area categories. Statistical analyses were performed using R environment software (R Core Team 2015).

Furthermore, we proposed a prioritization scheme for management and conservation actions using some of the studied indicators (the species richness and the number of characteristic species). Each variable was classified into quartiles to categorize the plots as a function of conservation status. The combination of these two variables was overlap in quartiles to show what plots are at the top of the list if we consider the two concepts. Our proposed methodology uses this scheme to define four levels of prioritization, giving more importance to species composition than to species richness.

Results and Discussion

The effects of environmental conditions

The selected species richness model included the minimum temperature. This variable was selected because temperature has a negative effect on species richness (Table 2, Table S1). The species richness of the sessile oak forest (35.24 ± 10.31) decreased in hot locations. Likewise, the Shannon diversity index (1.86 ± 0.46) was similar because the model selected fitted the mean temperature as an independent variable, and it also showed a negative relationship. All biodiversity indicators showed higher values in colder locations and a decrease in biodiversity in warmer locations.

Table 2. Mean values (\pm SE) for each estimated parameter in the selected models for evaluating the effect of environmental variables on conservation indicators. The parameters are the interception (a) and the slope (b). For all models, the significance (*): $p < 0.05$; (**): $p < 0.01$; (***): $p < 0.001$.

Dependent variable	Selected model	Parameters	Estimate
Richness (S)	Tmin AIC=255.25	a	$43.77 \pm 4.19^{***}$
		b	$-2.18 \pm 0.98^*$
Diversity (H)	Tmean AIC=31.97	a	$3.72 \pm 0.43^{***}$
		b	$-0.20 \pm 0.5^{***}$
N. characteristic species	Tmax AIC=208.23	a	5.30 ± 8.84
		b	0.95 ± 0.60
N. CORINE species	Tmin AIC=133.67	a	$4.91 \pm 0.70^{***}$
		b	-0.27 ± 0.16

In addition, the model selected for the number of characteristic species of the *Lathyro montani-Quercetum petraeae* association (19.24 ± 4.99) included the maximum temperature (Tmax). In this case, the number of characteristic species was higher in warm conditions and lower in cold locations. The other compositional indicator was the number of CORINE species (3.85 ± 1.67). Here, the selected model included the minimum temperature (Tmin), but instead of the positive relationship, as for the previous indicator, this indicator had a negative relationship with temperature. In cold locations, the number of species was high, while this decreased in warmer conditions.

Current habitat protection effectiveness

Differences between the protected area categories were tested with one-way ANOVA (Table 3, Table S2) and did not show any significant differences in biodiversity indicators (richness and Shannon diversity). This result was also the case for one of the compositional indicators (the number of CORINE species), where no significant differences are observed. However, the number of characteristic species showed significant differences between the protected

categories. The sessile oak forests found in the natural parks contained only a few species characteristic of this community (16.58 ± 3.53). In contrast, the Natura 2000 and non-protected sessile oak forests had more characteristic species than the natural parks (22.00 ± 4.72 and 19.77 ± 5.40).

Table 3. ANOVA results for the conservation indicators between protection categories.

Conservation indicators	F	P	Sig.
Richness (S)	F _{2,31}	1.98	0.16
Diversity (H)	F _{2,31}	0.63	0.54
N° characteristic species	F _{2,31}	3.66	0.04 *
N° CORINE species	F _{2,31}	0.20	0.82

Richness and number of characteristic species were classified in quartiles (Table 4). The two conservation indicators showed that forests in natural parks principally constituted the fourth quartiles. In addition, no sessile oak forests from natural parks were in the first quartile. Additionally, using the quartiles, four levels of prioritization were established (Table S3) to define the packets of conservation and management actions as a function of this prioritization.

Table 4. Inventories classified in conservation indicator quartiles and their classification as a protection category.

