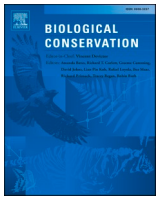
Biological Conservation 261 (2021) 109231

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon



Perspective

The European Union can afford greater ambition in the conservation of its threatened plants

Juan Carlos Moreno-Saiz [a,b,*], Belén Albertos [c], Elena Ruiz-Molero [d], Rubén G. Mateo [a,b]

[a] Departamento de Biología, Facultad de Ciencias, Universidad Autónoma de Madrid, Spain
[b] Centro de Investigación en Biodiversidad y Cambio Global (CIBC-UAM), Universidad Autónoma de Madrid, Spain
[c] Departamento de Botánica y Geología, Facultad de Farmacia, Universitat de València, Spain
[d] Departamento de Biología Animal, Biología Vegetal y Ecología, Facultad de Biociencias, Universitat Autònoma de Barcelona, Spain

ARTICLE INFO

Keywords:
Conservation
Effectiveness
European Union
Habitats Directive
Spanish flora
Threatened species

ABSTRACT

The importance of Natura 2000 network for the conservation of natural habitats, wild flora and fauna at European level is undeniable. However, it may not have reached its full potential since the loss of biodiversity continues to increase year on year. Further on, a third of the plant species listed in the Habitats Directive to guide the declaration of European Union Natura 2000 network of protected areas is not threatened and there is broad agreement on the need to review and update the species list. Here, the effectiveness of Natura 2000 in the conservation of Spanish bryophytes and vascular plants included in the Habitats Directive Annex II is analysed and compared with the one offered to the species included in the Spanish Red Lists. Results show a remarkable coverage of Natura 2000 over the distribution areas of threatened species, thus providing an umbrella effect on these taxa. It confirms that the number of plant species in the Habitats Directive could be significantly extended without altering the current configuration of the network. This would allow the incorporation of scientific advances produced since the Habitats Directive was approved almost 30 years ago, and will contribute to the goals of the new European Biodiversity Strategy for 2030, such as to consider impacts caused by alien species, land use or climate changes.

1. Introduction

Although the biodiversity crisis and the ongoing sixth mass extinction are facts assumed by the scientific community and international agencies, responses adopted to halt the loss of biodiversity have not increased at the same rate as the threats (Johnson et al., 2017). Both the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report (Díaz et al., 2019) and the recent Global Biodiversity Outlook (SCBD, 2020) noted progress in conservation and sustainable use of biodiversity, yet this was insufficient to redress the situation and meet the Convention on Biological Diversity Targets for 2011–2020 (Butchart et al., 2015; SCBD, 2020). For example, the IPBES report for Europe and Central Asia confirms that the situation has worsened and up to 28% of their species are threatened, most notably mosses and liverworts (50%), and vascular plants (33%) (Fischer et al., 2018).

To address this dramatic loss of biodiversity, the Convention on Biological Diversity (Aichi Biodiversity Target 11) proposed to protect a significant percentage of the planet, at least 17% of the Earth's surface by 2020 (CBD, 2010). Following the 5th Global Biodiversity Outlook, the proportion of the planet's land and oceans designated as protected areas has been achieved, but the elements related to the quality of protected areas were not (SCBD, 2020). Meanwhile, another more ambitious proposal has suggested protecting half of Earth to remedy the massive loss of biodiversity and natural habitats (Locke, 2014; Wilson, 2016). Complementary, organizations such as BirdLife proposed to select critical areas for bird conservation (Important Bird Areas; cf. Bennun and Njoroge, 2000), an initiative later followed for other taxonomic groups such as plants (Important Plant Areas, cf. Anderson, 2002), and finally extended to sites of global significance for the conservation of biodiversity through the concept of Key Biodiversity Areas (Eken et al., 2004).

The European Union (EU) opted for the declaration of a coordinated network of natural areas, the Natura 2000 network (N2000), which is the largest continent-wide comprehensive framework of protected areas worldwide (Hochkirch et al., 2013). Nowadays, Europe has protected 26% of its land area, of which 18% corresponds to N2000. The idea of an

* Corresponding author at: Departamento de Biología, Facultad de Ciencias, Universidad Autónoma de Madrid, Calle Darwin 2, 28049 Madrid, Spain.
E-mail address: jcarlos.moreno@uam.es (J.C. Moreno-Saiz).

https://doi.org/10.1016/j.biocon.2021.109231
Received 22 September 2020; Received in revised form 19 June 2021; Accepted 24 June 2021
Available online 7 July 2021

ambitious transnational system aimed to ensure the long-term survival of Europe's most valuable and threatened species and habitats, which would later crystalize in N2000, was discussed in the late 1980s by the European Union, at the time with 15 Member States. This network began to develop in the early 1990s combining areas of interest based on two nature acts: i) the Birds Directive (1979), focused on protecting all European wild birds and their habitats through the designation of *Special Protection Areas*; ii) and the Habitats Directive (1992), which aimed to protect a selection of natural habitats, plants and animals (other than birds) through the designation of *Sites of Community Importance* (SCI). These Sites are proposed on the basis of *Habitats of Community Interest* comprised in Annex I of the directive, or animal and plant *Species of Community Interest* listed in Annex II (no algae or fungus were selected for such annex). Member States must monitor the conservation status of such habitats and species every six years to review the progress made towards the level of conservation set by the Directive (EC, 2016).

Some challenges have emerged in relation to species selection within Annex II to the Habitats Directive (HD Annex II). Thus, criteria for choosing these taxa were not explicit and deviated from selecting the most endangered or rare species in Europe (Cardoso, 2012; Domínguez et al., 1996). At the time, the information on European threatened species was fragmentary and governments negotiating the species to be included in Annex II relied mainly on their own national Red Lists. In addition, the annex included some regional extinctions, species of dubious taxonomic consistency or with no indigenous presence in Europe (e.g. Aránega, 2005; Maiorano et al., 2015). Therefore, some authors have advocated expanding and reforming this HD Annex II, accommodating more taxonomic groups and listing only unquestionable threatened species (Hermoso et al., 2019a; Hochkirch et al., 2013; Jantke et al., 2011). Despite these shortcomings, the Habitat Directive annexes have rarely been amended over the years. The reasons for this lack of flexibility were several, but they could be summarized in three: i) legal uncertainty when the implementation of the network was in progress; ii) possible implications for the design and extension of N2000; and iii) an alleged 'umbrella effect' of the network that made the reform of such annexes expendable (EC, 2016; Maes et al., 2013).

