



Are protected areas preserving ecosystem services and biodiversity? Insights from Mediterranean forests and shrublands

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Abstract

Context Protected areas (PAs) are essential for biodiversity conservation and the provision of ecosystem services (ES), representing 15% of the earth's surface and targeted to increase until 17% by 2020. But previous studies showed different results on the effectiveness of PAs in preserving ES and biodiversity, which has implications for landscape conservation.

Objectives (1) To know whether the spatial distribution of ES (carbon stocks and water provision),

biodiversity (woody and bird richness) and conservation variables (threatened bird richness, habitats and geology) varies between PAs (with different protection status) and buffer zones; and (2) to quantify and compare the percentage of high values (hotspots) of ES, biodiversity and conservation variables inside PAs (with different protection status) and buffer zones.

Methods We analyzed 108 PAs from a Mediterranean region using linear mixed models with ES, biodiversity and conservation variables as response factors, and type of zone (PA vs buffer) and protection status as fixed factors.

Results We found higher values of carbon stocks in PAs than in buffer zones. We also found more coverage of community-interest habitats, priority-habitats and geological-interest sites in PAs than in buffer zones. However, PAs with higher degree of protection did not provide higher levels of ecosystem services and biodiversity, or vice versa. We found more hotspots of woody richness, bird richness and threatened bird richness in buffer zones than in PAs.

Conclusions This study highlights the importance of landscape planning in conservation, which should include PAs within broader landscapes by considering also their buffer zones and non-PAs. It also emphasizes the importance of integrating ES and biodiversity to define effective conservation policies.

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Introduction

Protected areas (hereafter PAs) are the main focus of conservation strategies. Currently, PAs represent 15% of the earth's surface and should increase to 17% by 2020 (CBD 2010). PAs have been established to avoid deforestation, preserve iconic landscapes and ecosystem representativeness, as well as to protect biodiversity and charismatic or endangered species (Eken et al. 2004; Hannah 2008). However, a considerable proportion of the world's PAs is being ineffective at achieving conservation targets, such as maximizing biodiversity and maintaining species populations (Wiersma and Nudds 2009; Geldmann et al. 2013).

Part of the conservation community claims that conservation should look at protecting, restoring and enhancing the services that nature provides to people (Doak et al. 2014), whereas others suggest that both biodiversity and ecosystem services (i.e., intrinsic and instrumental values, respectively) need to be included to achieve conservation objectives (Reyers et al. 2012). Although PAs provide multiple ecosystem services (hereafter ES), previous studies have generated diverse results regarding the type of ES. Some studies have showed that provisioning ES are more often found outside than inside PAs (Castro et al. 2015; Mukul et al. 2017), whereas others have found no negative impact of protection on provisioning services (Eastwood et al. 2016). Concerning regulating services, PAs are found to maintain carbon stocks and mitigate climate change by preventing deforestation, especially because forests are one of the most protected ecosystems (Rodríguez et al. 2013; Vačkář et al. 2016). Moreover, water-regulating services that are essential for ecosystem functioning (e.g., stream-flow and erosion control) and for human well-being (e.g., water quality) are found to be more preserved inside than outside PAs (Quijas et al. 2012; Dos Santos et al. 2018). PAs also supply multiple cultural services such as environmental education, recreation and aesthetic values (Palomo et al. 2013; Vlami et al. 2017), as well as socioeconomic benefits for local people (Oldekop et al. 2016). Therefore, there is not a decisive agreement regarding the effectiveness of conservation strategies in maintaining ES. One of the reasons of this divergence is that PAs should be considered with a landscape broader perspective, considering their surrounding land cover and land uses, because landscapes and species are dynamic so

that buffer zones surrounding PAs as well as other non-PAs can be relevant in conservation planning (Wiens 2009).

Biodiversity conservation has been one of the main priorities for establishing PAs. Some studies have indicated that PAs are an effective tool to maintain global (Butchart et al. 2012) and tropical biodiversity (Bruner et al. 2001), whereas others have suggested that current PAs are not sufficiently effective in conserving biodiversity at the global level, as PAs are neither ecologically representative nor efficiently allocated (Pimm et al. 2014; Venter et al. 2014). However, effective conservation strategies need to take into account that biodiversity has multiple organizational levels and spatial scales (Wu 2008) and that PAs exist within broader landscape mosaics that allow or interfere in the movement of species (Wiens 2009). PAs have been proved to be beneficial for species of conservation interest, such as endemic birds and endangered species (Le Saout et al. 2013). Together with the protection of particular species, the conservation of habitats has been claimed to be integrated in PA management (Brooks et al. 2002), because habitats with a good conservation status can provide more biodiversity and ES than habitats with unfavorable conservation status (Maes et al. 2012). Specifically, habitats of biological value, in danger of disappearance or with a small natural range have been a focus of protection (92/43/EEC). Previous studies have showed that PAs have lower rates of habitat loss than non-PAs (Joppa and Pfaff 2011; Geldmann et al. 2013), but others have suggested that PAs have not being effective in preventing habitat conversion (Clark et al. 2013). In addition, particular geologies (e.g., geological heritage sites) are also claimed to be considered inside PAs (Gordon et al. 2017) as geology is considered a framework for life on Earth (Brilha 2002). The importance of geological heritage conservation has been recognized by international institutions such as UNESCO and IUCN (2008).

