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On how much biodiversity is covered in Europe by national protected areas and by the Natura 2000 network: insights from terrestrial vertebrates

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Abstract: *The European Union has made extensive biodiversity conservation efforts with the Habitats and Birds Directives and with the establishment of the Natura 2000 network of protected areas, one of the largest networks of conservation areas worldwide. We performed a gap analysis of the entire Natura 2000 system plus national protected areas and all terrestrial vertebrates (freshwater fish excluded). We also evaluated the level of connectivity of both systems, providing therefore a first estimate of the functionality of the Natura 2000 system as an effective network of protected areas. Together national protected areas and the Natura 2000 network covered more than one-third of the European Union. National protected areas did not offer protection to 13 total gap species (i.e., species not covered by any protected area) or to almost 300 partial gap species (i.e., species whose representation target is not met). Together the Natura 2000 network and national protected areas left 1 total gap species and 121 partial gap species unprotected. The terrestrial vertebrates listed in the Habitats and Birds Directives were relatively well covered (especially birds), and overall connectivity was improved considerably by Natura 2000 sites that act as stepping stones between national protected areas. Overall, we found that the Natura 2000 network represents at continental level an important network of protected areas that acts as a good complement to existing national protected areas. However, a number of problems remain that are mainly linked to the criteria used to list the species in the Habitats and Birds Directives. The European Commission initiated in 2014 a process aimed at assessing the importance of the Birds and Habitats Directives for biodiversity conservation. Our results contribute to this assessment and suggest the system is largely effective for terrestrial vertebrates but would benefit from further updating of the species lists and field management.*

Keywords: Birds Directive, connectivity, European Union, gap analysis, Habitats Directive

Cuánta Biodiversidad Europea es Tomada en Cuenta por las Áreas Protegidas Nacionales y cuánta por la Red Natura 2000: Percepciones de los Vertebrados Terrestres

Resumen: *La Unión Europea ha hecho esfuerzos extensos de conservación de la biodiversidad con las Directivas de Hábitat y de Aves y con la creación de la red de áreas protegidas Natura 2000, una de las redes más grandes de áreas de conservación a nivel mundial. Realizamos un análisis de falta de datos en todo el sistema Natura 2000 más las áreas protegidas nacionales y todos los vertebrados terrestres (excluimos a los peces de agua dulce). También evaluamos el nivel de conectividad de ambos sistemas, proporcionando así un primer estimado de la funcionalidad del sistema Natura 2000 como una red efectiva de áreas protegidas. La red Natura 2000, junto con las áreas protegidas nacionales, cubrió más de un tercio de la Unión Europea. Las áreas protegidas nacionales no ofrecieron protección para un total de 13 especies del vacío (es decir, las especies que no abarcaron ninguna área protegida) o para casi 300 especies parciales del vacío (es decir, especies cuyo objetivo de representación no es alcanzado). La red Natura 2000, junto con las áreas protegidas nacionales,*

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dejó un total de una especie del vacío y 121 especies parciales del vacío sin protección. Los vertebrados terrestres enlistados en las Directivas de Hábitat y de Aves fueron tomados en cuenta relativamente bien (especialmente las aves), y la conectividad general mejoró considerablemente por los sitios Natura 2000, los cuales funcionan como peldaño entre las áreas protegidas nacionales. En general, encontramos que la red Natura 2000 es, a nivel continental, una red importante de áreas protegidas que actúa como un buen complemento para las áreas protegidas nacionales existentes. Sin embargo, todavía permanece un número de problemas que están conectados principalmente con la lista de especies en las Directivas de Hábitat y de Aves. La Comisión Europea inició en 2014 un proceso enfocado a la importancia de estas directivas para la conservación de la biodiversidad. Nuestros resultados contribuyen a esta evaluación y sugieren que el sistema es generalmente efectivo para los vertebrados terrestres pero que se beneficiaría de una mayor actualización de las listas de especies y del manejo en el campo.

Palabras Clave: análisis de falta de datos, conectividad, Directiva de Aves, Directiva de Hábitat, Unión Europea

Introduction

The Aichi Targets, adopted in 2010 by the Convention on Biological Diversity (CBD) (CBD 2011), are aimed at tackling the continuing decline in biodiversity. A key element is Aichi Target 11, which commits CBD to improve connectivity within existing networks of protected areas (PAs) and to expand the global coverage of terrestrial PAs up to 17% by 2020 (Venter et al. 2014).