The degree of coverage and effectiveness of N2000 as a framework of protected areas, not only for the listed species but also for the European fauna and flora, has been a matter of discussion over the years. Several publications found poor coverage of N2000 for some regions or certain taxonomic groups (e.g. Dimitrakopoulos et al., 2004; Jantke et al., 2011; Rossi et al., 2016). However, other works highlighted its effectiveness even with respect to threatened species unrepresented in HD Annex II (e.g. Hermoso et al., 2019a,b; Maiorano et al., 2015; Rosso et al., 2017). The European Union contributed to this debate by commissioning a report on the presumed 'umbrella effect', which positively supported the approach of N2000 (van der Sluis et al., 2016). This report was based on data collected at a coarse scale (50 km resolution) and handled distributional information mainly on vertebrates and butterflies, but still concluded that threatened and rare plant species occur significantly more often inside than outside N2000 (van der Sluis et al., 2016).

Nevertheless, inconsistencies in the species chosen for the HD Annex II have only become more apparent with the repeated six-year monitoring. For instance, a considerable number of bryophytes and vascular plants thought to be at risk in the 1980s have been shown to be non-threatened (Bilz et al., 2011; Hodgetts et al., 2019). The lack of regular updates and amendments for 29 years calls into question the validity of the HD annexes and the efficiency of funds earmarked for monitoring and conserving non-threatened species (Domínguez et al., 1996; Fenu et al., 2017).

Spain harbours a large proportion of habitats and species included in the HD annexes. Leaving aside the Canary Islands (in the Macaronesian biogeographic region, with its own habitats and species selection process), mainland Spain and the Balearic Islands host 113 habitats included in Annex I (50% of the total), and 117 animals and 113 plants listed in Annex II (27.4% and 19.2% of the total, respectively). These high proportions have led to the designation of 1257 terrestrial Sites of Community Importance (115,099 km^2, 23% of Peninsular and Balearic Spain), with several Habitats and Species of Community Interest coinciding at each Site. Therefore, it is an excellent example to test the effectiveness of the network in the conservation of protected and threatened species, and to determine the extensibility of Annex II in model groups such as plants.

The Spanish flora comprises 1260 bryophytes (59% of the European flora; cf. Hodgetts et al., 2020) and over 6150 vascular plants (25–30% of the European total; cf. Aedo et al., 2013; Bilz et al., 2011). This remarkable diversity in the Mediterranean and European context faces a multitude of risk factors: overgrazing, land use change, trampling, competition (Bañares et al., 2004; Garilleti and Albertos, 2012; Moreno-Saiz, 2008). In addition, different climate change predictions forecast high risks to biodiversity (Cramer et al., 2018[1]; IPCC, 2014), especially forests and threatened flora (Felicísimo et al., 2011). Despite the noteworthy extension of Spanish protected surface, the selection of areas has not been efficient enough for the protection of flora, leaving a part of its endemic and threatened plants out of protected areas and demanding new sites for *in situ* conservation (Muñoz-Rodríguez et al., 2016).

In this work, we analyze the percentage of representation in N2000 sites of mainland and Balearic Spanish plant species listed in HD Annex II, and compare it with the percentage of endangered plants found in N2000 sites that are included in the Spanish Red Lists of threatened species (Brugués et al., 2014; Moreno-Saiz, 2008). We expect to find that N2000 offers significant habitat coverage for threatened Iberian-Balearic plants, although less than it provides for the species in HD annexes for which it was designed. As a second objective, we aim to determine whether the list of plants in Annex II could be expanded to include a greater number of threatened plants that may already be present in the existing N2000 areas. We would expect that, given the large protected Spanish territory included in N2000, an appreciable number of threatened species could be represented in this network, providing arguments for the expansion of HD Annex II.

2. Material and methods

2.1. Plant distribution data

A comprehensive compilation of data was gathered (see Appendix A) to map the distribution of bryophytes and vascular plants for mainland Spain and the Balearic Islands to build two data sets: 1) cells occupied by the 9 bryophytes and 104 vascular plant species included in HD Annex II; 2) cells occupied by 178 bryophytes included in the Red List (75% of the enlisted taxa in the study area, cf. Brugués et al., 2014), and 786 vascular plants included in the Red List (95% of the enlisted taxa, cf. Moreno-Saiz, 2008). All collected occurrence data were transferred to the scale of 10 km UTM cell resolution, which was the most detailed scale possible for the vast majority of threatened species (Buira et al., 2020).

2.2. Map of the N2000 network

The digital map of N2000 was downloaded from the Spanish Ministry for Ecological Transition official site (MITECO, 2019). Areas only included because of their designation under the Birds Directive (Special Protection Areas) were not selected because their management plans only optionally deal with the protection and monitoring of habitats and species included in HD Annexes I and II (EC, 2011: 56). Protected areas included in N2000 are polygons frequently less than 10 km cells or with a different shape. To solve the mismatch between the grid of distribution data and N2000 polygons, following Alagador et al. (2011), we filtered the UTM cells considered as protected taking into account the

[1] Please, prevent the parentheses from being separated from the text

percentage of the cell enclosed by N2000 polygons. Five commonly used thresholds (10%, 20%, 30%, 40%, and 50%) were selected (cf. Alagador et al., 2011, and references therein), and cells covered by N2000 polygons in the percentage stated or more were computed as protected. The results are five N2000 maps at 10 km UTM cell resolution for the different thresholds.

2.3. Evaluation of N2000 representativeness

2.3.1. Measure of species representation

The proportion of each species' areal distribution that overlapped N2000 sites, that is the species' representation in protected areas for both datasets, was used as our measure of effectiveness. We implemented a gap analysis (Rodrigues et al., 2004) to assess the level of protection of the Spanish plants inside N2000. We overlaid each of the species distribution datasets in turn with the five N2000 maps (described in Section 2.2), and then calculated the percentage of representation, i.e. the number of UTM cells considered as protected by N2000 in relation to the total number of UTM cells where the species is present.

To evaluate whether the degree of coverage of N2000 on the threatened Spanish plants is better than the coverage given by chance, we carried out a second round of gap analyses on the locations of threatened bryophytes and vascular plants. We randomly selected 100 times the same number of species included in Annex II (9 bryophytes, 104 vascular plants) within the species included in the Spanish Red Lists and calculated the percentage of representation by the five N2000 maps. The results can be considered an estimate of the percentage of representation (i.e. effectiveness) that would be expected to be represented by chance (Araújo et al., 2007).

2.3.2. Number of species protected by N2000

Finally, we calculated how many threatened Spanish plant species had their distributions covered by the current design of N2000 (i.e. number of species protected), with equal or superior effectiveness as that exerted for the species listed in HD Annex II. We computed the percentage of representation for all taxa included in the Spanish Red Lists under the five N2000 maps generated, and counted the number of species with an equal or higher percentage of representation for eight different levels (30%, 40%, 50%, 60%, 70%, 80%, 90%, 100% representation levels).

3. Results

The database compiled with the Spanish occurrences of the bryophytes from HD Annex II amounted to 164 records spread across 147 UTM cells. Meanwhile, the database for vascular plants in the HD Annex II comprised 2088 records across 1406 UTM cells. While bryophytes and vascular plants are unevenly distributed throughout the study area, the former show a certain concentration in the Pyrenees mountain range (border with France) and in the northern coastal areas (Fig. 1a), whereas cells with vascular plants are grouped following the main mountain ranges (i.e. Cantabrian Mountains, Iberian System, Baetic Systems, etc.) (Fig. 1b).