Quartile	Richness (S)					N. characteristic species				
	Interval	Code	Not protected	Natura 2000	Natural Park	Interval	Code	Not protected	Natura 2000	Natural Park
Q4	13-27.2	S4	2	2	5	10-16	C4	3	1	6
Q3	27.2-35.5	S3	3	2	3	16-20	C3	3	2	5
Q2	35.5-41	S2	4	1	4	20-22	C2	3	2	1
Q1	41-67	S1	4	4	0	22-29	C1	4	4	0

What are the optimal environmental conditions for this habitat?

To evaluate the conservation of the sessile oak forest on the NE Iberian Peninsula, we need to understand the ecology of these forests. Conservation indicators have been modelled as a function of environmental conditions, and the results showed that temperature explained the patterns of these parameters (Figure 2). In cool zones, although there were more species, higher diversity and more CORINE species than in warm zones, there were fewer characteristic species of the community. On the other hand, in locations with high maximum temperatures, the sessile oak forest had more characteristic species of the community but lower values for the other indicators.

The temperature of the locations was correlated with the altitude, which explained the difference in parameters between the cool and warm locations. In cooler locations, such as the Pyrenees, the sessile oak forests were surrounded by subalpine forests, such as those of *Pinus sylvestris* and *Betula pendula*. The species of these other habitats colonized the sessile oak forest (Bou & Vilar, 2020b), and the number of companion

species increased; as a result, the total richness also increased. In the warmer areas at lower elevations, there are typical species from the Mediterranean forests that can colonize the sessile oak forest (Bou & Vilar, 2020b), but the colonization potential is limited compared to the former case. These warmer locations have high annual precipitation; consequently, the sessile oak habitat is surrounded by other deciduous forests and plantations (Bou & Vilar, 2018), such as chestnut plantations (*Lathyro-Quercetum petraeae* subass. *castaneetosum* Lapraz 1966), which has some characteristic species in common with the sessile oak forest. As such, the richness and diversity of the sessile oak forest were greater in cooler locations.

On the other hand, this pattern had some effect on the characteristic species of the community, which were more difficult to model. The CORINE species showed the same pattern as the richness, but the best fitting model of the characteristic species of the associated plants showed that the maximum temperature increased the number of characteristic species in the sessile oak forest. This result was related to the fact that *Lathyro montani-Quercetum petraeae* is not a subalpine community and that, in most cases, the community does not grow on

the north face of the mountain (Bou & Vilar, 2019a). Therefore, compared to other deciduous mountain

forests, the optimal conditions for this habitat include some relatively warm conditions.

