Vol. 35: 125–139, 2018
https://doi.org/10.3354/esr00878

ENDANGERED SPECIES RESEARCH
Endang Species Res

Published March 15

Representation and protection of threatened biodiversity by the largest Spanish regional network of protected areas

David Rodríguez-Rodríguez[1,2,*], Javier Martínez-Vega[1]

[1]Institute of Economy, Geography and Demography, Spanish National Research Council (IEGD-CSIC), Associated unit GEOLAB, 28037 Madrid, Spain

[2]Andalucía Tech, European Topic Centre, University of Malaga, 29010 Málaga, Spain

ABSTRACT: The main global strategy to stop biodiversity loss is the designation of protected areas (PAs). Spain is a highly biodiverse country. It has one of the world's greatest terrestrial PA coverages. However, the status of its biodiversity is delicate as a result of serious pressures, and some important areas for biodiversity are outside PAs. We used official census data to spatially assess how 71 habitats of community interest (HCIs), 126 regionally threatened flora, fauna and fungi species and subspecies (RTSs), and 33 globally threatened species or subspecies (GTSs) are represented in a network of 404 PAs in Andalusia, a region rich in biodiversity in southern Spain. We also assessed the legal and managerial protection afforded to these threatened habitats and species by those PAs. The Andalusian PA network expands across one-third of the region's territory and includes the threatened species' richest areas. However, it only covers 57 % of the area of occupancy of RTSs, 81 % of the regional area of occupancy of GTSs, and 53 % of the extent of HCIs. Over 61 % of the regional PA network area is assigned more than 1 PA designation category, although cumulative legal protection is marginally related to RTS richness and unrelated to GTS richness. RTSs and especially GTSs occupy the most relative area in Ramsar sites (i.e. wetlands of international importance), although these are of relatively minor importance for threatened habitats. Wetlands and agricultural areas are the broad ecosystem types showing the greatest numbers of RTSs and GTSs. Seven GTSs were not included in the Andalusian Register of Threatened Species. One hundred and eleven unprotected Areas of High Importance for Threatened Species (AHITSs) and one Area of High Importance for Threatened Biodiversity (AHITB) were identified. Those species and sites are good candidates for a targeted expansion of legal protection of biodiversity in the region.

KEY WORDS: Endangered species · Endangered habitats · Land use-land cover · Gap analysis · Reserves · Andalusia

INTRODUCTION

Biodiversity is defined as the variability among living organisms, including diversity within species, between species and of ecosystems (CBD 1992). Global biodiversity is seriously declining due to human activities which result in habitat destruction, fragmentation and pollution, direct persecution, climate change and the introduction of alien invasive species (Gaston et al. 2008, Butchart et al. 2010, WWF 2016). The main global strategy to stop global biodiversity loss is the designation of protected areas (PAs) (Dudley 2008, Gaston et al. 2008). In the European Union (EU), the Habitats Directive (EEC 1992) created a wide ecological network of PAs to protect sensitive species and habitats in Europe: the Natura 2000 net-

*Corresponding author: david.rodriguez@csic.es

Publisher: Inter-Research · www.int-res.com

work. It distinguishes 2 types of PAs: Sites of Community Importance (SCIs)/Special Areas of Conservation (SACs), for the conservation of natural and semi-natural habitats and wild species of flora and fauna, except bird species; and Special Protection Areas (SPAs), for the conservation of wild bird species, according to the EU Birds Directive (EEC 1979). The Natura 2000 network includes >27 000 sites that span across 18% of the terrestrial territory of the EU (EC 2016). Despite the continuous growth in PA coverage worldwide, concerns are expressed that important areas for biodiversity are not included in PA networks, that PA effectiveness evaluations still need to be generalised (Juffe-Bignoli et al. 2014, Bhola et al. 2016) and that protection afforded to existing PAs might not be sufficient to avert biodiversity loss (Craigie et al. 2010, Laurance et al. 2012).

Spain is a highly biodiverse country in the European context (Múgica et al. 2010). It is located in the Mediterranean basin, one of the global biodiversity hotspots critical for biodiversity conservation (Myers et al. 2000). Moreover, southeastern Spain is considered one of the top 10 fine-scale biodiversity hotspots around the Mediterranean basin in terms of plant species richness and endemicity (Médail & Quézel 1999). Accordingly, Spain's terrestrial PA network covers more than 27% of its land and freshwater territory (Múgica et al. 2014), largely exceeding international PA coverage targets at 17% by 2020 (CBD 2010). However, the status of Spanish biodiversity, especially of coastal biodiversity, is delicate, mainly due to extensive habitat destruction and degradation in recent decades (Estévez et al. 2016), and important areas for biodiversity are outside PAs (Muñoz-Rodríguez et al. 2016, Zamora-Marín et al. 2016). In addition, restoration plans for threatened species are scarce and not always implemented (Jiménez 2012). Finally, regular, systematic and comprehensive evaluation of the effectiveness of the country's PAs is restricted to the National Park network (Rodríguez-Rodríguez et al. 2015a) and the periodic (though of improvable completeness and accuracy) reporting on the status of species and habitats under Habitats Directive obligations (EEC 1992).

Spain is a highly decentralised country, with 17 regional governments. The Spanish government is responsible for making and passing basic legislation on nature conservation that all the regions must abide by. However, most nature conservation policies, including the legal protection and management of species and PAs, are regional competencies in Spain. The Andalusian network of PAs is the broadest and most numerous sub-national PA network in the EU (Andalusian Government 2016a). However, most regional PA designations occurred in the late 1980s on the basis of limited ecological knowledge, when Andalusia was transferred the administrative competencies for designation and management of PAs and passed its own law on PAs (Andalusian Government 1989). Yet the first PA in the region was designated as early as 1969 (i.e. Doñana National Park). Since those days, PA designation criteria and ecological knowledge have evolved (Múgica et al. 2002), making it advisable to assess whether the regional PA network has grown in an ecologically consistent manner and is currently fit for the purpose of conserving threatened biodiversity, as national and international regulations require (Spanish Government 2007, CBD 2010).