Otherwise, the database for the 178 bryophytes included in the Red List comprised 1619 records across 555 UTM cells, whose distribution is also predominantly mountainous (Fig. 2a). The 786 vascular plants in the Red List reached 7309 records across 2592 UTM cells (47% of all peninsular and Balearic cells), without clear geographic patterns but distributed over a good part of the study area (Fig. 2b).

3.1. Species representation in N2000

In the evaluation of species representation in protected areas according to the thresholds considered in the five N2000 maps, the group with widest range of coverage is the bryophyte group, with 24% to 73% of cells for HD Annex II species, and 35% to 77% of cells for threatened species, contained within N2000 sites (Fig. 3a). Regarding to vascular plants the representativeness is somewhat lower but still high, with 26% to 58% of cells with HD Annex II species, and 29% to 63% of cells with threatened species, covered by N2000 (Fig. 3b).

Moreover, for both taxonomical groups the effectiveness of a network of the same number of cells as those contained in N2000 distributed at random, was lower for all the overlap thresholds considered (Fig. 3), thus supporting the robustness of the results.

3.2. Number of species protected by N2000

A major finding was that the current design and extension of N2000 would allow representation within protected areas of a higher number of threatened bryophyte and vascular plant species of mainland Spain and the Balearic archipelago. For any of the overlap thresholds 10–50% in N2000 maps, and for any of the representation levels of total distribution area (from 40 to 100%), the number of threatened species found within N2000 sites is greater than the number currently included in the HD, for both taxonomic groups (Table 1). Only when the highest

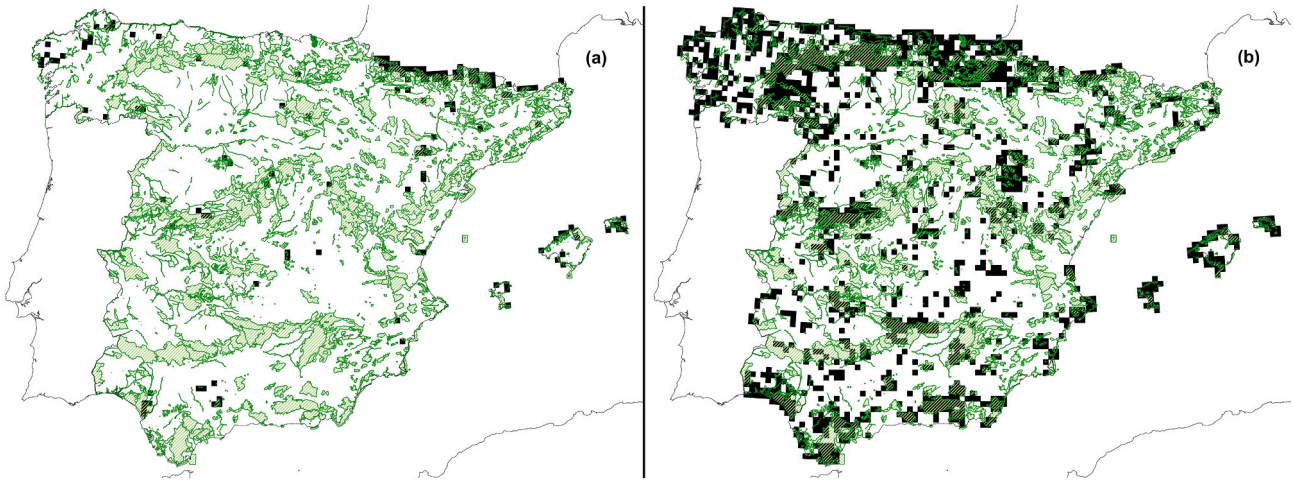


Fig. 1. Map of continental Spain and the Balearic Islands with the outline of the Natura 2000 sites (in green) and UTM cells in which species of Habitats Directive Annex II are found, including (a) bryophytes, with 164 records distributed among 147 cells, and (b) vascular plants, with 2088 records distributed among 1406 cells. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

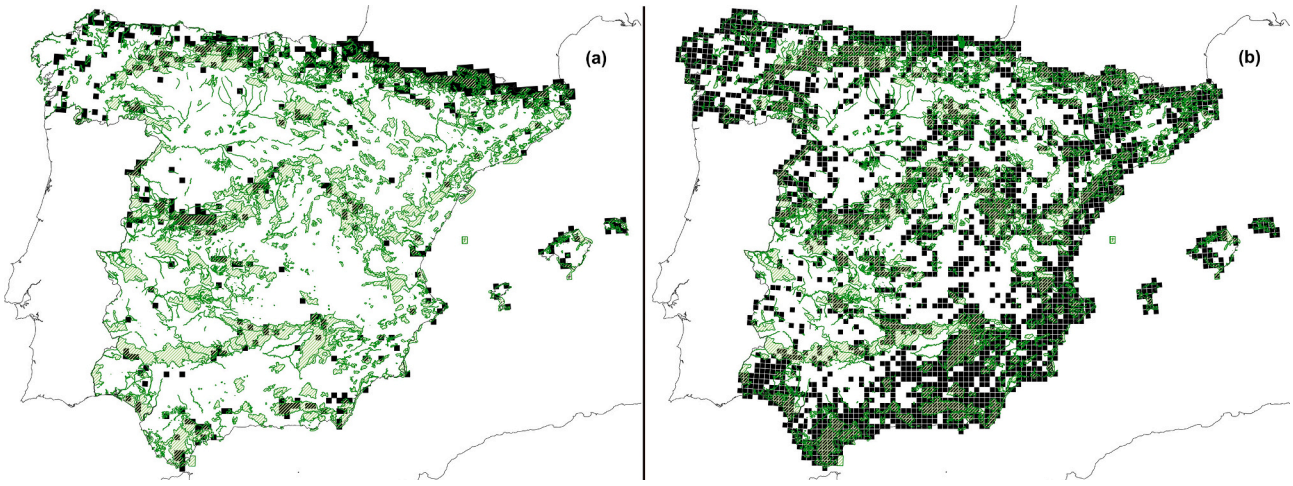


Fig. 2. Map of continental Spain and the Balearic Islands with the outline of the Natura 2000 sites (in green) and UTM cells in which species of the Spanish Red Lists are found, including (a) bryophytes, with 1619 records distributed among 555 cells, and (b) vascular plants, with 7309 records distributed among 2592 cells. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