The European Union (EU) is a pioneer at the global level due to its efforts toward nature conservation. Already in 1979 the EU adopted Directive 79/409/EEC (Birds Directive) aimed at the conservation of wild birds (193 endangered species and subspecies or populations) and then in 1992 adopted Directive 92/43/EEC (Habitats Directive) aimed at the conservation of natural habitats, wild faunas (other than birds), and floras (approximately 900 species, subspecies, and populations of plants and animals). Under the framework of the 2 directives, each member state has to identify specific areas for inclusion in the EU Natura 2000 conservation network, the aim of which is to conserve an extensive range of threatened habitat types and species throughout Europe, and to maintain at or restore to "favorable conservation status" listed habitat and species.

The EU clearly represents a complex and highly peculiar case study compared with other continent-wide national or international systems. With its 28 member states, the EU alone covers a total land area of about 4.5 million km^2 and contains parts of the Mediterranean biodiversity hotspot (Mittermeier et al. 2005), several of Earth's most biologically valuable ecoregions (Olson & Dinerstein 1998), and many centers of plant diversity (Davies et al. 1994). At the same time, the overall human population is currently >500 million, leaving a very limited space for natural and semi-natural ecosystems. Humans have extensively reshaped the region for at least the last 10,000 years, substantially longer than most regions globally, making it considerably different from most of Australia or North America. For example, Australia is 1.7 times bigger than EU28 and has a human population of about 21.5 million, whereas the United States and Canada together are 4.4 times bigger and have a human population of about 350 million. The local footprint of human consumption with the related environmental impacts is many times higher in the EU than in either of these areas (Imhoff et al. 2004), leaving only limited options for conservation.

Nonetheless, the EU had implemented a unique system of PAs, and the Natura 2000 network is undoubtedly one of the largest and more articulated networks of conservation areas worldwide (EEA 2012). At present, however, it is unlikely that the Aichi Target of halting biodiversity loss by 2020 will be met. In fact, although PAs represent one of the most important responses to the global biodiversity crisis (Watson et al. 2014), their biodiversity benefits are far from guaranteed, with PAs often established in locations that are remote or have low economic value (Maiorano et al. 2006; Joppa & Pfaff 2009).

Explicitly recognizing this problems, CBD asks for the establishment of PAs in places that are of "importance for biodiversity" and "ecologically representative."

To date, many analyses focused on the national scale or smaller parts of the Natura 2000 network have been performed to assess the patterns of biodiversity coverage (Dimitrakipoulos et al. 2004; Maiorano et al. 2007; López-López et al. 2011; D'Amen et al. 2013; Lison et al. 2013; Rubio-Salcedo et al. 2013). Other analyses have considered connectivity (e.g., Gurrutxaga et al. 2011; Opermanis et al. 2012), human activities (Tsiafouli et al. 2013), and ecosystem services (Bastian 2013), but they all focused on particular areas and few species or habitats. Some analyses have considered the entire Natura 2000 network as part of a much larger study areas (e.g., Zupan et al. 2014), therefore making it impossible to evaluate the contribution of the network to biodiversity conservation. Only a few analyses have been explicitly focused on the Natura 2000 network, considering for example bird species richness (Albuquerque et al. 2013), a subset of threatened species (Trochet & Schmeller 2013), population trends for birds (Donald et al. 2007), and climate change (Araujo et al. 2011). Gruber et al. (2012)

included the entire Natura 2000 network in an analysis of the system's coverage of over 77% of the species listed in the Habitats Directive (Annex II only). However, they based their analyses on species presence data obtained from national reports, which are often of variable quality and resolution from country to country (Evans 2012) and spatially coarse (100 km^2 resolution) relative to the size of many Natura 2000 sites (often below 1 km^2) (Maiorano et al. 2007). Such mismatch in resolution between the size of PAs and the data available on biodiversity may generate problems and spurious results, especially in conservation planning and gap analysis exercises (Alagador et al. 2011).

This wealth of studies provides no information that can clearly be applied to the EU as a whole because the primary findings are relevant only to the particular study area considered and depend on the quality of the input data and the particular research question. To date, no comprehensive and reliable analysis of the Natura 2000 network aimed at evaluating its "importance for all biodiversity" or its ecological representativeness has been performed at the level of the EU.