The degree of protection in natural areas might influence the ES they provide. Strictly PAs (e.g., natural reserves) are found to provide the highest carbon storage by preventing the conversion from forests to agriculture or tourism areas (Castro et al. 2015). However, PAs with non-strict protection (e.g., Natura 2000 sites) are also found to be important for preserving ecosystem services and biodiversity (Gaston et al. 2008a; Bastian 2013). In fact, regulating and

provisioning services (e.g., fodder and water) are the highest in areas with lower-levels of protection, as local stakeholders are allowed to maintain traditional management of ecosystems that ensure the delivery of ES (Castro et al. 2015). Specifically, non-strict PAs are important for regulating services such as water purification or regulation (Castro et al. 2015; Manhães et al. 2016) and for cultural services such as socio-economic outcomes for local people (Oldekop et al. 2016).

The identification of areas with high values (hereafter “hotspots”) for different ES and biodiversity is essential to know whether priority areas for ES and biodiversity are located inside or outside PAs. Some studies have suggested that most of the ES hotspots are included inside PAs (García-Nieto et al. 2013), indicating that the conservation strategy provides ES. In contrast, other studies have showed that substantial portions of hotspots of ES are located outside PAs (Davids et al. 2016).

Given the above considerations, we aim to determine the role of PAs in preserving ES and biodiversity, with Catalonia as a case study. It is a region located in the Mediterranean Basin with around 60% of its surface covered by forests and shrublands. PAs in Catalonia are under different administrative levels (European, national, regional and provincial) and different protection levels (from strict to partial PAs). Together, all PAs in Catalonia cover 31% of the territory. Specifically, we aim (1) to know whether the spatial distribution of ES (carbon stocks and water provision), biodiversity (woody and bird richness) and conservation variables (threatened bird richness, habitats and geology) varies between PAs (with different protection status) and buffer zones; and (2) to quantify and compare the percentage of high values (hotspots) of ES, biodiversity and conservation variables inside PAs (with different protection status) and buffer zones. We considered the following hypotheses:

Hypothesis 1 PAs in this region are a useful tool to preserve ES and biodiversity, thus there are higher levels of ES, biodiversity and conservation variables (in the whole range of the variables and their hotspots) in PAs than in buffer zones, especially carbon stocks (Hypothesis 1.1) and biodiversity (Hypothesis 1.2). There is more water provision in buffer zones than in PAs because there PAs have more forest than buffer zones and highly vegetated areas consume more water

and contribute to the avoidance of water runoff, resulting in less water provision (Hypothesis 1.3).

Hypothesis 2 Regarding the protection status, higher levels of protection have higher levels of ES, biodiversity and conservation variables (in the whole range of variables and hotspots) (Hypothesis 2.1), except for bird richness and habitats of interest, that are higher in partial than moderate PAs because these areas are mainly Natura 2000 sites, designated for these purposes (Hypothesis 2.2).

Methods

Study area

The study was carried out in Catalonia (NE Spain), a region located between 40°5' and 42°9' latitude North and 0°2' and 3°32' longitude East (Fig. 1). Catalonia has a heterogeneous geomorphology and a large climatic gradient. It encompasses mountainous areas such as the Pyrenees (up to 3143 m.a.s.l), inland agricultural plains and coastal zones along the Mediterranean Sea. The climate is Mediterranean, with a mean annual temperature of 12.5 °C and a mean annual precipitation of 739 mm (Hijmans et al. 2005). Around 60% of the area is covered by forests and shrublands (MCSC 2005), the ecosystems considered in our study.

Type of zones

To determine the role of PAs in preserving ES and biodiversity in Catalonia, we considered three types of zones (Fig. 1): (a) protected areas; (b) buffer zones and (c) other unprotected areas. These three types are described as follows:

Protected areas

In Catalonia, 31% of the surface is under some degree of protection. As the World Database on Protected Areas (WDPA) does not reflect the regional variability on protection status in Catalonia, we grouped the existing PAs in Catalonia in three groups depending on their protection status (Fig. 1):