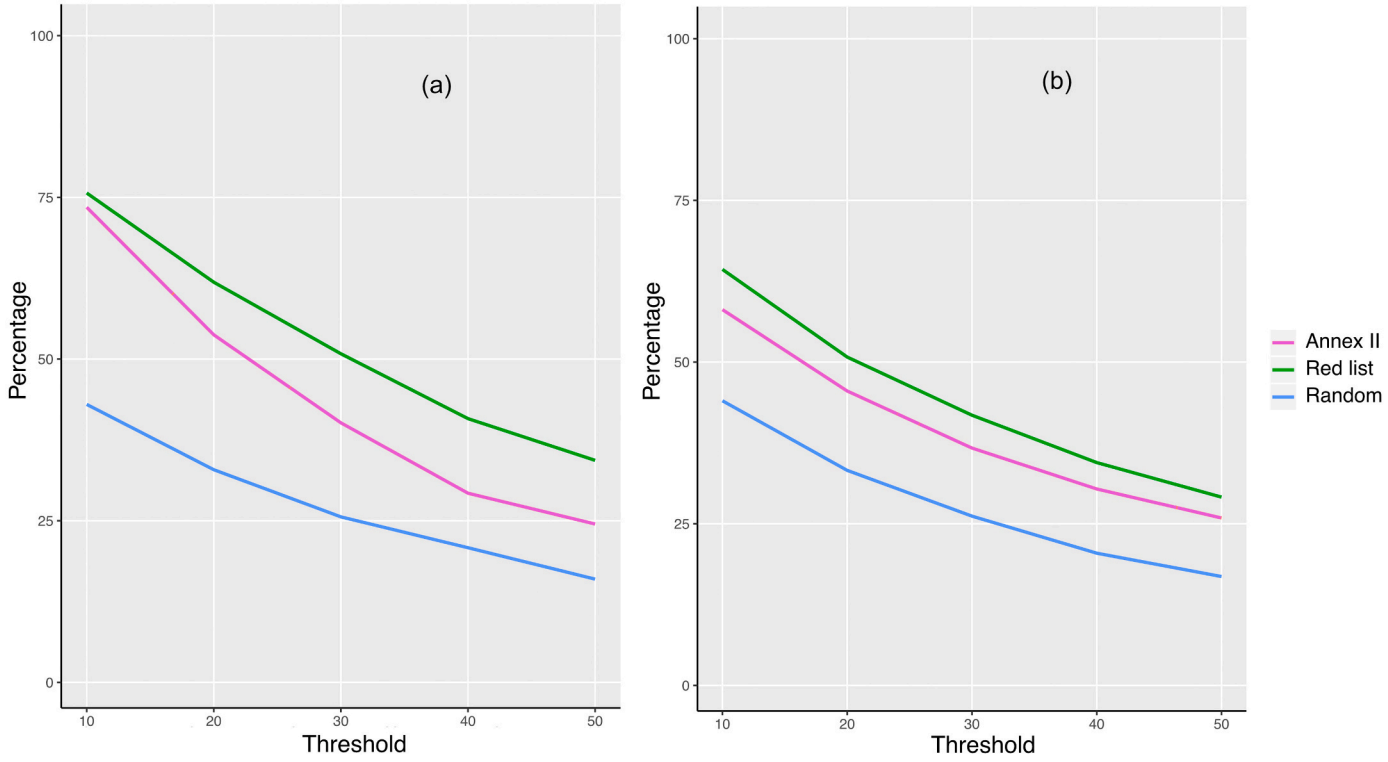


Fig. 3. Natura 2000 coverage for Spanish plants. The magenta line shows the percentage of representativeness according to five thresholds overlap with the Natura 2000 network for the 113 species included in the Habitats Directive Annex II; the green line shows actual representativeness for a random selection of 113 threatened species (9 bryophytes and 104 vascular plants); and the blue line is actual representativeness for the same number of UTM cells within Natura 2000 distributed at random: a) bryophytes, b) vascular plants. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

threshold overlap (50%) of distribution data and N2000 coverage (90%–100%) is combined does the coverage of threatened bryophytes covered by N2000 is equal to those included in Annex II, and the figures of red-listed vascular plants are lesser than the number of species included in the HD Annex II (Table 1).

4. Discussion

The Natura 2000 network covers a significant percentage of the distribution of plants included in HD Annex II, according to the results concerning the Spanish plants listed in that Annex. This effectiveness is in good measure greater for bryophytes and vascular plants included in the Spanish Red Lists, irrespective of whether they are part of the aforementioned Annex II. Our results confirm the 'umbrella effect' of N2000 (in the spatial conception of van der Sluis et al., 2016) with respect to the distribution areas of threatened species.

The European Union carried out a similar study (van der Sluis et al., 2016) at a smaller resolution (50 km), where it was found that N2000 had a mean area coverage of 26.5% for mammals, 26.4% for amphibians, 29.7% for reptiles, and 37.4% for butterflies. Except for the higher

Table 1
Number of Spanish red-listed plants protected by the Natura 2000 network depending on eight representation levels of their UTM cells in the Natura 2000 network and the five N2000 maps (10%, 20%, 30%, 40% and 50% overlap thresholds) previously generated.

Surface of N2000 in the cell	Percentage of species area protected by N2000							
	30%	40%	50%	60%	70%	80%	90%	100%
Bryophytes								
10%	166	157	153	139	122	100	48	39
20%	154	140	133	102	77	41	28	26
30%	138	124	102	68	36	26	18	18
40%	121	96	75	41	22	17	15	15
50%	101	74	50	29	12	11	9	9
Vascular plants								
10%	696	675	643	569	484	414	323	284
20%	624	573	535	441	357	298	225	209
30%	535	474	440	345	277	219	168	159
40%	467	409	368	287	216	166	126	122
50%	414	355	316	220	154	122	99	96

overlap threshold (50% of the cells included in N2000), our results show greater coverage for Spanish bryophytes and vascular plants, both if they are part of HD Annex II or if they are part of Red Lists (Table 1, Fig. 3). In the few other gap analyses using the percentage of the distribution areas as a measure of N2000 effectiveness, the results vary but roughly resemble the degree of coverage obtained here: 40% for threatened Spanish lichens (Martínez et al., 2006), 40.8% for Spanish bats (Lisón et al., 2015), and 45% for Slovenian butterflies (Verovnik et al., 2011).

Results are not completely unrelated to a possible bias towards protected areas in biodiversity studies. Nevertheless, the Spanish network of protected areas (i.e. national and natural parks) covers a large surface of the national territory and its boundaries were drawn taking into account the known populations of the most threatened plants and animals. N2000 sites were later approved matching to a large degree with these parks, so we think that this possible bias is lesser regarding threatened species. Likewise, new analyses should be carried out in the future as distributional data on a larger scale become available, both at European and Spanish context, to check the validity of this 'umbrella effect'.

4.1. The necessary reform of the Habitats Directive

Our analysis shows that the number of plant species in HD Annex II could be significantly extended without altering the current configuration of N2000 network (see Table 1). Thus, Spanish bryophytes could be increased by 66% (from 9 to 15) and vascular plants by 17% (from 104 to 122) in the restrictive case of considering those UTM cells covered by at least 40% overlap with N2000 and with an representation level of 100% of their populations. If we had not been so restrictive and accepted the same level of effectiveness shown by the plants of HD Annex II (over 30% of distribution coverage, cf. Fig. 3), this annex could extend to 101–166 bryophytes and up to 414–696 vascular plants (Table 1).