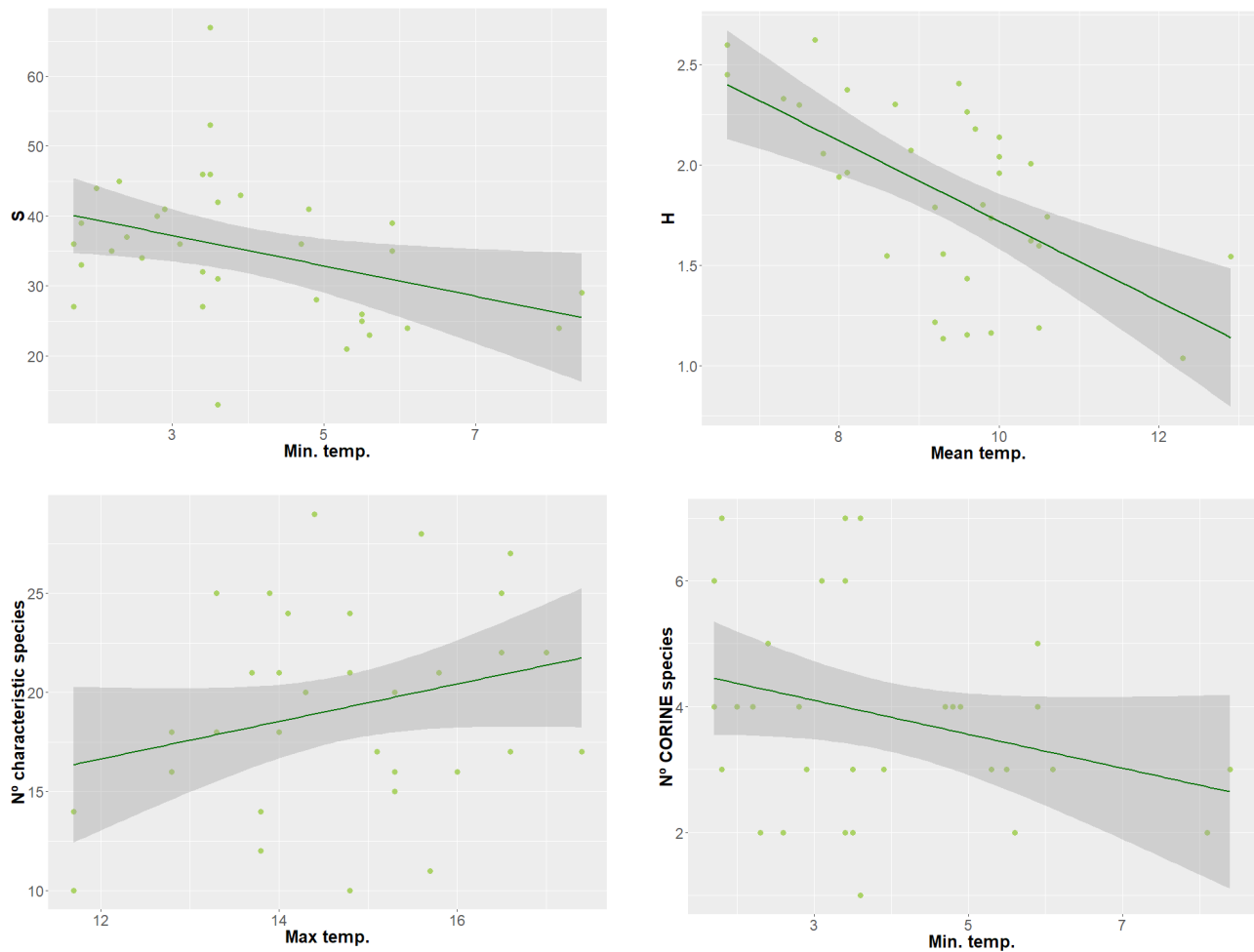


Figure 2. Conservation indicator variations for the sessile oak forests along climatic variables according to GLM fits.

Is the protection of this habitat efficient?

The conservation indicators do not show high values in the protected zone network of the NE Iberian Peninsula (Figure 3). There are fewer characteristic species of the community in the natural parks than in the sessile oak forests found in the Natura 2000 and non-protected areas. Therefore, sessile oak forests with high biodiversity and/or the most well-established communities do not experience any higher levels of protection. Moreover, no sessile oak forest was found in a natural reserve, which is the highest protection category on the NE Iberian Peninsula. This current situation represents a high risk for forest conservation because sessile oak forests are highly exposed to threats, especially those that are directly or indirectly related to human activity. Intensive exploitation and the presence of invasive species are considered important endangerments to the conservation of this species (Bou, 2019), and this territorial ordination hinders their management. In contrast, the non-protection of the forest does not necessarily mean increased vulnerability to climate change issues. Nevertheless, natural parks have resources to be invested in the adaptive management of the forest in response to climate change. This condition

is very important for the sessile oak forests in the Coastal Range, where the impact of global warming has been noted (Bou & Vilar, 2019a), and precisely because they do not come under the umbrella of the natural park protection scheme, which, in turn, means that not all possible resources are available for new adaptive management. The sessile oak forests with high conservation statuses have a complex situation in terms of management and conservation. For this reason, some strategies and levels of prioritization have to be established to provide more efficient management and cover the deficit that the network of protected zones can have in terms of conservation.