Therefore, this study seeks to (1) spatially assess whether threatened biodiversity, including species, subspecies and habitats, is adequately represented in the regional PA network; (2) ascertain the regional distribution of threatened biodiversity by broad ecosystem types; (3) estimate the legal and managerial protection afforded to threatened biodiversity; and (4) spatially analyse whether areas rich in threatened biodiversity exist outside current PAs, with a view to proposing sustainable territorial planning and management recommendations.

METHODS

Study area

Andalusia is the second biggest autonomous region in Spain, covering >87 000 km^2, or 17% of the country's territory. It is entirely in the Mediterranean biogeographical region (EEA 2012), where nearly half of the species and more than half of the habitats included in the Habitats Directive are found (Barredo et al. 2016), and where habitat conversion exceeds habitat protection by a ratio of 8:1 (Hoekstra et al. 2005).

Andalusia was chosen for this study for being a biodiversity-rich region subject to numerous threats (Andalusian Government 2014, 2015). It also has the most comprehensive, consistent and updated official repository of data on biodiversity of conservation importance of all the Spanish regions. Moreover, in 2013 almost 19% of Andalusian territory was covered by regional PA designation categories, reaching 30% if Natura 2000 sites were included, making it the largest regional PA network in Spain in absolute terms (Múgica et al. 2014; our Fig. 1). Finally, biodi-

Fig. 1. Andalusia and its protected area network in the administrative regional map of Spain (except the Canary Islands Region)

versity management is a regional competency in Spain. Thus, from a practical, administrative point of view, regional analyses are the most meaningful scale for proposing biodiversity conservation measures in the country.

Definitions, assumptions and data sources

In this study, we considered 'threatened biodiversity' to be (1) threatened species and subspecies, and (2) habitats of community interest (HCIs). For linguistic simplicity, we will refer to 'species' and 'subspecies' simply as 'species'. According to the Habitats Directive, HCIs are those entirely natural or semi-natural habitats that, within the territory of EU member states (1) are endangered, or (2) have a small natural range, or (3) are representative of the biogeograhical regions present in the territory of the EU (EEC 1992).

We were provided comprehensive official vector distribution data for terrestrial and freshwater species of flora, fauna and fungi for which official monitoring had been done in the region (Andalusian Government 2017a). These data were provided by the Regional Ministry of Environment at 1 km^2 spatial resolution. Restricting our analysis to complete regional censuses between the years 2010 and 2014 resulted in 617 species. Of these, the 126 species that were included in the Andalusian Register of Threatened Species under the categories Extinct, Endangered, or Vulnerable (regionally threatened species or RTSs; Andalusian Government 2017b), and the 33 species that were included in the IUCN Red List under the categories of Regionally Extinct, Critically Endangered, Endangered, or Vulnerable (globally threatened species or GTSs) were selected for our analysis of threatened species (IUCN 2017).

Regional registers of threatened species are official lists that must abide by the Spanish Register of Threatened Species (Spanish Government 2007, 2011), which classifies species according to their degree of threat at the country scale based on specific scientific criteria on population trends, areas of occupancy, or population viability analyses (Spanish Government 2017). Regional registers must include the species in the Spanish Register that inhabit the region of concern with at least the same threat category as in the Spanish Register or higher, as assessed at the regional scale. The inclusion of a taxon in one of these registers implies a legal obligation for the respective regional government to conduct periodic censuses and conservation actions, depending on the category of threat.

Spatial data for the 71 HCIs identified in the region (Andalusian Government 2015) were downloaded from the regional ministry's environmental information website (Andalusian Government 2016b). For habitats, we considered their regional extent, a globally recommended criterion for assessing the conservation status of habitats (Bland et al. 2017). Both the complete species layer and the HCIs layer included data updated in 2015.

We defined regional Areas of High Importance for Threatened Species (AHITSs) as those unprotected areas ≥100 ha in which at least 1 GTS or 3 RTSs occur. Areas of High Importance for Threatened Biodiversity (AHITBs) were defined as AHITSs that spatially coincide with HCIs. New possible PAs in the region were identified by selecting areas that qualify as AHITSs or AHITBs. To assess 'protection' of PAs, we followed the definition by Rodríguez-Rodríguez et al. (2016), who discriminated between 'legal protection' and 'management effort'.

The digital boundaries of PAs were obtained from the Andalusian Ministry of Environment's digital repository (Andalusian Government 2017c). They included all national and international PA designation categories for biodiversity conservation existing in Andalusia by September of 2017: (1) national PAs (N = 192), including the 8 regional designation categories: Natural Monument, Protected Landscape, Nature Site, National Park, Nature Park, Peri-urban Park, Nature Reserve, and Private Nature Reserve (Table S1 in the Supplement at www.int-res.com/articles/suppl/n035p125_supp.pdf); (2) SCIs (N = 27); (3) SACs (N = 163); (4) SPAs (N = 63); (5) biosphere reserves (BRs; N = 9); (6) Ramsar sites (i.e. wetlands of international importance as defined by the Ramsar Convention) (N = 25); and (7) World Heritage Sites (WHSs; N = 1). The regional terrestrial PA network can be considered almost complete as analysed here, notwithstanding possible future additions or modifications due to, for instance, global change (Ruiz-Mallén et al. 2015) or managerial regime (EEC 1992).

Data analysis

PA layers were clipped against the Andalusian land territory layer (IGN 2011), to select just the terrestrial PAs present in the region. The 7 PA category layers were unioned and the resulting protected polygons ≥100 ha were selected (n = 404) in order to minimise layer intersection errors (mostly smaller than that area) and also in order to obtain protected polygons of at least equal size to the species' resolution data. The layers were dissolved later on to calculate the total PA in the region. The complete PA layer and each of the 7 PA designation category layers were then intersected with the dissolved RTSs and GTSs layers showing their regional distribution, as well as with the HCI layer. PA area and percentage calculations by designation category do not account for overlaps among PA designation categories, so they should be read individually for each category.

Broad ecosystem types were estimated from land use-land cover data. To determine the main ecosystem type at each level of analysis, the Corine Land Cover (CLC) 2012 vector layer (Copernicus Land Monitoring Services 2016) was clipped against the Andalusian territorial layer (IGN 2011), and the complete PA layer, RTS and GTS layers, and descriptive statistics were computed. In order to rank every CLC subclass according to its importance to threatened species, a unit-less ecosystem importance index (EII) was produced for each level-three CLC subclass: EII $= \sum (N_n \times A_n)$, where N is the number of threatened species and A is the percentage of the area occupied by that number of species in CLC subclass n.