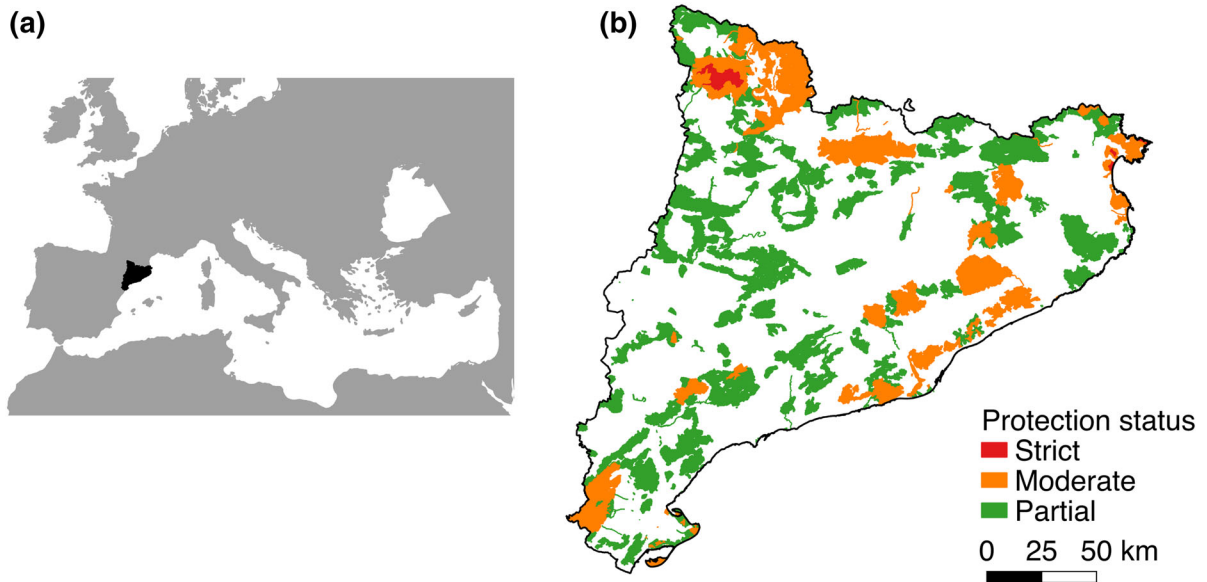


Fig. 1 **a** Location of the study area (in black) and **b** protected areas with different protection status

Strict protected areas Natural areas with a high ecological and cultural values, with little transformation from exploitation or human activities. Their protection is due to the beauty of their landscapes, the representativeness of their ecosystems or the singularity of their flora, fauna, geology or geological formations, that have important ecological, aesthetic, cultural, educative and scientific values and whose conservation deserves priority attention (<http://www.mapama.gob.es/es/red-parques-nacionales/sig/>). In the study area, this category includes a national park and two strict nature reserves.

Moderate protected areas Natural areas with a medium conservation level that allow traditional and cultural management practices. This includes 11 natural parks, 53 small partial natural reserves, 1 buffer zone of national park, 1 buffer zone of natural park, 7 national interest sites and 12 provincial parks.

Partial protected areas It includes 83 Natura 2000 areas without any of the above-mentioned protected status. Natura 2000 is a network aiming to ensure long-term survival of most valuable and threatened species and habitats of Europe, listed in the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC).

In cases of overlapping polygons with the same protection status (e.g., partial natural reserves inside natural parks), we dissolved them into one polygon. In cases of overlapping of polygons with different protection status, we classified them into the highest protection status.

Buffer zones

To provide similar environmental conditions and to avoid heterogeneity caused by location, we defined a buffer area of 5 km from each PA boundary (Fig. 1). These areas were used to compare the effect of protection with PAs in the provision of ES, biodiversity and conservation variables and covered the 54% of the study area.

Other unprotected areas

These areas are defined as the rest of the territory of Catalonia that was neither protected nor a buffer zone, covering the 16% of the study area.

Ecosystem services, biodiversity and conservation variables

In order to have the same scale for the two main data sets (forest inventory plots and Breeding Bird Atlas),

we defined a reference grid at 1×1 km resolution. All variables were computed at this scale and were afterwards upscaled at the PA/buffer scale (Table 1 in Online Appendix 1).

Ecosystem services

Carbon stocks There were four different grid nodes including different sources of information: (a) nodes including a forest inventory plot, according to the Land Cover Map of Catalonia (MCSC 2005); (b) nodes without forest inventory plot but including trees; (c) nodes without forest inventory plot and corresponding to shrubland; and (d) nodes corresponding to other land cover types (grasslands, outcrops, agricultural areas, etc.). We computed carbon stocks for the first three types of nodes.

Forest with inventory data: The third Spanish National Forest Inventory (IFN3) was conducted in Catalonia between 2000 and 2001 (Ministerio de Medio Ambiente 2007). The data consisted of a systematic sampling of permanent plots with a sampling density of one plot in every 1 km^2 of forest area, where woody species were identified and measured within variable circular size. Tree biomass (above-ground + belowground) of each live tree in each forest inventory plot was computed from dbh using species-specific allometric equations developed by Gracia et al. (2004) and Montero et al. (2005).

Forest without inventory data: In these plots, the dominant tree species were identified using the Land Cover Map of Catalonia (Ibañez and Burriel 2010) (Online Appendix 2). Aboveground biomass was computed with statistical models from LIDAR data, that were calibrated using forest inventory plots from the third Spanish National Forest Inventory (Ministerio de Medio Ambiente 2007). Belowground biomass was computed using the same species-specific allometric equations as outlined for plots with inventory data (previous section).

Shrubland: After selecting the nodes without forest inventory plot but classified as shrubland, according to the Land Cover Map of Catalonia (MCSC 2005), we selected the data from the third Spanish National Forest Inventory (Ministerio de Medio Ambiente 2007) that was analogous to shrublands (i.e., open-forests inventory plots with basal area $< 5 \text{ m}^2/\text{ha}$). We grouped them into similar biomass groups depending on their main species following

Pasalodos-Tato et al. (2015) to obtain mean values of shrub carbon in relation with their dominant shrub species. In each node of this category, we carried out a photointerpretation of aerial images to estimate shrub-cover, and dominant species were identified using the Catalan Habitats Map (Carreras and Ferré 2014). Then, shrub biomass in each node was computed following the expression:

$$\text{Shrub biomass} = \bar{b}_i * c$$

where \bar{b}_i is the average value of biomass of the species i and c is the percentage of shrub coverage at the node (Online Appendix 2). To obtain carbon stocks from biomass data in the three types of nodes above stated, we applied the relationship of 1:0.5 between biomass and carbon (McGroddy et al. 2004).

Water provisioning Blue water was defined as the sum of water exported daily via runoff and deep drainage. Annual sums of daily blue water were calculated for each 1 km cell by applying the water balance model described De Cáceres et al. (2015). Details of each of the eco-hydrological processes considered and species parameter values of the model are given in De Cáceres et al. (2015) and in Online Appendix 3.