Even without an enlargement of the current N2000 network or the adoption of a new set of rules for the designation of SCIs, a review of the level of risk faced by HD Annex II plants in the European Union and its Member States (Table 2) shows that this list is not a useful reference for the priority species in Europe. One-third of the plants listed are not threatened at the European Union extension (Bilz et al., 2011; Hodgetts et al., 2019), and this percentage is even lower in various countries (Portugal, Sweden), reaching to the extreme case in France, where only one third of such plants are threatened at a national scale. These disappointing statistics are in the same line as other results for European vertebrates listed in the annexes, 82% of which are unthreatened according to their IUCN categories (Hermoso et al., 2019c).

Several authors have drawn attention to the need to implement regular updates and amendments to the HD annexes (e.g. Cardoso, 2012; Domínguez et al., 1996; Hochkirch et al., 2013; Maiorano et al., 2015) and could almost be considered a constant among those who have reviewed the role of HD for various territories or taxa (but see Maes et al., 2013, although they opposed for circumstantial reasons at the time). At present, funds for research and monitoring of threatened species are scarce, and spending money on sexennial reporting on species lacking immediate risks, diverting attention and resources from species that are currently identified as threatened (Fenu et al., 2017; Hermoso et al., 2016), could be deemed wasteful.

It is thus necessary to update the lists of species in the annexes of the Habitats Directive to reflect new scientific information on continental biodiversity produced over the last 30 years through national and European funds (Cardoso, 2012; Hochkirch et al., 2013; Trouwborst et al., 2017). While the annexes of the Bird Directive have been amended, HD annexes have not changed except to add new habitats and species from new Member States.

4.2. European challenges for the next decade

The improvement in the selection of species in the annex not only affects N2000, but also the legal protection of such species in the EU Member States. As European directives must be transposed into national legislation, their annexes of protected species go to the endangered species act of each country. This leads to the incorporation of national initiatives for *in situ* and *ex situ* conservation, which several European countries have developed complementary to the management of these protected species (e.g. Campbell and Lockhart, 2017; Fenu et al., 2017). It therefore concerns not only protected areas, but also affects natural and semi-natural areas that are not part of N2000 but that can be the

Table 2
Risk categories given to plants included in the HD Annex II for the European Union (EU) and all European countries with national red lists for vascular plants and bryophytes. Figures express the number of HD Annex II species present in each territory, according to the IUCN category awarded for the whole EU or for each country. Abbreviations for the IUCN categories are as follows: Regional Extinct (RE), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), and Not Evaluated (NE). *Further 62 species endemics to the Canary Islands are not included. **The percentage reflects the proportion between the sum of RE, CR, EN and VU with respect to the total number of HD Annex II species present in each territory. See Appendix B for red-list references from which the information was extracted.

IUCN category	EU	Finland	France	Germany	Greece	Italy	Portugal	Slovakia	Spain	Sweden
RE				3		1	2	3		
CR	90	9	2	11	4	16	8	9	22	4
EN	112	14	7	10	11	25	14	5	29	7
VU	112	10	8	1	19	7	18	8	30	12
NT	69	8	17	3	1	10	14	10	16	19
LC	87	5	15	2		14	28	2	13	11
DD	85					2	3		2	
NE	34		13	4	11	5	8	2	1	6
Total	589	46	62	34	46	80	95	39	113*	59
% Threatened**	66.8	71.7	34.7	83.3	97.2	67	50.7	67.6	73.7	49.2

object of actions within the EU green infrastructure strategy (EC, 2020).

The intent of the precautionary strategy that maintains the current N2000 design is to avoid substantial alteration of the management of approved SCIs integrated in N2000. However, as the new European Biodiversity Strategy for 2030 (EC, 2020) envisages that the European protected area will reach 30% of the Union at the end of the decade, this expansion provides an opportunity to include habitats and taxa currently absent or underrepresented in the Habitats Directive, a long-delayed demand (Cardoso, 2012; Rosso et al., 2017). Thus, this expansion must serve to provide protection to all those threatened plant species that are completely absent from the N2000 protection. For example, in Spain, around 5% of the taxa on the Red List (62 taxa) have all their populations outside the network of protected areas (Muñoz-Rodríguez et al., 2016). Furthermore, it will provide the opportunity to incorporate impacts such as those caused by alien species, land use or climate changes into European conservation policy, factors not foreseen at the time the Directives were approved but which are already having a deep effect on the status of many European listed species (Araújo et al., 2011). By means of modelling the future distributions of habitats and species from the EU Nature Directives, their range shifts could be anticipated and taken into account for the coverage and design of any expansion of the N2000 network in the future (Kujala et al., 2011).

5. Conclusions

Based on bryophytes and vascular plants, we confirm previous results showing that N2000 could efficiently house species of interest beyond those included at present in HD annexes (Hermoso et al., 2019b). The data show that it is possible to add a greater number of threatened species to the critical Annex II without enlarging the N2000 network. With its current design, the 'umbrella effect' could be maximized by including new species to reinforce the role of HD in the conservation of European biodiversity. Also, our work shows that while truly threatened species may be incorporated, those that have not been European conservation priorities can also be removed from Annex II.

Data accessibility

All distributional data needed to evaluate the conclusions in the paper are available upon request.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgements

Thanks to Ricardo Garilleti, Francisco Guil, Helena Hespanhol, Thomas Hövelmann, Nikos Krigas, Sara Mora, Ignacio Ramos, Michael Sauer, and Noelia Vallejo for their help, ideas and assistance. Eladio Fernández-Galiano suggested many useful comments on an early version of the manuscript. The Spanish Ministry of Science, Innovation and Universities supported J.C.M.S. through the Bioregions 2.0 project (CGL2017-86926-P).

Appendix A. Sources of distribution data

References:

Alcántara, M., Goñi, D., Guzmán, Puente, J., 2007. *Catálogo de Especies Amenazadas en Aragón. Flora*. Gobierno de Aragón, Departamento de Medio Ambiente. Retrieved from https://www.aragon.es/-/catalogo-de-especies-amenazadas-en-aragon

Aseginolaza, C., Gómez, D., Lizaur, X., Montserrat, G., Morante, G., Salaverría, M.R., … Alejandre, J.A., 1984. *Catálogo florístico de Alava, Vizcaya y Guipúzcoa*. Gobierno Vasco, Vitoria.

Sáez, L., Aymerich, P., Blanché, C., 2010. *Llibre vermell de les plantes vasculars endèmiques i amenaçades de Catalunya*. Argania Editio, Barcelona.