The degree of coincidence in threat categories between common species in both subsets (RTSs and GTSs) and between their degree of threat and their areas of occupancy were assessed via Spearman rank correlation tests, for a significance level of 0.05, after normality checks of the original and $\log_{10}$-transformed variables. Legal protection afforded to the 404 protected polygons of the complete PA layer was calculated by counting the number of overlapping PA designation categories in each polygon, as done previously (Rodríguez-Rodríguez et al. 2015b, 2016). The protected polygon layer was then intersected with the 2 threatened species' richness layers after dissolving them by the number of different threatened species present in each 1 km^2 plot and counting them. A Spearman rank correlation test was then performed to ascertain the degree of relationship between RTS and GTS richness and number of PA overlapping designation categories after checking the non-normality of the original and $\log_{10}$-transformed variables using SPSS software for an $\alpha = 0.05$. A methodological summary flux diagram is shown in Fig. 2.

Management effort was estimated in a generic manner by asking the regional government's managers whether entire PA designation categories were generally actively managed and allocating their responses (actively managed vs. not actively managed) to each analysed PA designation category in the region. All GIS calculations were done using ArcGIS v.10.3 (ESRI 2014) in the ETRS89 UTM 30N projection.

RESULTS

Official protection of threatened species

One hundred and twenty-six species in Andalusia were regionally threatened and/or globally threatened. Of these, 119 species were RTSs and 33 were GTSs (Table S2 in the Supplement). Seven GTSs were not included in the Andalusian Register of Threatened Species: *Aythya ferina*, *Eryngium galioides*, *Galium viridiflorum*, *Genista ancistrocarpa*, *Prunus ramburii*, *Santolina elegans*, and *Succisella andreae-molinae*. There was no statistically significant correlation between the regional and global categories of threat to the species in both subsets (RTS and GTS). The regional area of occupancy of GTSs was negatively correlated with their global degree of threat ($r_{S(31)} = -0.512$; $p = 0.02$).

Representation of threatened species in the regional PA network

PAs covered approximately 58% of the area of occupancy of RTSs and 81% of the area of occupancy of GTSs (Fig. 3). Species' richness in 1 km^2 plots varied from 1 to 12 species for RTSs and from 1 to 4 species for GTSs. PA coverage was high (>80%) for all plots containing ≥3 RTSs (Table S3 in the Supplement). PA coverage in GTSs' plots was also high

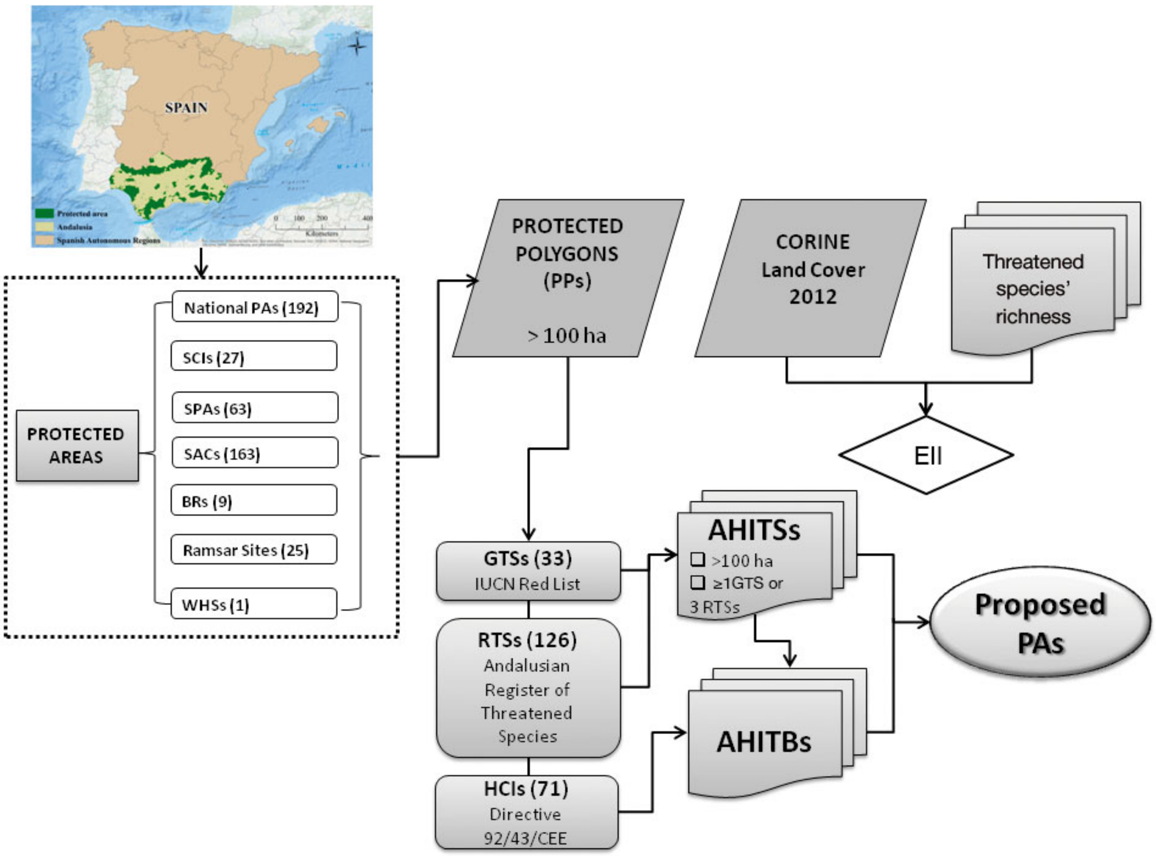

Fig. 2. Methodological flux diagram for the present study. AHITB: Area of High Importance for Threatened Biodiversity, AHITS: Area of High Importance for Threatened Species, BR: Biosphere Reserve, EII: Ecosystem Importance Index, GTS: globally threatened species, HCI: Habitat of Community Interest, PA: Protected Area, RTS: regionally threatened species, SAC: Special Area of Conservation, SCI: Site of Community Importance, SPA: Special Protection Area, WHS: World Heritage Site