We calculated the proportion of annual blue water over annual precipitation, and selected the 10-year period 1993–2002 to account for the interannual variability in the water balance and to adjust to the periods of the rest of the data (Table 1 in Online Appendix 1).

Biodiversity

We computed biodiversity from two taxonomic groups of species: woody species and birds. We used these two taxonomic groups of species because woody species include trees and shrubs so they can provide different habitats, whereas birds represent the group of vertebrates where we have one of the most extensive databases and an in-depth knowledge of their relationships with forests at global scale (Gil-Tena et al. 2007; Drever et al. 2008).

Woody species richness Woody species richness was computed in the same three grid nodes as in the Carbon stocks section.

Forest with inventory data: In the nodes with data from the IFN3, we counted the number of woody species (tree and shrubs) in each plot.

Forest without inventory data: We developed two linear models, one for tree species richness and the other one for shrub species richness as response variables, respectively (Online Appendix 4). The explanatory variables in the models were: location (x and y coordinates), shrub carbon stocks (Mg C/ha), tree carbon stocks (Mg C/ha), slope (°), mean annual temperature (Hijmans et al. 2005), mean annual precipitation (Hijmans et al. 2005) and main forest species. We therefore applied these models ($R^2 = 0.24$, p value < 0.001 and $R^2 = 0.51$, p value < 0.001 for tree and shrub richness, respectively) to forest nodes without inventory data. We computed woody species richness in a plot by adding tree and shrub species richness values obtained for this plot (Online Appendix 4).

Shrubland: We developed a linear model for shrub species richness using data of open forest inventory plots (i.e., plots with basal area < 5 m²/ha, the most similar to shrublands) (Online Appendix 4). The explanatory variables were location (x and y coordinates), shrub carbon stocks (Mg C/ha), slope (°), mean annual temperature (Hijmans et al. 2005) and mean annual precipitation (Hijmans et al. 2005). This model ($R^2 = 0.49$, p value < 0.001) was applied to obtain shrub species richness in nodes without forest inventory plot and corresponding to shrubland, according to the Land Cover Map of Catalonia (MCSC 2005) (Online Appendix 4).

Bird richness We used the accumulative number of bird species observed in each 1×1 km cell from the second Catalan Breeding Bird Atlas (Estrada et al. 2004). It was conducted in 1999–2002 at a 10×10 km cell and downscaled to 1×1 km cell. Given that ecosystem services were only assessed in forest and shrub areas, we only considered those bird species having forest (both forest specialist and forest generalist) and shrub habitats.

Conservation variables

As conservation strategies rely on PAs, we included variables directly related to conservation, most of them coming from two of the powerful international

legal tools for nature protection (Birds and Habitats Directives).

Threatened bird richness The Birds Directive aims “to protect the 500 wild bird species naturally occurring in the European Union” (79/409/EEC). From these, 194 species are particularly threatened and are included in the Annex I from the Directive. We selected bird species with forest and shrub habitats that were listed in the Birds Directive annex (79/409/EEC), because they represent a conservation value at the European extent and are subject of special conservation measures. We therefore counted the number of these species within each 1×1 cell from the second Catalan Breeding Bird Atlas (Estrada et al. 2004).

Habitats The Habitats Directive (92/43/EEC) has listed habitats of European concern to ensure biodiversity through the conservation of rare and characteristic natural habitat types (92/43/EEC). As one of the most important aspects in conservation strategies is the maintenance of habitats, we have defined two types of habitats from the Habitats Directive (92/43/EEC), from which we quantified their percentage of surface in each PA and buffer zone: habitats of Community interest and priority habitats.

Habitats of community interest: Defined as natural habitats types that “(1) are in danger of disappearance in their natural range; or (2) have a small natural range following their regression or by reason of their intrinsically restricted area; or (3) present outstanding examples of typical characteristics of one or more of the five following biogeographical regions: Alpine, Atlantic, Continental, Macaronesian and Mediterranean” (92/43/EEC). As the map has different habitats in the same polygon, we selected the habitats classified as forested and shrublands habitats having the highest coverage within each polygon.

Priority habitats: We selected the habitats from the previous classification defined as “natural habitat types in danger of disappearance [...] and for the conservation of which the Community has particular responsibility in view of the proportion of their natural range which falls within the territory”, also defined as “threatened to disappear in the EU” (92/43/EEC).

Geological-interest sites Geology has important conservation values for being part of all natural

systems, providing framework for life on Earth, thus it is claimed to be integrated into PA management (Brilha 2002). The inventory of Catalan geological-interest sites is a map with a selection of rocky outcrops and geological-interest sites needed to be preserved as geological heritage. This inventory is defined as a framework for decision-making in landscape planning and management (“Inventari d’espais d’interès geològic”). We quantified the percentage of surface of geological-interest sites in each PA and buffer zone.

Hotspot delimitation

We applied the 20th percentile (Armenteras et al. 2015; Mora et al. 2016), which defines 20% of the cells with the highest values for each variable. We computed each variable at the 1×1 cell scale (Table 1 in Online Appendix 1) to obtain a numerical value for each variable in each cell. We then selected the 20% of cells with the highest values for each variable and defined them as hotspots. We generated one hotspot map for each ES, biodiversity and conservation variable.