The Natura 2000 network has been designed to protect only the species and habitats listed in the Annexes of the Habitats and Birds Directives; there is no pretense of conserving all European biodiversity. However, the network is currently considered the most effective tool for biodiversity conservation in the EU, even though the potential umbrella effect of the network in conserving more than the species listed remain untested. Therefore, the question of primary importance is what is the value of the Birds and Habitats Directives as a general tool for biodiversity conservation in the EU, especially considering the possible revision of the 2 directives in the next few years and the ongoing discussions on the need for a broad conservation tool that can be applied at the European level.

A second important point yet to be explored is the level of complementarity and overlap between the Natura 2000 network and national PAs. The Natura 2000 network has been conceived as a network of areas independent of national PAs (although with a widespread overlap); thus, Natura 2000 should be able to cover biodiversity, at least listed species, by itself. However, this point has never been tested with data that homogeneously cover the entire EU and include a substantial portion of all biodiversity.

We attempted to provide such an evaluation for all terrestrial vertebrates (freshwater fish excluded) that occur naturally in the EU. We used a database with high-resolution data on species presence that covered the entire EU. We considered species listed and not listed in the directives as well as endemicity and threat status. We determined the coverage provided by national PAs and by the Natura 2000 network to terrestrial vertebrates; the role of the Natura 2000 in adding to the coverage provided by the national PAs; and the contribution of Natura 2000 to overall connectivity between PAs. In our examination of connectivity, we accounted only for nonflying terrestrial vertebrates (excluding birds and bats) and compared the connectivity of national PAs with that of national PAs plus the Natura 2000 areas.

Methods

To map the currently existing national PAs, we downloaded the 2014 version of the World Database on Protected Areas (Protected Planet 2014) and extracted data on International Union for Conservation of Nature (IUCN) category I-VI PAs. We excluded all proposed PAs, all areas lacking a national designation, and all areas without polygonal representation. We retained IUCN categories V and VI because, although not specifically aimed at biodiversity conservation, they can provide some protection (Venter et al. 2014). Data on the Natura 2000 network was downloaded from the European Environmental Agency for the entire EU except Croatia. The Croatian State Institute for Nature Protection (courtesy Ivana Plavac) provided the national Natura 2000 database.

We obtained validated species distributions models for all terrestrial vertebrates occurring in the study area from Maiorano et al. (2013). For each species we considered the threat status from the global IUCN Red List and defined as threatened all species classified as critically endangered, endangered, or vulnerable. Furthermore, using the global distribution range as reference (see Maiorano et al. [2013] for details on data source), we calculated the percentage of the distribution included in the EU and defined as endemics all taxa with distributions totally encompassed in the EU.

Analyses

To investigate the level of coverage offered by national PAs, by the Natura 2000 network, and by both systems to terrestrial vertebrates in the EU, we took three main steps: gap analysis considering only national PAs, gap analysis considering only the Natura 2000 network, and gap analysis considering both.

We defined for each species a representation target based on the area occupied and on the percentage of the global distribution range occurring in the EU, a modification of Rodrigues et al.'s (2004) approach. The representation target was set to a maximum of 100% of the area occupied for species with a narrow distribution (area occupied < 1000 km^2) and with more than 10% of their global distribution range in the EU and to a minimum of 10% for widespread species (area occupied $> 100{,}000$ km^2) or species only marginally present in the EU ($< 10\%$ of their global distribution range in EU). For all other species the representation target was interpolated

between the 2 extremes with a linear regression on the log-transformed area occupied. A species not represented in any PA was considered a total gap species, a species whose representation target is only partially met was considered a partial gap species, and a species whose representation target is met was considered covered.

Because functional connectivity depends on several species-specific aspects that cannot be easily generalized, we estimated connectivity based only on the role of dispersal distance and network topology. Ignoring the role of landscape matrix heterogeneity and animal behavior may result in uncertain predictions (Bender & Fahrig 2005); however, it allowed us to provide generic estimates of the functionality of the network for a range of dispersal distances representing broad species categories. To measure connectivity among PAs, we converted the layers of national PAs and of the Natura 2000 network in a raster with roughly 1 km^2 resolution and calculated the distance of each PA to all neighboring PAs. Assuming a negative exponential dispersal kernel, and considering only non-flying vertebrates, we limited our analyses to a maximum radius of 500 km. For Natura 2000 areas, we considered only areas established under the Habitats Directives because we excluded breeding birds from the connectivity analyses.