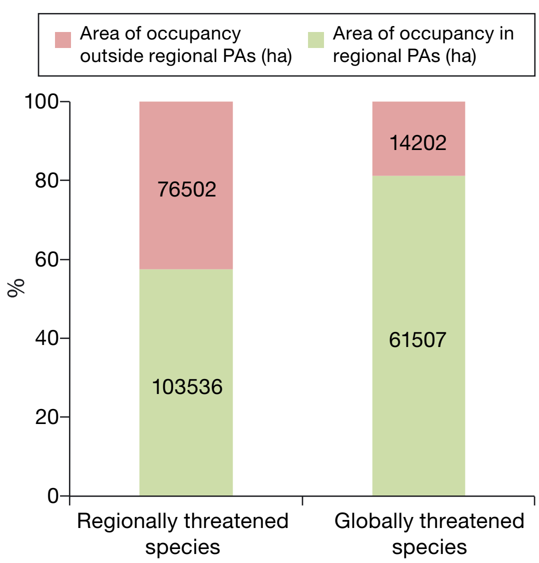

Fig. 3. Area of occupancy of regionally threatened species and globally threatened species inside and outside Andalusian protected areas (PAs)

(>79%) and increased with GTSs richness. All the plots having 3 or 4 GTS were included in the regional PA network (Table S4 in the Supplement).

The areas of occupancy of RTSs and GTSs cover 1.8 times and 2.5 times more relative area inside regional PAs than in the rest of the territory, respectively. The total and detailed distribution of the area occupied by threatened species by PA designation category in the region is shown in Table 1.

Representation of threatened species in broad ecosystem types

Diverse 'agricultural' ecosystems (CLC Class 2) covered most of the region (Table S5 in the Supplement). In turn, 'forest and semi-natural' ecosystems (CLC Class 3) extended over the largest part of the region's PA network (Table S6 in the Supplement). The majority of the area of occupancy of RTSs and

Table 1. Descriptive statistics on protected areas (PAs), regionally threatened species (RTSs) and globally threatened species (GTSs) in Andalusia. SAC: Special Area of Conservation, SCI: Site of Community Importance, SPA: Special Protection Area

Distribution (ha)	PAs (n = 404) Area (ha)	Coverage in region (%)	RTSs (n = 126) Area of occupancy in region (%)	Area of occupancy in PAs (ha)	Total area of occupancy protected (%)	Protected area including RTSs (%)	GTSs (n = 33) Area of occupancy in region (%)	Area of occupancy in PAs (ha)	Total area of occupancy protected (%)	Protected area including GTSs (%)
Andalusia	2 817 830	32.17[b]	2.06	103 536	57.51	3.67	0.86	61 507	81.24	2.18
National PAs[a]	1 655 900	18.90	0.83	73 144	40.63	4.42	0.50	44 009	58.13	2.66
SCIs	244 843	2.79	0.12	10 297	5.72	4.21	0.04	3363	4.44	1.37
SPAs	1 628 680	18.59	0.93	81 568	45.31	5.01	0.58	50 412	66.59	3.10
SACs[a]	2 285 920	26.09	0.87	76 162	42.30	3.33	0.55	47 884	63.25	2.09
Ramsar sites[a]	139 325	1.59	0.42	36 731	20.40	26.36	0.32	28 174	37.21	20.22
Biosphere reserves[a]	1524780	17.41	0.81	70 826	39.34	4.64	0.51	44 949	59.37	2.95
World Heritage Sites[a]	69 587	0.79	1.08	17 813	9.89	25.60	0.90	14 900	19.68	21.41

[a]Managed PA categories; [b]Accounting for overlaps

GTSs lay in 'agricultural areas', chiefly on non-irrigated arable land (25 and 22%, respectively; Tables S7 & S8 in the Supplement). Table 2 shows the representation of major ecosystems across these assessment units.

The distribution of land uses–land covers according to threatened species' richness is shown in Tables S9 & S10 in the Supplement. The most important ecosystems for RTSs and GTSs according to the EEI coincided: 'wetlands', chiefly 'salines' (EII_{RTS} = 2904; EII_{GTS} = 466) and 'inland marshes' (EII_{RTS} = 2224; EII_{GTS} = 296; Tables S11 & S12 in the Supplement). They covered most of the area of the species-richest plots (up to 100% for the richest plots). Of the 5 most important ecosystems for threatened species according to the EII, 2 were 'wetlands' and 3 were 'agricultural areas'. In contrast, 'forest and semi-natural' ecosystems had a medium to low importance as threatened species-rich areas.

Representation of HCIs in the regional PA network

Over 52% of the extent of the 71 HCIs in Andalusia was included in the regional PA network. This amounts to 62% of the PA network area (Table 3). Proportionally, the most important PA designation category for HCIs was SCIs, with 75% of the SCI area incorporating HCIs. WHSs and SCIs included proportionally 2.84 times and 2.32 times more HCI area than the regional HCI coverage, respectively.

Protection afforded to threatened biodiversity by the regional PA network

Most regional protected area was protected by 4 designation categories, although nearly the same proportion was protected by just 1 legal category (Fig. 4). The legal protection of regional HCIs followed a similar pattern (Fig. 5). The number of GTSs was not correlated with the number of overlapping protection categories, nor was the number of RTSs, although this correlation was nearly significant ($r_{S(50)}$ = 0.259; p = 0.06).

Fig. 6 shows the spatial overlap between threatened species' richness and the number of overlapping PA designation categories.

Considering that, in general (although not always), national PAs, SACs, BRs, Ramsar sites and WHSs all had active management in place, 75.2% of the regional PA can be considered actively managed. Thus, 74.9 and 77.0% of areas occupied by RTSs and GTSs in regional PAs (not considering overlaps) were in managed PAs (Table 1). SCIs and SPAs do not normally have active management, although some of them do, especially when they overlap with any of the 'managed' designation categories. Not accounting for overlaps among PA designation categories, 74.6% of the HCI area in regional PAs can be considered actively managed (Table 3).