Comparison between protected areas and buffer zones

To quantify and compare PAs (with different protection status) and buffer zones in terms of ES, biodiversity and conservation variables considering the whole range of the variables (i.e., not their hotspots), we computed the average value of each variable of all nodes in the PA and in the buffer zone. As the surface of forest and shrubs was not proportional to the total surface of the protected/buffer area, we weighted the average value of each forest and shrub variable by the percentage of surface of forest and shrubs, respectively (except for geological-interest sites, that were not dependent on forest and shrub surface). To obtain the averaged value for each variable in each PA/buffer area, we summed and divided them by the total percentage of forest and shrubs, as follows:

$$X = \frac{\bar{x}_f \cdot a_f + \bar{x}_s \cdot a_s}{a_f + a_s}$$

where \bar{x}_f and \bar{x}_s are the average of the variable x in forested (f) and shrubland (s) areas, respectively; a_f and a_s are the percentage of forest and shrub area within each protected/buffer area.

In the case of hotspots, we quantified the percentage of hotspots of each variable (i) in each PA/buffer zone (j) as follows:

$$\text{hotspots (\%)} = \frac{s_i^j}{s_i} * 100$$

where s_i^j is the surface of hotspots of the variable i in the PA/buffer zone j and s_i is the total area of hotspots of the variable i in the whole study area.

Data analysis

To determine the differences in ES, biodiversity and conservation variables between PAs and buffer zones, as well as in PAs with different protection status, we used linear mixed models with the ES, biodiversity and conservation variables as response variables (carbon stocks (Mg/ha), water, biodiversity—woody richness, bird richness—, threatened bird richness, habitats of community interest (%), priority habitats (%) and geological-interest sites (%)). Data on habitats of community interest, priority habitats and geological-interest sites were transformed (using square root, logarithm and square root, respectively) to meet the assumptions of normality of residuals. Fixed factors were type of zone (PA or buffer zone), protection status (moderate and partial, because due to the low sampling size, i.e., 3, we excluded strict-PAs from the analyses) and their interaction. We include each PA, together with their buffer zone, as a random effect to account for masking-effect of location. In the case of hotspots analysis, the same analyses were carried with percentage of hotspots surface as response variable. We log-transformed carbon stocks and geological-interest sites and calculated the square root of the rest of the hotspots variables to reach normality. In this case, we also included the area of forests and shrubs in each PA as a fixed factor.

Results

Ecosystem services, biodiversity and conservation variables in protected areas and buffer zones

The results of linear mixed models showed that carbon stocks were significantly higher in PAs than in buffer zones, whereas water provision was not significant

(Table 1, Fig. 2a). None of biodiversity variables considered showed differences between PAs and buffer zones. However, conservation variables of community-interest habitats, priority habitats and geological-interest sites showed more coverage inside PAs than in buffer zones (Table 1, Fig. 2a).

Focusing on PAs, we found that carbon stocks and geological-interest sites were significantly different depending on the protection status (moderate or partial), as there were more carbon stocks and more surface of geological-interest sites in moderate than in partial PAs (Table 1, Fig. 2b).

Hotspots of ES, biodiversity and conservation variables inside and outside PAs

The highest values (i.e., hotspots) of the variables showed a different pattern than considering their whole range (Table 2, Fig. 3). Although hotspots of carbon stocks, bird richness, community-interest habitats and priority-habitats showed more coverage in PAs than in buffer zones (Table A3), the results varied when applying the mixed models. Thus, we found more hotspots of woody richness, bird richness and threatened bird richness in buffer zones than in PAs (Table 2, Fig. 3). However, hotspots of priority habitats and geological-interest sites followed the same pattern as when considering the whole range of the variables (i.e., higher in PAs than in buffer zones). When considering protection status, none of the

variables showed significant differences between protection levels (Table 2).

Discussion

Ecosystem services, biodiversity and conservation variables in protected areas and buffer zones