Using the software Conefor (www.conefor.org) and considering a set of 12 dispersal distances (from 180 m to 100 km), we calculated the equivalent connected area index (Saura et al. 2011), which represents the amount of reachable habitat (species-specific habitat defined in Maiorano et al. [2013]) for a given dispersal distance (i.e., the total area of habitat available in national PAs or Natura 2000 sites that a species would be able to reach by moving within and among protected sites).

Results

Our final national PA layer (Supporting Information) included 87,719 areas covering 19.5% of the study area. The Natura 2000 network was almost equivalent. It covered more than 18% of the EU (>26,000 terrestrial sites) and thus exceeded the Aichi Target 11 (Table 1). Considering the combined national PAs and Natura 2000 networks, 32.6% of EU28 was covered (almost 1,400,000 km^2). The two networks overlapped extensively; 28.9% of the area protected was covered by both systems (Supporting Information).

On average, 3133 national PAs and 943 Natura 2000 areas have been established per country, corresponding to a mean country coverage of 22.4% for national PAs and of 19.2% for Natura 2000 areas (Table 1). On average national PAs were smaller (mean area = 10.8 km^2) relative to the Natura 2000 areas (mean area = 29.8 km^2), with a large portion of PAs smaller than 1 km^2 in central and northern Europe.

Habitats and Birds Directives Species Lists

There were 842 species of terrestrial vertebrates occurring in the EU (Table 2). Among these, 33% were listed in Appendix II of the Habitats Directive or in Appendix 1 of the Birds Directive. We excluded from further analyses 3 species listed in the Habitats Directive (*Capra pyrenaica pyrenaica*, which went extinct in 2000; *Mauremys caspica* and *Capra aegagrus*, whose populations in the EU are introduced) and 9 species listed in the Birds Directive (*Numenius tenuirostris* and *Perdix perdix italica*, both extinct in EU28; *Branta ruficollis*, *Gavia immer, Anser albifrons flavirostris, Chlamydotis undulata, Cursorius cursor, Branta bernicla,* and *Polysticta stelleri*, all only winter in the EU). The full list of species is in the online Supporting Information.

Overall, 71 species or subspecies (8%) are strictly EU endemics. Amphibians have the highest share of endemic taxa (57.6%), and breeding birds have the lowest (7.1%) (Table 2). The Birds Directive covered endemic species extremely well; 28 species out of 31 endemics are listed in the directive. To the contrary, the Habitat Directive species list did not include many of the endemic species. In particular, 80.4% of endemic reptiles were not listed. Exactly the same pattern occurred for threatened species. All threatened breeding birds were listed, but 60.9% of threatened reptiles were not (Table 2). Overall, 29 endemic and at the same time threatened species (7 amphibians, 11 mammals, 11 reptiles) were not listed in the directives; 7 of these endemic species are critically endangered at the global level. In contrast, 79% of the species listed in the 2 directives (229 out of 288) are not categorized as threatened by the IUCN. Almost half of these species (12 mammals and 92 breeding birds) occur only marginally in the EU (<10% of their global distribution range is in the EU [mean = 3.4%, min = 0.005%, max 9.8%]).

GAP Analyses and Connectivity

Breeding birds were by far the best-covered taxon. A minimum of 74% of the species met their representation targets inside national PAs and a maximum of 93% of the species were totally covered inside national PAs plus the Natura 2000 network (Table 3). A similar pattern, although with smaller percentages, was found for mammals, whereas reptiles (closely followed by amphibians) were the least protected (Table 3).

Overall, only 13 species were not covered by any national PA in the EU, 9 of which were listed in the Habitats or Birds Directives. Amphibians (8 species, 7 of which are listed) were the main taxon among total gap species (Table 3). Nine out of the 13 total gap species are classified as threatened by IUCN and 8 are also endemic. Two of the total gap species (*Mertensiella luschani* and *Pterodroma feae*) occur marginally in the EU (0.7% and

Table 1. Country data on area of national protected areas (PAs) and Natura 2000 areas (N2k) and terrestrial vertebrate species covered by these areas.