Bañares, Á., Blanca, G., Güemes, J., Moreno, J.C., Ortiz, S. (Eds.), 2004-2011. *Atlas y Libro Rojo de la Flora Vascular Amenazada de España + Adendas 2006, 2008 and 2010*. Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid. Retrieved from https://www.miteco.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/ieet_flora_vascular.aspx

Garilleti, R., Albertos, B. (Coords.), 2011. *Atlas y Libro Rojo de los briófitos amenazados de España*. Organismo Autónomo Parques Nacionales, Madrid. Retrieved from https://www.miteco.gob.es/es/biodiversidad/temas/inventarios-nacionales/briofitos_tcm30-198033.pdf.

Moreno-Saiz, J.C., Iriondo-Alegría, J.M., Martínez-García, F., Martínez-Rodríguez, J., Salazar-Mendías, C. (Eds.), 2019. *Atlas y Libro Rojo de la Flora Vascular Amenazada de España. Adenda 2017*. Ministerio para la Transición Ecológica-Sociedad Española de Biología de la Conservación de Plantas, Madrid. Retrieved from https://www.miteco.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/inventario-nacional-de-biodiversidad/ieet_flora_vasc_adenda_2017.aspx

Sáez, L., Rosselló, J.A., Fraga, P., 2017. *Llibre vermell de la flora vascular de les Illes Balears*. Segona edició. Conselleria de Medi Ambient, Agricultura i Pesca. Retrieved from https://www.caib.es/sites/proteccioespecies/ca/d/llibre_vermell_de_la_flora_vascular_de_les_illes_balears_2017

Sánchez P., Carrión M.A., Hernández A., Guerra, J., 2002. *Libro rojo de la flora silvestre protegida de la Región de Murcia*. Consejería de Agricultura, Agua y Medio Ambiente, Región de Murcia. Retrieved from http://www.murcianatural.carm.es/web/guest/especies-protegidas1/-/journal_content/56_INSTANCE_M1rn/14/108016

Web pages:

Anthos. Sistema de información de las plantas de España. Real Jardín Botánico, CSIC- Fundación Biodiversidad. http://www.anthos.es.

Atlas de la Flora de Aragón. Instituto Pirenaico de Ecología, CSIC - Gobierno de Aragón. http://floragon.ipe.csic.es

Atlas de la flora del Pirineo. http://florapirineos.ipe.csic.es

Banc de dades de biodiversitat. Generalitat Valenciana. http://www.bdb.gva.es/es/

Banc de dades de biodiversitat de Catalunya. Generalitat de Catalunya. http://biodiver.bio.ub.es/biocat/

BioAtles. Comunidad Autónoma de las Illes Balears. http://bioatles.caib.es/serproesfront/VisorServlet

Cartografia de Briòfits. Península Ibèrica i Illes Balears. Institut d'Estudis Catalans, Universitat Autònoma de Barcelona, Jardim Botânico Universidade de Lisboa. http://briofits.iec.cat

Appendix B. Red Lists used as source of data for Table 2

ArtDatabanken, 2016. The Swedish Species Information Centre. http://artfakta.artdatabanken.se/ (accessed 3 April 2020).

Bilz, M., Kell, S.P., Maxted, N., Lansdown, R.V., 2011. European Red List of Vascular Plants. Publications Office of the European Union, Luxembourg. Retrieved from https://op.europa.eu/es/publication-detail/-/publication/ad44df42-f7d2-4297-a4c2-932859effccd/language-en

Brugués, M., Cros, R.M., Infante, M. (2014). Lista Roja de los briófitos amenazados de España peninsular y balear, in: Garilleti, R., Albertos, B. (Coords.), Atlas de los briófitos amenazados de España. Universitat de València. Published online 04/07/2014. Retrieved from http://www.uv.es/abraesp

Caspari, S., Dürhammer, O., Sauer, M., & Schmidt, C. (2018). Rote Liste und Gesamtartenliste der Moose (Anthocerotophyta, Marchantiophyta und Bryophyta) Deutschlands, in: Metzing, D., Hofbauer, N., Ludwig, G., Matzke-Hajek, G. (Eds.), Rote Liste gefährdeter Tiere, Pflanzen und Pilze Deutschlands. Band 7: Pflanzen. – Münster (Landwirtschaftsverlag). Naturschutz und Biologische Vielfalt, 70: 361–489.

Fenu, G., Bacchetta, G., Giacanelli, V., Gargano, D., Montagnani, C.,

Orsenigo, S., … Ercole, S., 2017. Conserving plant diversity in Europe: outcomes, criticisms and perspectives of the Habitats Directive application in Italy. Biodiv. Conserv. 26, 309–328. https://doi.org/10.1007/s10531-016-1244-1

Hodgetts, N., Cálix, M., Englefield, E., Fettes, N., García Criado, M., Patin, L., … Żarnowiec, J., 2019. A miniature world in decline: European Red List of Mosses, Liverworts and Hornworts. IUCN, Brussels, Belgium. https://doi.org/10.2305/IUCN.CH.2019.ERL.2.en

Hyvärinen, E., Juslén, A., Kemppainen, E., Uddström, A., Liukko, U.-M. (Eds.), 2019. The 2019 Red List of Finnish Species. Ympäristöministeriö & Suomen ympäristökeskus. Helsinki. Retrieved from https://www.environment.fi/redlist

Lista Vermelha da Flora Vascular de Portugal Continental. https://listavermelha-flora.pt/ (accessed 13 March 2020).

Metzing, D., Hofbauer, N., Ludwig, G., Matzke-Hajek, G. (Eds.), 2018. Rote Liste gefährdeter Tiere, Pflanzen und Pilze Deutschlands. 7. Bundesamt für Naturschutz, Bonn-Bad Godesberg. Retrieved from https://www.bfn.de/themen/rote-liste.html

Mišíková, K., Godovičová, K., Širka, P., Šoltés, R., 2020. Checklist and red list of mosses (Bryophyta) of Slovakia. Biologia, 75, 21–37. https://doi.org/10.2478/s11756-019-00349-1

Moreno-Saiz, J.C. (coord.), 2008. Lista Roja 2008 de la flora vascular española. Ministerio de Medio Ambiente, Medio Rural y Marino – Sociedad Española de Biología de la Conservación de Plantas, Madrid. Retrieved from https://doi.org/10.2478/s11756-019-00349-1

Eliáš, P., Dítě, D., Kliment, J., Hrivnák, R., Feráková, V., 2015. Red list of ferns and flowering plants of Slovakia, 5th edition. Biologia, 70, 218—228. https://doi.org/10.1515/biolog-2015-0018

Phitos, D., Constantinidis, T., Kamari, G. (eds.), 2009. The Red Data Book of rare and threatened plants of Greece. 2 vols. Hellenic Botanical Society, Patras.

Sérgio, C., Garcia, C.A., Sim-Sim, M., Vieira, C., Hespanhol, H., Stow, S., 2013. Atlas e Livro Vermelho dos Briófitos Ameaçados de Portugal. Universidade de Lisboa – Museu Nacional de História Natural e da Ciência, Lisboa.