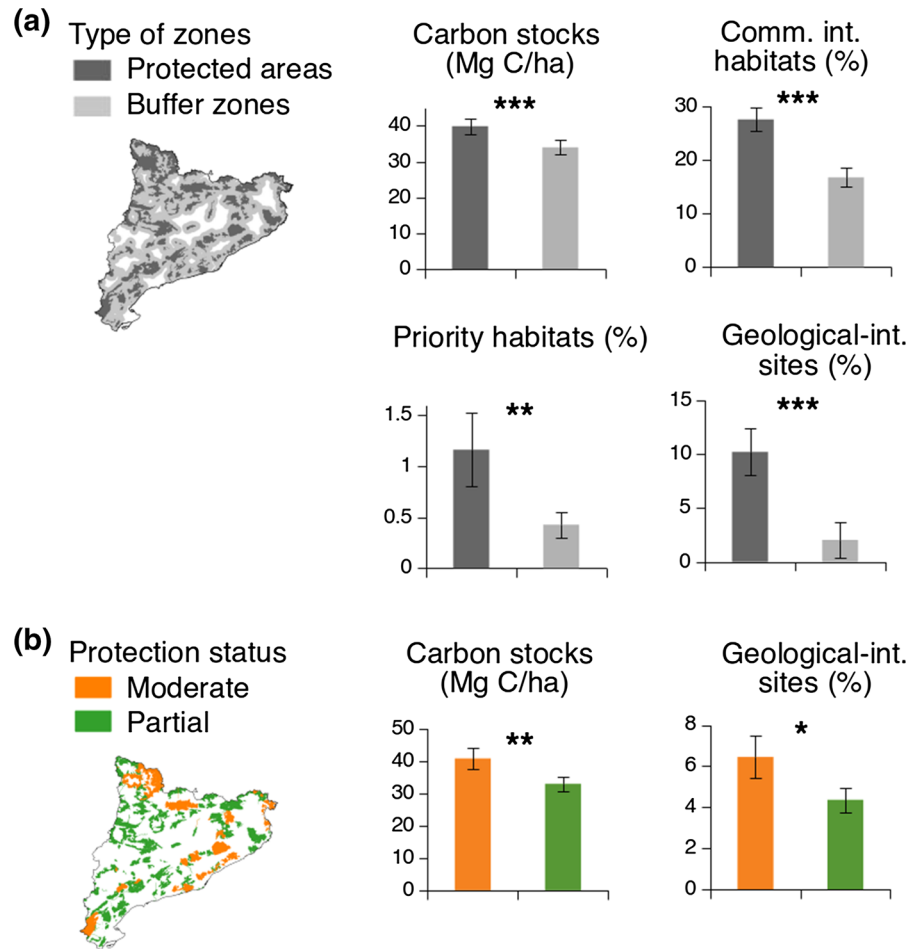
Overall, some of our findings agreed with our initial hypotheses. As expected in Hypothesis 1.1, carbon stocks were higher in PAs than in buffer zones (Table 1, Fig. 2a). We expected more water provision in buffer zones than in PAs (Hypothesis 1.3), but we did not find significant differences between them. PAs have been shown to be effective in avoiding deforestation and consequently maintaining carbon storage (Andam et al. 2008; Vačkář et al. 2016). But this is not the case of Catalonia as many other European and Mediterranean areas, where forest surface increased since the mid-20th century due to agricultural abandonment (Bielsa et al. 2005; Améztegui et al. 2010). However, the percentage of forests and shrublands in our study is higher in PAs than in buffer zones ($51 \pm 27\%$ of forests and $22 \pm 19\%$ of shrubs in PAs; $36 \pm 22\%$ of forests and $14 \pm 8\%$ of shrubs in buffer zones). Most PAs are located in mountainous areas, where the highest values of carbon stocks are found (i.e., north of Catalonia, Pyrenees and Pre-Pyrenees, as well as coastal mountainous plains) (Fig. 1b). Other

Table 1 Results of the linear mixed models (t-value and level of significance) for ecosystem services, biodiversity and conservation variables

	Ecosystem services		Biodiversity		Conservation			
	Carbon stocks (Mg C/ha)	Water provision	Woody richness	Bird richness	Threatened bird richness	Habitats Comm.interest habitats (%) Priority habitats (%)	Geology Geological-interest sites (%)	
Intercept	13.1***	15.5***	20.4***	15.0***	20.5***	15.4***	− 8.4***	12.8***
Type of zone: buffer zone	− 3.8***	1.8	0.7	− 1.6	1.0	− 4.5***	− 3.1**	− 6.5***
Protection status: partial	− 2.8**	0.8	0.5	− 1.1	0.9	− 0.2	− 0.3	− 2.4*
Buffer zone * protection status: partial	2.6*	− 0.3	1.3	1.0	− 0.5	0.1	2.0	1.9

Signification codes: *** < 0.001, ** < 0.01, * < 0.05

Fig. 2 Plot bars of mean values and standard error of the studied variables showing significant differences between **a** the types of zones (protected and buffer) and **b** the protection status (moderate and partial). Signification codes: *** < 0.001, ** < 0.01, * < 0.05



studies have already showed that location of PAs is biased towards higher elevation, steeper slopes and greater distances to roads and cities (Joppa and Pfaff 2009), and that forests have higher protection coverage than other land-uses (Hermoso et al. 2018). Besides, contrarily as expected (Hypothesis 1.3), no significant differences in water provisioning between PAs and buffer zones were found (Table 1). In this region, there is more forest percentage in PAs than in buffer zones. As forests use more water and contribute more to the avoidance of water runoff than shrublands, water provision and runoff was expected to be lower in forests than in shrublands (Brauman et al. 2007). But PAs have also more percentage of shrubs than buffer zones, which results in higher levels of water provisioning than expected. Thus, no significant results suggested that other factors operating at local scales can be influencing water provisioning, such as micro-climatic effects or the particular type of vegetation

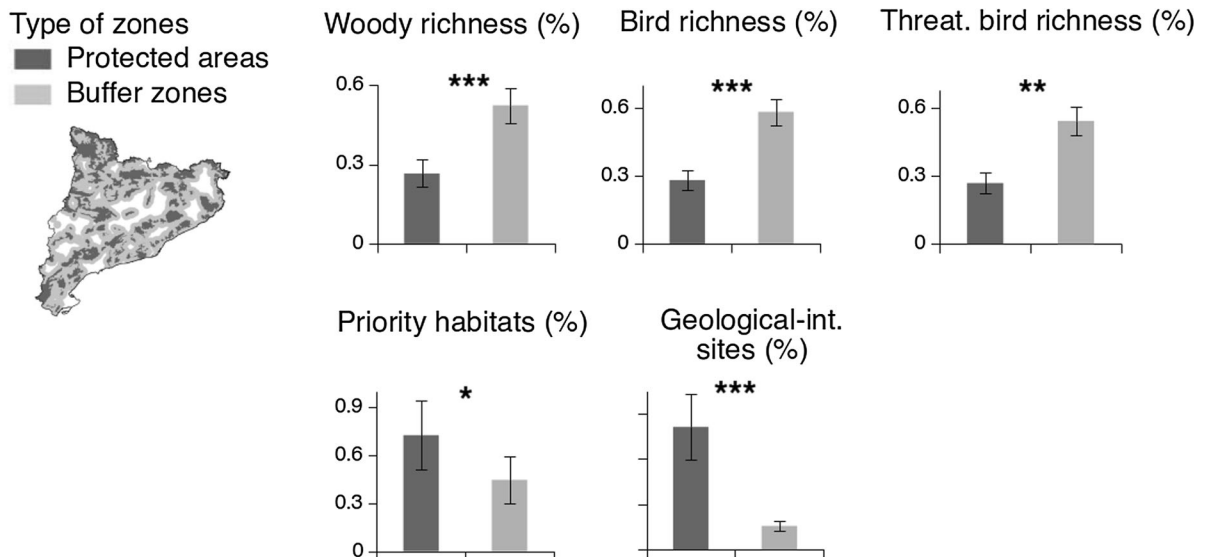
(e.g., species with different root depths) (Scott et al. 2000; Brauman et al. 2007).