Table 2. Representation of broad ecosystem types across assessment units, in percentage. PA: protected area, RTS area: area occupied by regionally threatened species, GTS area: area occupied by globally threatened species

Assessment unit	Broad ecosystem type				
	Agricultural ecosystems	Forest ecosystems	Wetland ecosystems	Other freshwater ecosystems	Artificial ecosystems
Region	56.99	38.66	0.76	0.93	2.66
Regional PAs	29.29	66.48	2.13	1.64	0.45
RTS area	51.00	31.97	11.89	3.14	1.57
GTS area	44.27	32.15	19.25	3.05	1.28

AHITBs: new candidate PAs

HCIs only spatially coincided with RTSs or GTSs on 1 site of 111 ha (of a 200 ha AHITS) to the north of Cordoba province. There is a total of 111 AHITSs, ranging from 100 to 400 ha in size (Fig. 7). The biggest one, of 400 ha, was also to the north of Cordoba province and contained *Otis tarda* (a GTS) and *Rhinolophus ferrumequinum* (an RTS). It bordered with other unpro-

Table 3. Descriptive statistics on protected area (PA) coverage and extent of habitats of community interest (HCIs) in Andalusia. SAC: Special Area of Conservation, SCI: Site of Community Importance, SPA: Special Protection Area

Distribution	PAs (n = 404)		HCIs (n = 71)			
	Area (ha)	Coverage in region (%)	Extent in region (%)	Extent in PAs (ha)	Extent in PAs (%)	Extent in PA category (%)
Andalusia	2 817 830	32.17	37.68	1 733 274	61.51	61.51
National PAs[a]	1 655 900	18.90	13.12	1 149 489	40.79	69.42
SCIs	244 843	2.79	2.08	182 429	6.47	74.51
SPAs	1 628 680	18.59	12.48	1 093 147	38.79	67.12
SACs[a]	2 285 920	26.09	16.92	1 482 095	52.60	64.84
Ramsar sites[a]	139 325	1.59	0.83	72 632	2.58	52.13
Biosphere reserves[a]	1 524 780	17.41	11.39	998 172	35.42	65.46
World Heritage Sites[a]	69 587	0.79	2.29	37 342	2.26	53.66

[a]Managed PA categories

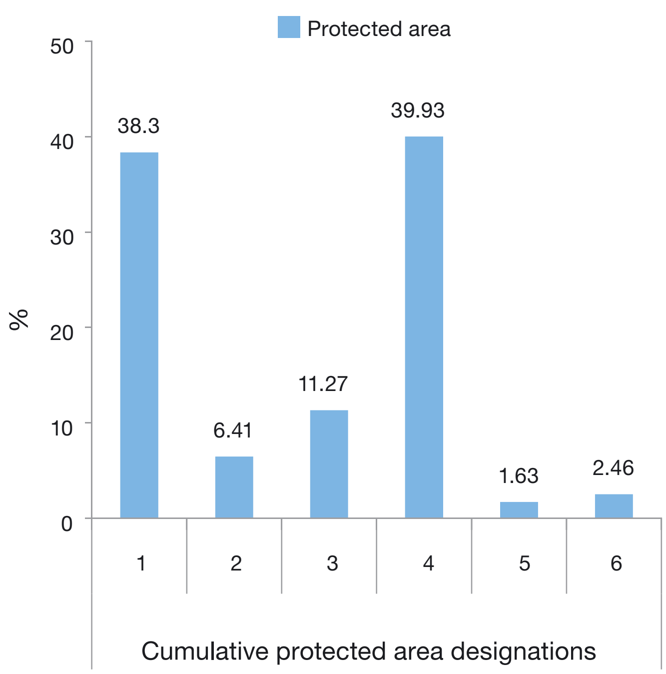

Fig. 4. Percentage of Andalusian protected area covered by overlapping legal designations

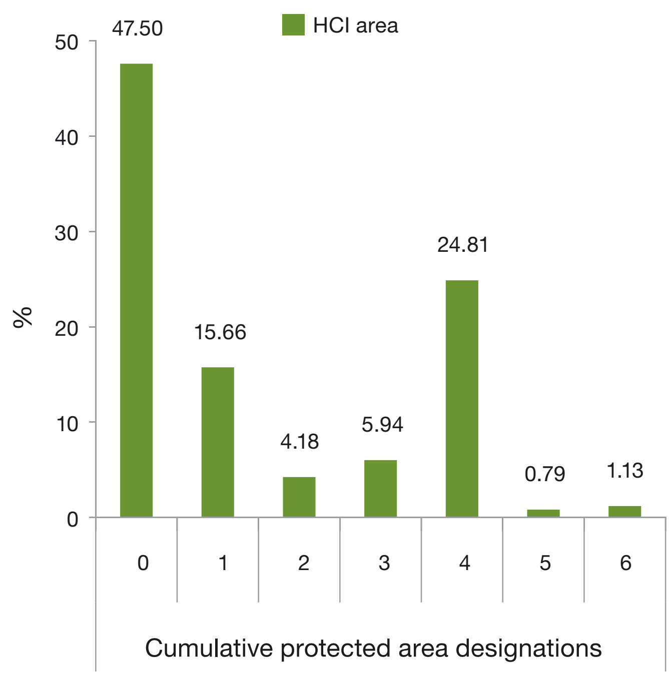

Fig. 5. Percentage of habitat of community interest (HCI) area covered by overlapping protected area categories in Andalusia