Country	*Country area (km^2)*	*No. of PAs*	*No. of N2ks*	*Mean area PAs (km^2)*	*Mean area N2ks (km^2)*	*Total area PAs (km^2)*	*Total area N2ks (km^2)*	*Total area of PAs + N2ks (km^2)*	*Species covered by PAs (%)*	*Species covered by N2ks (%)*	*Species covered by by PAs + N2ks (%)*
Austria	83,859	1,250	219	22.17	57.35	27,715	12,559	31,673	33.05	14.98	37.77
Belgium	30,528	3,398	453	1.62	8.57	5,521	3,883	7,046	18.09	12.72	23.08
Bulgaria	110,910	1,007	335	25.03	113.63	25,206	38,066	50,557	22.73	34.32	45.58
Croatia	56,594	436	577	13.52	35.83	5,895	20,675	21,580	10.42	36.53	38.13
Cyprus	5,736	45	58	75.89	28.07	3,415	1,628	3,671	59.54	28.38	64.00
Czech Rep.	78,866	4,073	1,116	4.48	9.91	18,231	11,062	23,780	23.12	14.03	30.15
Denmark	43,093	3,923	294	2.35	12.19	9,214	3,584	12,779	21.38	8.32	29.66
Estonia	45,226	12,639	557	1.07	14.50	13,479	8,076	15,326	29.80	17.86	33.89
Finland	338,145	9,270	1,803	7.59	27.09	70,363	48,851	109,148	20.81	14.45	32.28
France	549,192	1,758	1,665	36.30	41.52	63,818	69,127	125,597	11.62	12.59	22.87
Germany	357,031	17,532	5,217	11.91	10.57	208,833	55,142	232,973	58.49	15.44	65.25
Greece	131,940	794	403	27.63	88.74	21,939	35,761	44,564	16.63	27.10	33.78
Hungary	93,030	133	525	36.56	38.00	4,863	19,950	21,145	5.23	21.44	22.73
Ireland	70,280	218	544	8.06	16.95	1,757	9,222	10,587	2.50	13.12	15.06
Italy	301,333	821	2,479	38.45	23.05	31,570	57,137	75,164	10.48	18.96	24.94
Lithuania	65,301	339	484	28.21	16.30	9,562	7,890	16,392	14.64	12.08	25.10
Luxembourg	2,597	25	60	21.52	7.82	538	469	933	20.72	18.08	35.93
Latvia	64,589	701	326	10.22	22.85	7,163	7,449	11,986	11.09	11.53	18.56
Malta	316	153	35	0.64	1.16	98	41	107	31.02	12.88	33.86
Netherlands	41,526	2,099	192	4.11	28.97	8,620	5,563	9,185	20.76	13.40	22.12
Poland	312,685	1,854	978	42.25	62.43	78,338	61,059	107,355	25.05	19.53	34.33
Portugal	91,990	172	141	41.48	134.82	7,135	19,010	20,152	7.76	20.66	21.91
Romania	238,391	910	522	18.02	103.04	16,399	53,788	55,487	6.88	22.56	23.28
Slovakia	48,845	1,120	514	10.98	28.10	12,299	14,442	18,274	25.18	29.57	37.41
Slovenia	20,273	1,940	352	7.16	21.80	13,897	7,673	14,196	68.55	37.85	70.02
Spain	504,782	479	1,706	101.32	80.52	48,534	137,365	148,150	9.61	27.21	29.35
Sweden	414,864	11,860	4,020	4.26	14.28	50,559	57,410	130,249	12.19	13.84	31.40
UK	244,820	8,770	835	8.34	25.01	73,169	20,884	80,398	29.89	8.53	32.84
EU28	4,290,148	87,719	26,410	9.55	29.83	838,130	787,767	1,398,454	19.54	18.36	32.60

Table 2. Number of terrestrial vertebrate species by taxa naturally occurring in the 28 states that are part of the European Union (EU28) and, in parentheses, the number of taxa listed in the Annex II of the Habitat Directive or in Annex I of the Birds Directive.

	Number of species in EU28		
Taxon	*total*	*endemics*	*threatened*[*]
Amphibians	85 (30)	49 (20)	21 (13)
Reptiles	142 (21)	56 (11)	23 (9)
Breeding birds	435 (184)	31 (28)	17 (17)
Mammals	180 (43)	36 (12)	22 (10)

[*] *Includes all taxa listed by the International Union for Conservation of Nature as critically endangered, endangered, or vulnerable.*

0.0001%, respectively, of their global range is in the EU). Almost 34% of all species (285 species) did not meet their representation target in national PAs; an average of 53.4% of the representation target was met (minimum = 43.9% for reptiles; maximum = 63.4% for breeding birds). More than 37% of these species (106) are listed in the EU Directives, 19.6% (56 species) are threatened, and 48.4% (138 species) are endemic to the EU.