Although we expected higher biodiversity in PAs than in buffer zones (Hypothesis 1.2), none of the biodiversity variables showed differences between PAs and buffer zones (Table 1, Fig. 1 in Online Appendix 1). These results reinforce that PAs exist within broader landscape mosaics that allow or interfere in the movement of species (Wiens 2009). Additionally, we analyzed the results of a qualitative assessment made by the Catalan Government that looked at ES in PAs, and we found that biodiversity was the predominant supporting ES in Catalan PAs (Fig. 2 in Online Appendix 5). These results suggested that other biodiversity components can be relevant in PAs, such as other groups of species (plant, invertebrates, other terrestrial vertebrates, etc.) or other elements of diversity (functional diversity, endangered or rare species) (Brooks et al. 2006; Maiorano

Table 2 Results of the linear mixed models (t-value and level of significance) for hotspots of ecosystem services, biodiversity and conservation variables

	Ecosystem services		Biodiversity		Conservation			
	Carbon stocks (Mg C/ha)	Water provision	Woody richness	Bird richness	Threatened bird richness	Habitats Comm.interest habitats (%) Priority habitats (%)	Geology Geological-interest sites (%)	
Intercept	− 20.6***	7.1***	2.6*	2.0	1.9	5.7***	1.9	− 11.7***
Area of forests and shrubs	8.1***	18.6***	8.3***	12.6***	9.8***	14.3***	3.4**	5.3***
Type of zone: buffer zone	− 0.03	1.6	3.7***	4.7***	3.4**	− 1.7	− 2.1*	− 5.3***
Protection status: partial	0.03	0.4	0.5	0.6	1.7	0.2	0.4	− 0.7
Buffer zone * protection status: partial	0.02	0.3	− 0.2	− 0.4	0.8	− 0.02	1.8	2.1*

Signification codes: *** < 0.001, ** < 0.01, * < 0.05

**Fig. 3** Plot bars of mean values and standard error of hotspots showing significant differences between the types of zones (protected and buffer). Signification codes: *** < 0.001, ** < 0.01, * < 0.05

et al. 2015). But even when looking at other species, previous studies have revealed contradictory results. Some studies have showed a positive effect of PAs in birds, vertebrates (mammals, amphibians, reptiles) and arthropods, through reducing extinction risks (Butchart et al. 2012) and resulting in higher biodiversity in PAs than not PAs (Coetzee et al. 2014). But others have indicated that these groups of species are

not well covered in PAs (Brooks et al. 2004). Specifically, results vary when looking at specific groups of species, such as migratory birds which are not adequately covered by PAs (Runge et al. 2015). In our study, some PAs in Catalonia were designated to protect species that, in the case of birds, were not considered in our study because their habitat was not forest nor shrubland (e.g., *Aquila fasciata*, *Neophron*

percnopterus, *Falco peregrinus*, etc.). However, the effect on diversity of plants is not conclusive, as some studies have showed high tree diversity in good conservation status areas (Maes et al. 2012), whereas others indicate that plants are not well represented in PAs (Coetzee et al. 2014).

When considering conservation variables, we found higher coverage of community-interest habitats, priority habitats and geological-interest sites in PAs than in buffer zones (Table 1, Fig. 2a), as expected in Hypothesis 1. As stated before, most studied PAs are located in mountainous areas, thus higher coverage of forest and shrub community-interest habitats in PAs than in buffer zones could be expected. Even so, these results proved that the Habitats Directive is being effective in having more coverage of these habitats inside PAs than in the buffer zones. But we still do not know if this amount of coverage is sufficient, and an exhaustive evaluation of these habitats regarding their quality and conservation status (e.g., degradation and fragmentation) (Wilson et al. 2016; Sallustio et al. 2017), as well as their changes over time (Bunce et al. 2013) is needed to fully understand if community-interest habitats and priority habitats are achieving conservation goals. We also found more coverage of geological-interest sites inside PAs than in buffer zones, particularly because some specific PAs include geological heritage as an important value of conservation. In fact, the importance of geodiversity is stated in the qualitative assessment of ES in Catalan PAs (made by the Catalan Government) as it is, after biodiversity, the second most frequent supporting ES qualified as very important (Fig. 2 in Online Appendix 5).