Considering the data obtained, we can classify the sessile oak forest into quartiles, identify which forests are the most interesting from the different conservation perspectives, and analyze whether they are at risk using the protected area category as the approach (Figure 4). This classification can be translated into prioritization criteria focused on forests that need conservation actions first and what kinds of actions are necessary for each forest type. How well established is the community was the most important indicator because we were focusing on habitat conservation, but with that said, global richness is also important.

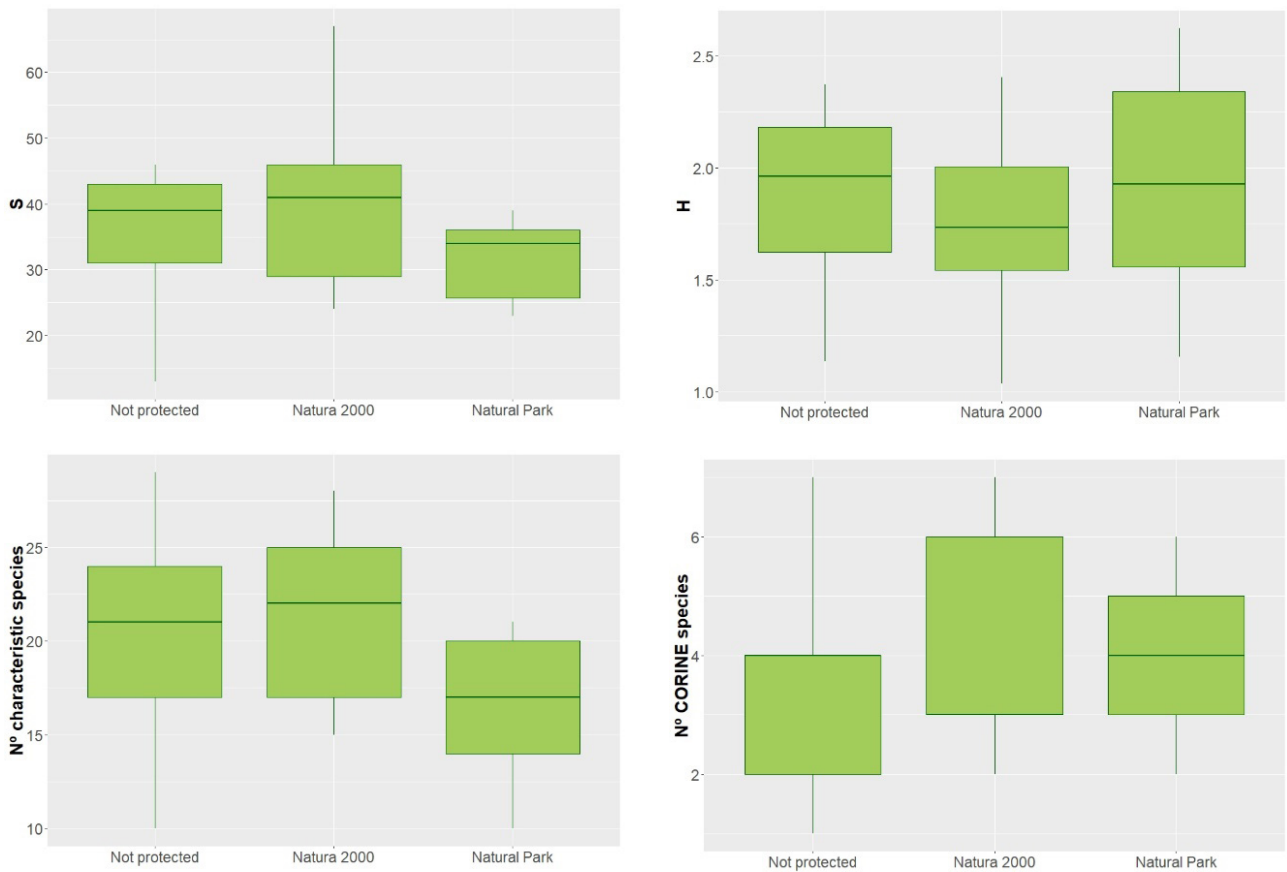


Figure 3. Conservation indicators of the sessile oak forest for each protection category.