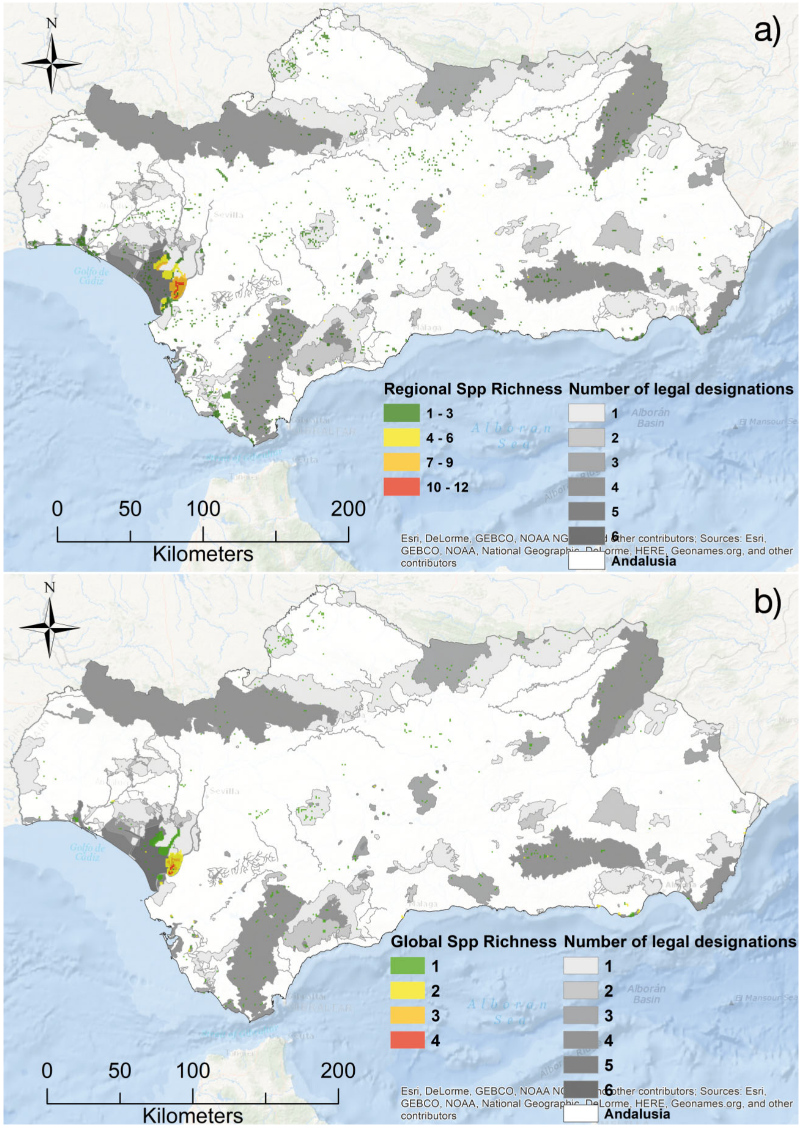

Fig. 6. Spatial overlap between cumulative legal protection of protected areas and (a) regionally threatened species' richness and (b) globally threatened species' richness in Andalusia

tected plots of 1400 ha in total that also contained *Circus pigargus* (an RTS).

DISCUSSION

Representation of threatened biodiversity in the regional PA network

The Andalusian terrestrial PA network can be considered mature and well developed in quantitative, general terms. It is now nearly 30 yr old and covers over one-third of the regional territory, more than twice the global PA coverage, at 14.7% (Bhola et al. 2016) and nearly doubling international PA coverage targets for terrestrial ecosystems (17%) by 2020 (CBD 2010). The network is positively skewed towards protection of threatened species, as expected, and includes the areas richest in threatened species in the region for both subsets. This is encouraging, as PAs have been found to reduce the extinction risk of threatened species (Butchart et al. 2012). However, substantial improvements can be made with respect to the spatial representation of threatened biodiversity in the regional network of PAs, especially for RTSs and HCIs. Even though the areas occupied by RTSs and GTSs cover a very small fraction of the regional area, a substantial proportion of this area is currently afforded no specific legal protection. Nevertheless, the disjoint and geographically scattered location of most of that unprotected area makes it challenging to endow it some legal and, especially, managerial protection regime. Our results are in accordance with a number of studies that show insufficient representation of threatened species in PAs globally (Gaston et al. 2008, Bhola et al. 2016), across Spain (Muñoz-Rodríguez et al. 2016) and in southeastern Andalusia (Mendoza-Fernández et al. 2014).

Ramsar sites occupy comparatively small areas in Andalusia, but are by far the most representative PA category for RTSs and GTSs. This was unexpected, given the relatively broad designation objectives of such areas (Ramsar Convention 1971) and that some other PA designation categories were specifically created for threatened biodiversity (e.g. SCIs, SACs and SPAs). This result underpins the importance of wetland ecosystems for the conservation of threatened species in the region and may be explained by the unique nature, vital territorial function, and restricted distribution of wetlands in Andalusia (Andalusian Government 2002). However, our results might have been biased by greater inclusion of wetland biodiversity in the original threatened species' dataset.

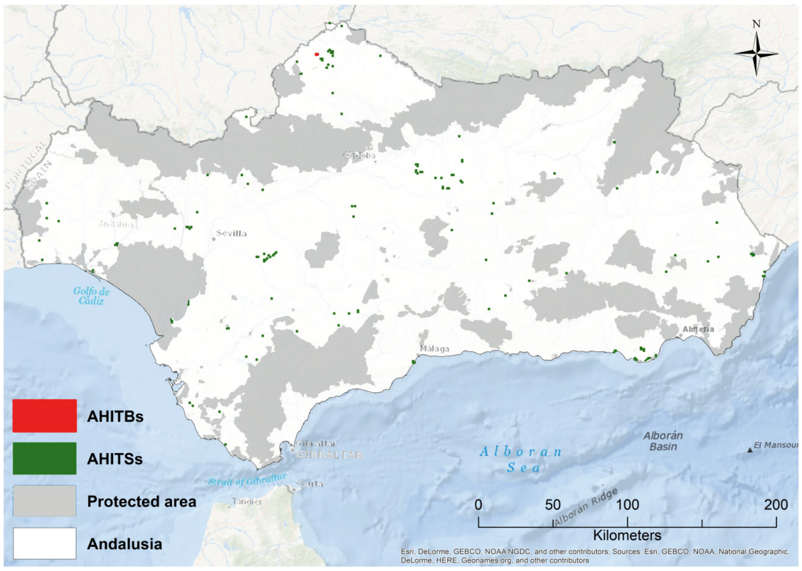

Fig. 7. New candidate protected areas in the Andalusian region (≥100 ha) according to the number of threatened species (AHITS: Area of High Importance for Threatened Species) and extent of habitats of community interest (AHITB: Area of High Importance for Threatened Biodiversity)

Almost half of the regional HCI area is outside the regional PA network. However, the large area covered by regional HCIs makes it challenging to completely protect them (Cabello et al. 2009). Global habitat-scale data were not available, but representation of terrestrial biodiversity in PAs at broader scales, such as ecoregions, could be much improved since only 10% of ecoregions enjoy legal protection for ≥50% of their area (Bhola et al. 2016). The fact that HCIs are best represented in WHSs was also unexpected, given the broad designation objectives of such a PA category (UNESCO 1972) and the HCI-specific designation of SCIs and SACs (EEC 1992). Actually, SCIs were less important for HCI protection than WHSs. However, this can be explained by the fact that WHS data comes from just one exceptionally biologically rich site (Doñana wetland), which is also a SAC.