On average, the Natura 2000 network offered more coverage than national PAs to each species. The mammal *Microtus bavaricus* was the only total gap species and it is not listed in the directives. The species is known only for a single locality at the German-Austrian borders and it is considered critically endangered by the IUCN. However, *M. bavaricus* was considered extinct at the time the Habitat Directive was drafted; a residual population was discovered only recently. The number of partial gap species was lower relative to national PAs, particularly in the case of breeding birds listed in the Birds Directive (Table 3).

On average, adding the Natura 2000 network to national PAs increased the coverage offered to single species by 302.3% (477.8% for amphibians, 413.7% for reptiles, 246.7% for breeding birds, 273.2% for mammals), up to an average increase of 331.4% for species listed in the Habitats or Birds Directives (573.7% for amphibians, 279.0% for reptiles, 293.9% for breeding birds, 385.1% for mammals). Considering both national PAs and the Natura 2000 network, there was 1 total gap species (the same *Microtus bavaricus* cited above) and 121 partial gap species (14.4% of all species). Again, reptiles had the lowest level of protection. On average, 57.3% of the representation target was covered for partial gap species by national PAs and Natura 2000 network; a minimum of 49.2% for amphibians and a maximum of 62.5% for breeding birds were covered.

The two networks combined provided considerably improved potential connectivity for terrestrial vertebrates relative to national PAs only. The equivalent connected area index increased from 2.6 to 4.7 times along the range of dispersal distances considered (Fig. 1). For long dispersal distances ($\sim$ >30 km of median dispersal distance), the increase in the equivalent connected area was higher than the increase in the total area of protected habitat, whereas the opposite occurred for shorter dispersal distances. Therefore, Natura 2000 sites largely increased the amount of connected habitat and efficiently upheld connectivity for vagile species by playing a role as stepping stones among national PAs.

Discussion

We have provided the first complete gap analysis specifically tailored to the EU and on the Natura 2000 network for terrestrial vertebrates. We asked how much biodiversity is covered by national PAs, by the Natura 2000, and by the combination of both, including species listed under the Habitats or Birds Directives as well as species not listed.

The Natura 2000 network is possibly not the most efficient systems (area wise) of PAs, but this inefficiency is linked to the bottom-up process on which the network has been constructed (for a detailed description of the process see Evans [2012]). Specific problems with the Natura 2000 network are mainly related to the list of species considered in the 2 directives. The first issue is updating the lists to capture the changing species taxonomy and the definition of new species, currently a problem for 7.2% of the taxa listed (vertebrates only). Although this first point is relatively easy to solve by updating the annexes, the introduction in the listing process of more objective criteria to identify species (and habitats) with higher risk of extinction appears to be a more difficult task (Hochkirch et al. 2013*a*). If the list of bird species covers very well endemic and threatened species, the lists under the Habitats Directive presents several problems. Twenty-nine vertebrate species endemic to the EU and globally threatened are not listed (7 amphibians, 11 mammals, 11 reptiles), whereas more than 82% of the species listed are not threatened at the global level and more than 37% of the species listed are not threatened and occur only marginally in the EU. Similar problems have already been shown for insects (Cardoso 2012), butterflies (van Swaay et al. 2011), and dragonflies (Kalkman et al. 2010), all taxa for which the available information was (and still is) very limited when the Habitat Directive was drafted and updated.

Previous proposed amendments to the Annexes of the EU Directives have generated a polarized debate in the scientific literature (e.g., Hochkirch et al. 2013*b*; Maes et al. 2013). Maes et al. (2013), in particular, see the focus on the species list as a potential diversion of attention and resources from more important problems, like the implementation of the Natura 2000 network. We agree with the importance of local scale effective management measures for the Natura 2000 network such as, for

Table 3. Number of total and partial gap species[a] per taxon relative to national protected areas (PAs), to the Natura 2000 network, and to both systems (All).[b]