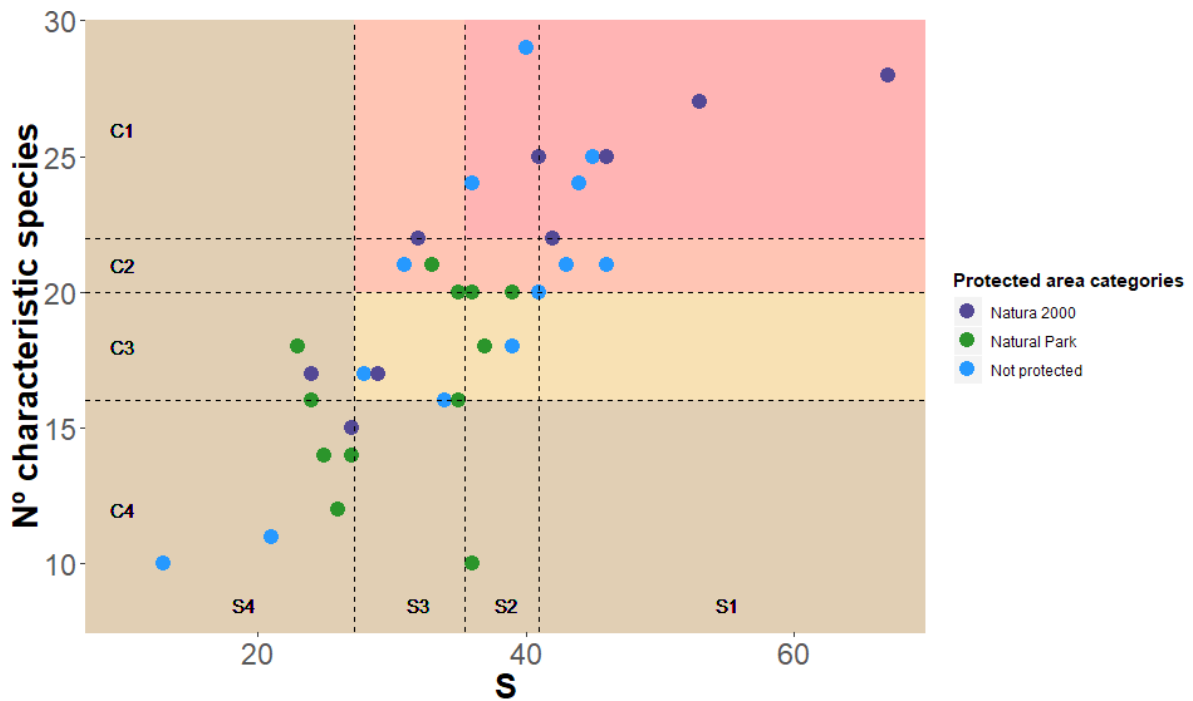


Figure 4. Prioritization system for conserving sessile oak forests on the NE Iberian Peninsula using two key conservation indicators: the number of characteristic species (Y axis) and the species richness (X axis); the quartiles are shown on each corresponding axis. The background colors depict the level of prioritization, with dark red being the top category, lighter red the second level, orange the third level, and brown the fourth. The points are the sessile oak inventories, with different colors corresponding to each protected area category.