Protection of threatened biodiversity afforded by the regional PA network

The regional PA network can be considered as highly legally protected and afforded high theoretical management effort. The networks' legal protection seems to be in accordance with RTS richness, which suggests coherent legal effort to protect RTSs. Nevertheless, the degree of legal protection assessed as the number of overlapping PA categories was not a very good predictor of threatened species' richness in the region, especially for GTSs. Incomplete ecological information prior to PA designation and multiple and changing PA designation criteria over time (Múgica et al. 2002) are likely to have influenced an improvable coverage of threatened species by many old PAs designated in the late 1980s in Andalusia, especially by 'National' PA designation categories (Andalusian Government 1989). It is worth noting that current *in situ* biodiversity conservation criteria and definitions largely derive from the 1992 Río Summit and the related Convention on Biological Diversity (CBD 1992) and subsequent amendments, notably the Strategic Plan for Biodiversity 2011–2020 (CBD 2010).

Assuming that legal designation of PAs, whatever their protection stringency, is insufficient for effective conservation without appropriate management is widely assumed (Hockings et al. 2006, Dudley 2008, Bhola et al. 2016). However, management of the Andalusian PA network was assessed here in very general terms and remains a pending research task.

Representation of threatened species by broad ecosystem types

The regional PA network is positively skewed towards the protection of wetlands, water bodies and forest areas, and negatively skewed towards the protection of agricultural areas. The PA network includes proportionally nearly 3 times more wetland area than wetland representation in the regional territory. Wetlands are even more disproportionally represented in the areas occupied by RTSs (almost 13 times more wetland area than in the whole of Andalusia) and GTSs (more than 25 times more wetland area). Wetlands are threatened ecosystems globally (Turner et al. 2000) as well as in the Mediterranean basin (Beltrame et al. 2012). It was estimated that Spain has lost around 60–70% of its historical wetland area to agricultural, urban and public health development, with similar figures for Andalusia (Andalusian Government 2002). Today, Andalusia has the highest number and area of protected wetlands of all the Spanish regions (Nieto 2012). The territorial value of Andalusian wetlands for threatened biodiversity is likely growing, as climate predictions forecast increased aridity in the northern Mediterranean basin and, more markedly, in the central and southern Iberian Peninsula (Barredo et al. 2016). Acknowledging the importance of wetlands for regional biodiversity, a Wetland Plan was produced with the purpose of conserving wetlands' ecological integrity and promoting their sustainable use (Andalusian Government 2002). The 25 Ramsar sites in Andalusia have also been designated as SPAs (20 of them) and/or national PAs (all sites; Andalusian Government 2016c), chiefly Nature Reserves and Nature Sites that, together with National Parks, are the most legally restrictive regional designation categories. Thus, these vital and spatially restricted ecosystems for threatened species are theoretically highly protected in Andalusia.

Forests are of limited importance regarding the spatial occurrence and richness of threatened species. In contrast to global figures, where PAs containing natural or recovering land uses were more biodiverse than those having human-dominated land uses (IUCN 2016), 5 of the 6 broad ecosystem types richest in threatened species (from 8 to 12 species, for RTSs, and from 3 to 4 species, for GTSs) can be considered human-modified ecosystems in Andalusia, including agricultural areas. This may be explained by the global character of the IUCN study and the exceptional species richness of tropical and equatorial forests, both in absolute terms and in relative terms related to threatened species (Myers et al. 2000). In the historically modified Mediterranean ecosystems, environmentally heterogeneous cultural landscapes have been found to have high levels of biological diversity (Schmitz et al. 2005) and contain semi-natural habitats of high conservation value (Araújo et al. 2007): Mediterranean ecosystems ranked second in threatenend species' richness after tropical forests (Myers et al. 2000). Human interventions in ecosystems seem to follow opposite trends but have similar consequences in tropical areas and in Mediterranean areas. Whereas in tropical areas, conversion of natural land covers to human-dominated ecosystems is a major cause of biodiversity loss, in Euro-Mediterranean areas, abandonment of traditional extensive uses of the land, such as non-irrigated farming or free-roaming livestock, is leading to natural succession towards forest habitats and subsequent loss of sparsely vegetated habitats and homogenisation of associated biodiversity (Martínez-Fernández et al. 2015, Herrando et al. 2016). Our results underpin the value of human-made ecosystems for threatened biodiversity in Mediterranean contexts, and suggest the importance of maintaining environmentally friendly land uses and practices aimed at threatened species in these ecosystems, both inside and outside PAs.

Opportunities for enhanced biodiversity protection

The number of threatened species outside PAs is generally low to medium in relative terms. Nevertheless, high absolute numbers of RTSs occur outside the regional PA network. This is worrisome, as the Mediterranean biogeographical region, which includes the whole of Andalusia, is territorially more dynamic than the Atlantic region in terms of land use– land cover changes in Spain (Martínez-Fernández et al. 2015). Actually, land cover changes towards land abandonment, urbanisation, increased land-use intensity and over-exploitation of water resources have been common in the recent history of Euro-Mediterranean regions, and very widespread in Spain between the late 1980s and mid-2000s (Stellmes et al. 2013). Even though massive residential and infrastructure construction declined abruptly in Spain from 2008 as a consequence of the burst of the housing bubble, economic recovery is posing a risk of natural habitat transformation, especially in the most dynamic areas around the main cities and coastal zones (Jiménez 2010, Alfonso et al. 2016). Therefore, legal protection of the identified AHITSs and AHITB should be considered, not only to protect threatened biodiversity but also to increase landscape permeability in a context of foreseen shifts in species' distribution ranges due to global change (Araújo et al. 2011). In this regard, some regional initiatives such as the draft master plan for the improvement of ecological connectivity in Andalusia (Andalusian Government 2016d) aim to anticipate and revert the irreversible consequences of those changes by sustainably managing the whole regional territory.