Stroh, P.A., Leach, S.J., August, T.A., Walker, K.J., Pearman, D.A., Rumsey, F.J., … Taylor, I., 2015. A Vascular Plant Red List for England. Botanical Society of Britain and Ireland, Bristol.

UICN France, FCBN, AFB, MNHN, 2018. La Liste rouge des espèces menacées en France – Chapitre Flore vasculaire de France métropolitaine. Paris, France. Retrieved from https://www.afbiodiversite.fr/sites/default/files/actualites/Fascicule%20Liste%20rouge%20de%20la%20flore%20vasculaire%20de%20France%20métropolitaine.pdf.

References

Aedo, C., Medina, L., Fernández-Albert, M., 2013. Species richness and endemicity in the Spanish vascular flora. Nord. J. Bot. 31, 478–488. https://doi.org/10.1111/j.1756-1051.2012.00009.x.

Alagador, D., Martins, M.J., Cerdeira, J.O., Cabeza, M., Araújo, M.B., 2011. A probability-based approach to match species with reserves when data are at different resolutions. Biol. Conserv. 144, 811–820. https://doi.org/10.1016/j.biocon.2010.11.011.

Anderson, S., 2002. Identifying Important Plant Areas. Plantlife International, London.

Aránega, R., 2005. Aclaraciones taxonómicas y nomenclaturales sobre *Reseda decursiva* Forssk. y *Reseda gayana* Boiss. en Andalucía. Acta Bot. Malacitana 30, 189–239. https://doi.org/10.24310/abm.v30i0.7197.

Araújo, M.B., Lobo, J.M., Moreno, J.C., 2007. The effectiveness of Iberian protected areas in conserving terrestrial biodiversity. Conserv. Biol. 21, 1423–1432. https://doi.org/10.1111/j.1523-1739.2007.00827.x.

Araújo, M.B., Alagador, D., Cabeza, M., Nogués-Bravo, D., Thuiller, W., 2011. Climate change threatens European conservation areas. Ecol. Lett. 14, 484–492. https://doi.org/10.1111/j.1461-0248.2011.01610.x.

Bañares, Á., Blanca, G., Güemes, J., Moreno, J.C., Ortiz, S. (Eds.), 2004. Atlas y Libro Rojo de la Flora Vascular Amenazada de España: especies prioritarias. Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid.

Bennun, L., Njoroge, P., 2000. Important bird areas in Kenya. Ostrich 71, 164–167. https://doi.org/10.1080/00306525.2000.9639900.

Bilz, M., Kell, S.P., Maxted, N., Lansdown, R.V., 2011. European Red List of Vascular Plants. Publications Office of the European Union, Luxembourg.

Brugués, M., Cros, R.M., Infante, M., 2014. Lista Roja de los briófitos amenazados de España peninsular y balear, in: Garilleti, R., Albertos, B. (Coords.), Atlas de los briófitos amenazados de España. Universitat de València. Published online 04/07/2014. Retrieved from http://www.uv.es/abraesp.

Buira, A., Cabezas, F., Aedo, C., 2020. Disentangling ecological traits related to plant endemism, rarity and conservation status in the Iberian Peninsula. Biodivers. Conserv. 29, 1937–1958. https://doi.org/10.1007/s10531-020-01957-z.

Butchart, S.H.M., Clarke, M., Smith, R.J., Sykes, R.E., Scharlemann, J.P.W., Harfoot, M., Burgess, N.D., 2015. Shortfalls and solutions for meeting national and global conservation area targets. Conserv. Lett. 8, 329–337. https://doi.org/10.1111/conl.12158.

Campbell, C., Lockhart, N., 2017. Natural Heritage Areas (NHAs) for Bryophytes: Selection Criteria. Irish Wildlife Manuals, No. 100. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland.

Cardoso, P., 2012. Habitats Directive species lists: urgent need of revision. Insect Conserv. Divers. 5, 169–174. https://doi.org/10.1111/j.1752-4598.2011.00140.x.

CBD, Convention on Biological Diversity, 2010. Conference of the Parties Decision X/2, The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets, Nagoya, Japan, 18 to 29 October 2010.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.-P., Iglesias, A., Xoplaki, E., 2018. Climate change and interconnected risks to sustainable development in the Mediterranean. Nat. Clim. Chang. 8, 972–980. https://doi.org/10.1038/s41558-018-0299-2.

Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Guèze, M., Agard, J., … Zayas, C.N. (Eds.), 2019. IPBES: Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 56 pages. Retrieved from doi:https://doi.org/10.5281/zenodo.3553579.

Dimitrakopoulos, P.G., Memtsas, D., Troumbis, A.Y., 2004. Questioning the effectiveness of the Natura 2000 special areas of conservation strategy: the case of Crete. Glob. Ecol. Biogeogr. 13, 199–207. https://doi.org/10.1111/j.1466-822X.2004.00086.x.

Domínguez, F., Galicia, D., Moreno, L., Moreno, J.C., Sainz, H., 1996. Threatened plants in Peninsular and Balearic Spain. A report based on the E.U. Habitats Directive. Biol. Conserv. 76, 123–133. https://doi.org/10.1016/0006-3207(95)00107-7.

EC., 2011. Commission Implementing Decision of 11 July 2011 concerning a site information format for Natura 2000 sites (notified under document C(2011) 4892) (2011/484/EU). Off. J. Eur. Union L 198: 39–70. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011D0484&from=EN.

EC., 2016. Fitness Check of the EU Nature Legislation (Birds and Habitats Directives). European Commission, Brussels. Retrieved from http://ec.europa.eu/environment/nature/legislation/fitness_check/docs/nature_fitness_check.pdf.

EC., 2020. EU Biodiversity Strategy for 2030. Bringing Nature Back into our Lives. European Commission, Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0380&from=EN.

Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Tordoff, A., 2004. Key biodiversity areas as site conservation targets. BioScience 54, 1110–1118. https://doi.org/10.1641/0006-3568(2004)054[1110:KBAASC]2.0.CO;2.

Felicísimo, Á.M., Muñoz, J., Villalba, C., Mateo, R.G., 2011. Impactos, vulnerabilidad y adaptación al cambio climático de la biodiversidad española. 2. Flora y vegetación. Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid.

Fenu, G., Bacchetta, G., Giacanelli, V., Gargano, D., Montagnani, C., Orsenigo, S., Ercole, S., 2017. Conserving plant diversity in Europe: outcomes, criticisms and perspectives of the habitats directive application in Italy. Biodivers. Conserv. 26, 309–328. https://doi.org/10.1007/s10531-016-1244-1.

Fischer, M., Rounsevell, M., Torre-Marin Rando, A., Mader, A., Church, A., Elbakidze, M., Christie, M. (Eds.), 2018. IPBES: Summary for Policymakers of the Regional Assessment Report on Biodiversity and Ecosystem Services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.3237428.