Using these criteria, we identified four levels of prioritization (Figure 4, Table S3). The sessile oak forests at the top of the prioritization list (in red in Figure 4) were the forests in the Natura 2000 and non-protected areas, which is why the strategies for these forests have to focus on reducing threats and risks. This result can be accomplished by bringing these forests into the protected zone network and upgrading their protection category. Although this process may be complex, it is feasible in the Ripollès (Pyrenees), where a natural park at a higher altitude than the sessile oak forest already exists, or in the Alta Garrotxa (pre-Pyrenees) where the Natura 2000 coverage can be increased to include not only the sessile oak forest but also a very interesting landscape. On the other hand, this scenario is less realistic at isolated points, such as Eth Portilhon (Pyrenees), far away from current protected areas. A useful solution in such cases, and for the general situation at this level of prioritization, would be to include the sessile oak forest in the land stewardship network. The network consists of an agreement between the private owner of a forest and an entity that will pay the owner to preserve this forest, like the payment of rent. Some Catalan administrations have used this type of agreement in the southern sessile oak forests at the Precoastal Range (Bou, 2019), and it seems to be an interesting tool for non-protected areas.

The areas with low prioritization levels mostly included sessile oak forests that are already located inside natural parks. In these cases, the conservation threats and risks can be considered low, so actions would have to focus on long-term objectives, using restoration as the key tool to improve the conservation status. The issues in these forests are that the communities have deteriorated, the habitat is poorly preserved, and restoration actions are sorely needed. The Montseny Natural Park in the Precoastal Range is a clear example of this situation. The conservation problems in this park have been extensively studied (Bou *et al.*, 2015, 2018; Bou & Vilar, 2018, 2019b), and possible actions would be recovering the old sessile oak forests that have been converted into chestnut plantations. Interestingly, without any specific action in the last few decades, the sessile oak forest on Montseny has started to recover, its cover has increased (Bou & Vilar, 2018), and the community has become more established (Bou & Vilar, 2019a). Therefore, increasing connectivity, reducing fragmentation and encouraging management programs focused on forest conservation could represent a turning point for sessile oak forest conservation strategies in natural parks. These forests provide an important opportunity because they are already protected and have suitable contexts for restoration and recovery actions. All these approaches need to be incorporated into a conservation strategy plan, and support from administrations, citizens, and landowners needs to be actively sought and encouraged.

Conclusions

From the perspective of conservation status, the effect of temperature is more important than precipitation. At

higher temperatures, the richness decreases, but in some ways, warm conditions are the best fit for the characteristic plants of the community. We need to take this result into account if we want to predict future changes and preserve the sessile oak forests on the NE Iberian Peninsula in the context of climate change. To protect these forests, it is also important to see how they are protected. Unfortunately, neither the best constituted communities nor those with high biodiversity have enough protection to preserve them and guarantee that they will survive and remain stable. For this reason, the current network of protected zones shows important inefficiency for the conservation of sessile oak forests on the NE Iberian Peninsula. To preserve this unique habitat, the effectiveness of the offered protection must be improved. The prioritization criteria proposed in this article show community ecology as a useful approach for improving the conservation of specific habitats, as it takes into account high-resolution data that are usually overlooked at other approach scales. The conservation of sessile oak forests on the NE Iberian Peninsula needs to be focused on increasing the degree of protection of the well-established forests in the short term to reduce the risk they face from forest uses. The current forests with the highest levels of protection but with poor community composition need indirect action, such as ecological restoration, to improve connectivity and their conservation statuses in the long term. With the cooperation of all actors involved in sessile oak forest management, the integration of all floristic information can play a key role in preserving and protecting this habitat on the NE Iberian Peninsula.

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Supplementary material

Table S1. Mean values (\pm SE) for each estimated parameter in the selected models for evaluating the effect of environmental variables on conservation indicators. The parameters were the interception (a) and the slope (b). For all models: the t-value; the p-value; the significance (*) $p < 0.05$, (**) $p < 0.01$, (***) $p < 0.001$.

Table S2. Mean values (\pm SD) for each conservation indicator between protection categories.

Table S3. Levels of prioritization for the conservation of sessile oak forests on the NE Iberian Peninsula with the values for each conservation indicator (number of characteristic species and species richness).