The mismatch between national (or regional) threat category criteria and international threat criteria (IUCN 2012a,b) makes it possible that some taxa of little global concern might be regionally threatened and that conservation actions are applied to them. It also makes the opposite and most worrisome possible: that some GTSs are not considered RTSs because they might be regionally abundant and are thus not afforded specific conservation actions by the regional government despite their global degree of threat. For instance, of the 7 such species identified here, 4 are globally Endangered species and 3 are Vulnerable species according to internationally agreed criteria

(IUCN 2017). Therefore, they should be given protection priority and be included in the Andalusian Register of Threatened Species. The application of threat categories based on administrative boundaries is discouraged by international guidelines (Gärdenfors et al. 2001), as threat level is very scale-dependent (IUCN 2012a,b). Thus, the current approach to taxa conservation followed by the national and, especially, the regional governments in Spain could probably be made more economically efficient and ecologically meaningful by considering broader spatial scales.

The easternmost part of the Doñana PA, in the southwestern part of the region, stands out in terms of the density of threatened species, with absolute maximal values of 12 RTSs and 4 GTSs by 1 km^2 plots. Previous studies highlighted high densities of threatened species in the Doñana PA, and also in Sierra Nevada National Park and northern Andalusia, respectively (Múgica et al. 2010). This high concentration of threatened species at the periphery of the PA would suggest some eastward expansion of the Doñana PA (under various possible designation categories) that could act as a buffer against external pressures to the PA. Such pressures are currently serious and manifold (Carmona 2012, Carmona et al. 2012, Carmona & Fuentelsaz 2013, 2015, WWF 2017). Thus, extreme caution should be exercised before authorising any potentially impacting activity in or near this exceptionally valuable area for threatened species and, whenever possible, other less environmentally valuable and vulnerable locations for such activities should be sought.

Methodological limitations

Methodological improvements to the study's accuracy could include: (1) analysing species' protection according to PA's legal zones, (2) assessing protection of particular species or habitats according to each PA's designation objectives (e.g. bird species in SPAs), or (3) determing population trends for species inside and outside PAs according to similar bio-physical covariates.

It should be noted that PAs <100 ha were discarded from this analysis, thus slightly underestimating representation and protection of threatened biodiversity, and making it possible that some small parts of the AHITSs or AHITB are actually protected but not reflected in our analysis. Also, managerial protection as assessed here is just a rough generalisation of actual management activities carried out in regional PAs and is, in contrast, most likely overestimated.

Other methodological issues such as the small scale of CLC data or inherent geometric and thematic errors when using spatial data techniques may have influenced our results to some degree (Martínez-Fernández et al. 2015). Moreover, the kind of data provided for species by the regional administration, where census points and areas of occupancy are depicted at 1 km^2 resolution, makes it most likely that the actual areas of occupancy are smaller than shown here for many species of limited mobility, and thus the regional distribution of some threatened species may be overestimated. Finally, completeness, consistency and accurateness of the official census data provided by the Regional Ministry of Environment cannot be assured, given the extent of the Andalusian territory, and the large number of species, habitats, monitoring protocols and people involved, and should thus be assumed to be the best available, most comprehensive existing data for the region. Data for a few emblematic species such as the grey wolf or the Iberian lynx were not included in the official database, possibly due to their high sensitivity, although both species are closely and regularly monitored in the region. However, the large effort made by the regional government to monitor such high numbers of threatened species and habitats at the level of detail shown here, as well as to compile and provide related data is uncommon, not only in Spain, where monitoring of protected biodiversity is very variable among regions and generally deficient (Rodríguez-Rodríguez et al. 2015a), but also European-wide (Davis et al. 2014) and globally (Gaston et al. 2008, IUCN 2012a), and merits recognition.

CONCLUSIONS

The Andalusian PA network has broad territorial coverage and is highly legally and managerially protected in general, quantitative terms. It also includes the regional areas that are richest in threatened species. However, our analysis suggests that representation of RTSs and HCIs can be improved and that legal protection can be better allocated according to threatened species' richness, chiefly of GTSs. Non-irrigated arable land was the most important ecosystem type for threatened species, in terms of areas of occupancy. Wetlands and some agricultural areas stood out as the broad ecosystem types richest in threatened species in Andalusia. Therefore, their proper delimitation, protection (where needed) and management are of paramount importance and should be granted.

Ramsar sites were especially important for the conservation of RTSs and GTSs, but less important for the conservation of threatened habitats. One-hundred and eleven AHITSs and one AHITB were identified. The designation as PAs of at least the biggest AHITB and AHITS in the northern part of the region (in Cordoba province) as well as the eastward expansion of Doñana PA also emerge as priorities from this analysis. Finally, the inclusion of the 7 GTSs not currently included in the Andalusian Register of Threatened Species is paramount.

This study is a snapshot of the status of the regional PA network up to 2017. It is thus advisable to take appropriate measures to improve the network according to today's data and environmental context. Global change effects will likely modify the distribution and density of threatened biodiversity. Scientists, managers and decision-makers should be ready to react soundly and promptly to such changes by adapting the boundaries of PAs, and their legal specifications and managerial practices to promote effective conservation. Natural and semi-natural areas surrounding existing PAs and ecological corridors between them will become essential to facilitate adaptation and survival of threatened biodiversity in the face of global change (Araújo et al. 2011).

Acknowledgements. This paper recognises contributions through the 'sequence-determines-credit' approach. We acknowledge and thank Pepe Perea, Francisco Marín, Yolanda Gil and José Manuel Moreira, from the Andalusian Environmental Information Network (REDIAM), Andalusian Ministry of Environment and Territorial Planning, for providing the official data on threatened species in Andalusia, and also for providing advice on how to treat and interpret species and habitat data. We also thank Gonzálo González, from the Andalusian Ministry of Environment, for providing useful insights on a draft version of the manuscript, and Milagros Pérez, for clarifying aspects of PA management in the region. Finally, we thank 3 anonymous reviewers whose remarks helped us to substantially enhance the content of this study. D.R.R. was funded for this study by the Spanish Ministry of Economy and Competitiveness in the framework of the SOSTPARK project (CSO2014-54611-JIN).

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Editorial responsibility: Nils Bunnefeld, Stirling, UK

Submitted: July 24, 2017; Accepted: December 5, 2017
Proofs received from author(s): February 9, 2018