Garilleti, R., Albertos, B. (Coords.), 2012. Atlas de los briófitos amenazados de España. Organismo Autónomo Parques Nacionales, Madrid.

Hermoso, V., Clavero, M., Villero, D., Brotons, L., 2016. EU's conservation efforts need more strategic investment to meet continental commitments. Conserv. Lett. 10, 231–237. https://doi.org/10.1111/conl.12248.

Hermoso, V., Morán-Ordóñez, A., Canessa, S., Brotons, L., 2019a. A dynamic strategy for EU conservation. Science 363 (6427), 592–593. https://doi.org/10.1126/science.aaw3615.

Hermoso, V., Morán-Ordóñez, A., Canessa, S., Brotons, L., 2019b. Four ideas to boost EU conservation policy as 2020 nears. Environ. Res. Lett. 14, 101001 https://doi.org/10.1088/1748-9326/ab48cc.

Hermoso, V., Morán-Ordóñez, A., Canessa, S., Brotons, L., 2019c. Realising the potential of Natura 2000 to achieve EU conservation goals as 2020 approaches. Sci. Rep. 9, 16087. https://doi.org/10.1038/s41598-019-52625-4.

Hochkirch, A., Schmitt, T., Beninde, J., Hiery, M., Kinit, T., Kirschey, J., Proelss, A., 2013. Europe needs a new vision for a Natura 2020 network. Conserv. Lett. 6, 462–467. https://doi.org/10.1111/conl.12006.

Hodgetts, N., Cálix, M., Englefield, E., Fettes, N., García Criado, M., Patin, L., Żarnowiec, J., 2019. A Miniature World in Decline: European Red List of Mosses, Liverworts and Hornworts. IUCN, Brussels, Belgium. https://doi.org/10.2305/IUCN.CH.2019.ERL.2.en.

Hodgetts, N.G., Söderström, L., Blockeel, T.L., Caspari, S., Ignatov, M.S., Konstantinova, N.A., Porley, R.D., 2020. An annotated checklist of bryophytes of Europe, Macaronesia and Cyprus. J. Bryol. 42, 1–116. https://doi.org/10.1080/03736687.2019.1694329.

IPCC, 2014. Summary for policymakers. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Jantke, K., Schleupner, C., Schneider, U.A., 2011. Gap analysis of European wetland species: priority regions for expanding the Natura 2000 network. Biodivers. Conserv. 20, 581–605. https://doi.org/10.1007/s10531-010-9968-9.

Johnson, C.N., Balmford, A., Brook, B.W., Buettel, J.C., Galetti, M., Guangchun, L., Wilmshurst, J.M., 2017. Biodiversity losses and conservation responses in the Anthropocene. Science 356 (6335), 270–275. https://doi.org/10.1126/science.aam9317.

Kujala, H., Araújo, M.B., Thuiller, W., Cabeza, M., 2011. Misleading results from conventional gap analysis – messages from the warming north. Biol. Conserv. 144, 2450–2458. https://doi.org/10.1016/j.biocon.2011.06.023.

Lisón, F., Sánchez-Fernández, D., Calvo, J.F., 2015. Are species listed in the Annex II of the Habitats Directive better represented in Natura 2000 network than the remaining species? A test using Spanish bats. Biodivers. Conserv. 24, 2459–2473. https://doi.org/10.1007/s10531-015-0937-1.

Locke, H., 2014. Nature needs half: a necessary and hopeful new agenda for protected areas. Nature New South Wales 58, 7–17. https://search.informit.org/doi/10.3316/informit.689951476354495.

Maes, D., Collins, S., Munguira, M.L., Sasic, M., Settele, J., van Swaay, C., Wynhoff, I., 2013. Not the right time to amend the annexes of the European Habitats directive. Conserv. Lett. 6, 468–469. https://doi.org/10.1111/conl.12030.

Maiorano, L., Amori, G., Montemaggiori, A., Rondinini, C., Santini, L., Saura, S., Boitani, L., 2015. On how much biodiversity is covered in Europe by national protected areas and by the Natura 2000 network: insights from terrestrial vertebrates. Conserv. Biol. 29, 986–995. https://doi.org/10.1111/cobi.12535.

Martínez, I., Carreño, F., Escudero, A., Rubio, A., 2006. Are threatened lichen species well-protected in Spain? Effectiveness of a protected areas network. Biol. Conserv. 133, 500–511. https://doi.org/10.1016/j.biocon.2006.08.003.

MITECO, 2019. Red Natura 2000. Accessed 3.04.2020 https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/red_natura_2000_inf_disp.aspx.

Moreno-Saiz, J.C. (Coord.), 2008. Lista Roja 2008 de la flora vascular española. Ministerio de Medio Ambiente, Medio Rural y Marino – Sociedad Española de Biología de la Conservación de Plantas, Madrid.

Muñoz-Rodríguez, P., Draper, D., Moreno-Saiz, J.C., 2016. Global strategy for plant conservation: inadequate in situ conservation of threatened flora in Spain. Israel J. Plant Sci. 63, 297–308. https://doi.org/10.1080/07929978.2016.1257105.

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., Yan, X., 2004. Effectiveness of the global protected area network in representing species diversity. Nature 428 (6983), 640–643. https://doi.org/10.1038/nature02422.

Rossi, G., Orsenigo, S., Montagnani, C., Fenu, G., Gargano, D., Peruzzi, L., Abeli, T., 2016. Is legal protection sufficient to ensure plant conservation? The Italian red list of policy species as a case study. Oryx 50, 431–436. https://doi.org/10.1017/S003060531500006X.

Rosso, A., Aragón, P., Acevedo, F., Doadrio, I., García-Barros, E., Lobo, J.M., Sánchez-Fernández, D., 2017. Effectiveness of the Natura 2000 network in protecting Iberian endemic fauna. Anim. Conserv. 21, 262–271. https://doi.org/10.1111/acv.12387.

SCBD., 2020. Global Biodiversity Outlook 5. Montréal, 208 pages. Retrieved from https://www.cbd.int/gbo5.

Trouwborst, A., Chapron, G., Fleurke, F., Epstein, Y., López-Bao, J.V., 2017. Europe's biodiversity avoids fatal setback. Science 355 (6321), 140. https://doi.org/10.1126/science.aam6200.

van der Sluis, T., Foppen, R., Gillings, S., Groen, T., Henkens, R., Hennekens, S., … Jones-Walters, L., 2016. How much Biodiversity is in Natura 2000?; The "Umbrella Effect" of the European Natura 2000 protected area network. Alterra Wageningen UR (University & Research centre), Alterra report 2730B, Wageningen. doi:10.18174/385797.

Verovnik, R., Govedič, M., Šalamun, A., 2011. Is the Natura 2000 network sufficient for conservation of butterfly diversity? A case study in Slovenia. J. Insect Conserv. 15, 345–350. https://doi.org/10.1007/s10841-010-9308-0.

Wilson, E.O., 2016. Half-Earth: Our Planet's Fight for Life. Liveright, New York.