Concerning protection status, moderate PAs have more carbon stocks than partial PAs (Table 1, Fig. 2b) because partial PAs are mainly Natura 2000 sites which were not being designated for carbon sequestration purposes (Hypothesis 2). In addition, moderate PAs are located in places with higher water availability (i.e., northern areas and mountainous areas, Fig. 1), resulting in higher levels of carbon storage (Zhao and Zhou 2006; Fischer et al. 2014). As partial PAs were mainly Natura 2000 areas, we expected higher levels of threatened bird richness, community-interest habitats and priority-habitats in partial than moderate PAs (Hypothesis 2.2). But we found no differences between protection statuses, suggesting that moderate PAs are also contributing to these variables. However,

previous studies showed that international conservation policies as Natura 2000 succeeded in covering threatened species stated in the Directive (Donald et al. 2007; Kukkala et al. 2016). In fact, the only conservation variable showing differences between protection status was the percentage of geological-interest sites, that was higher in moderate than partial PAs particularly because some specific moderate PAs were designated, among other reasons, for being geologically singular (e.g., ‘Serra del Montsant’ or ‘Zona volcànica de la Garrotxa’).

Hotspots of ES, biodiversity and conservation variables inside and outside PAs

Priority areas for conservation could be defined by identifying areas of high values of ES and biodiversity. Our results have showed that, contrarily as expected (Hypothesis 1), we found more hotspots of woody richness, bird richness and threatened bird richness in buffer zones than inside PAs, but more hotspots of priority habitats and geological-interest sites in PAs than buffer zones (Table 2, Fig. 3) (Hypothesis 1). In fact, the study of Rocés-Díaz et al. (2018) showed a negative relationship between bird richness and the existence of Natura 2000 sites in the same study area. However, previous studies have showed high tree species diversity in habitats with good conservation status (Maes et al. 2012). In this sense, although we found more hotspots of priority habitats in PAs, we lack information about the quality of the habitats and their conservation status, which might not be adequate inside PAs, thus resulting in lower levels of biodiversity. In addition, these results highlight the necessity of an effective management and the importance of conserving biodiversity not only inside PAs but also in their surrounding buffer zones (Cox and Underwood 2011). These buffer zones containing hotspots of biodiversity can be seen as an opportunity to delineate a network of green infrastructure that would enhance connectivity between PAs, already stated in the study of Lanzas et al. (2019). Moreover, the coverage of geological-interest sites was higher inside PAs than buffer zones either considering their whole range or their highest values (i.e., hotspots). Geological sites were one of the reasons of many PAs designation (especially in moderate PAs). The integration of geology in PAs is of great value because geological features and processes contribute to

biodiversity and it is considered an integral part of nature conservation. UNESCO Geoparks, which are defined as ‘single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development’ have already included the Central Catalonia UNESCO Geopark with two natural parks that have geological-interest sites, but the Catalan inventory includes many other sites, thus expanding the geological protection of the territory.

Concerning protection status, contrarily as expected (Hypothesis 2), none of the hotspots variables showed significant differences between moderate and partial PAs (Table 2, Fig. 2 in Online Appendix 1), meaning that a high degree of protection was not providing high levels of ES and biodiversity. In fact, partial PAs or non-strict levels of protection are found to be important for preserving biodiversity, but for other groups of species such as terrestrial vertebrates (Maiorano et al. 2015). Previous studies also stated that PAs with non-strict protection are important to maintain ES and biodiversity (Gaston et al. 2008b; Bastian 2013).

Conclusions

The conservation strategy in Catalonia was only effective at maintaining some of the ES and conservation variables considered. Higher values of carbon stocks were found in PAs than in buffer zones, and more coverage of community-interest habitats, priority-habitats and geological-interest sites in PAs than in buffer zones. PAs with higher degree of protection did not provide higher ecosystem services and biodiversity, or vice versa. We unexpectedly found more hotspots of woody richness, bird richness and threatened bird richness in buffer zones than in PAs. Our study provides a first step on a more in-depth evaluation of ES in PAs that can be applied to other regions, but a detailed analysis of each individual PA including more ES and conservation indicators is needed. Specifically, ES relevant for the specific stakeholders in each PA need to be considered. Cultural ES were not included in this study and they are proved to be important in the study area (Roces-Díaz et al. 2018), especially in PAs (Fig. 1 in Online

Appendix 5). Likewise, other ecosystems like freshwater or farmlands can provide essential ES.

Future scenarios of climate change in the Mediterranean area advert significant and increasing risks during next decades (Cramer et al. 2018). Forest productivity is expected to decline due to increased extreme events such as droughts and fire (Lindner et al. 2010). Global biodiversity indicators have showed declines during past years while, at the same time, pressures on biodiversity have increased (Butchart et al. 2010). Under these circumstances, it is a priority to identify which species, functions, and ecological processes are behind the loss of biodiversity to adequately apply the right conservation strategies. Future landscape configuration for conservation should take into account that species distributions might change under climate change scenarios, thus should not be only focused in PAs as an isolated system. In fact, PAs exist within broader landscape mosaics that can influence the movement of species (Wiens 2009), thus landscape conservation planning should also include buffer zones and non-PAs. Furthermore, scientific evaluation and monitoring of the impact that landscape management interventions have on particular PAs and their buffer zones is needed and should be done recognizing the dynamic nature of landscapes and their species (i.e., not relying on fixed lists of species) (Hermoso et al. 2017). Landscape ecology and sustainability science need to be integrated to develop comprehensive conservation strategies that consider the dynamic interactions between nature and society (Wu 2008).

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