	National PAs		*Natura 2000*		*All*	
Taxon	*total gap (%)*	*partial gap (%)*	*total gap (%)*	*partial gap (%)*	*total gap (%)*	*partial gap (%)*
All amphibians	8 (9.4)	35 (41.2)	0 (0.0)	30 (35.3)	0 (0.0)	26 (30.6)
Endemic amphibians	7 (8.2)	28 (32.9)	0 (0.0)	26 (30.6)	0 (0.0)	24 (28.2)
Threatened amphibians	7 (8.2)	13 (15.3)	0 (0.0)	17 (20.0)	0 (0.0)	15 (17.6)
Amphibians listed in EU directives	7 (8.2)	13 (15.3)	0 (0.0)	16 (18.8)	0 (0.0)	13 (15.3)
All reptiles	1 (0.7)	82 (57.7)	0 (0.0)	51 (35.9)	0 (0.0)	47 (33.1)
Endemic reptiles	0 (0.0)	56 (39.4)	0 (0.0)	42 (29.6)	0 (0.0)	41 (28.9)
Threatened reptiles	0 (0.0)	20 (14.1)	0 (0.0)	18 (12.7)	0 (0.0)	17 (11.9)
Reptiles listed in EU directives	0 (0.0)	12 (8.5)	0 (0.0)	10 (7.0)	0 (0.0)	9 (6.3)
All birds	2 (0.5)	110 (25.3)	0 (0.0)	40 (9.2)	0 (0.0)	31 (7.1)
Endemic birds	1 (0.2)	27 (6.2)	0 (0.0)	25 (5.7)	0 (0.0)	22 (5.1)
Threatened birds	0 (0.0)	8 (1.8)	0 (0.0)	4 (0.9)	0 (0.0)	4 (0.9)
Birds listed in EU directives	2 (0.5)	62 (14.3)	0 (0.0)	28 (6.4)	0 (0.0)	21 (4.8)
All mammals	2 (1.1)	58 (32.2)	1 (0.6)	35 (19.4)	1 (0.6)	26 (14.4)
Endemic mammals	2 (1.1)	27 (15.0)	1 (0.6)	20 (11.1)	1 (0.6)	17 (9.4)
Threatened mammals	2 (1.1)	15 (8.3)	1 (0.6)	11 (6.1)	1 (0.6)	10 (5.6)
Mammals listed in EU directives	0 (0.0)	19 (10.6)	0 (0.0)	13 (7.2)	0 (0.0)	10 (5.6)

[a]*Definitions: total gap species, species not covered by any protected area; partial gap species, species whose representation target is not met.*
[b]*Percentages in parentheses are calculated considering the total number of species per taxa.*

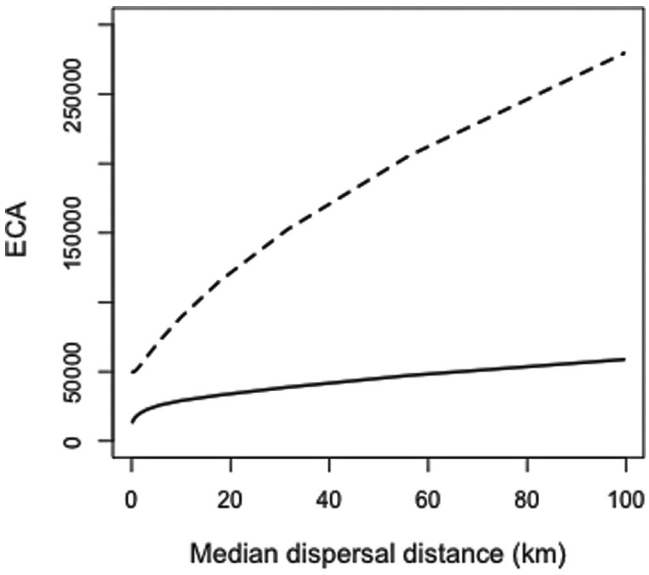

Figure 1. Equivalent connected area (ECA) index relative to dispersal distances of non-flying terrestrial vertebrates for national protected areas alone (solid line) and national protected areas plus the Natura 2000 network (dashed line). The index is a measure of the total area of habitat available in national protected areas or Natura 2000 sites that a species would be able to reach by moving within and among protected sites.

example, providing economic incentives to compensate for the losses due to productive activities limited by the conservation objectives. These measures, complemented by more effective controls, would ensure that Natura 2000 represents an effective conservation tool and not simply a system of paper parks. However, we claim that having a long list of not-threatened species and applying some of the limited resources available for conservation to species only marginally occurring in the EU could make all EU conservation efforts weaker and, in the long term, more difficult to sustain both economically and politically.

Changing the directive's annexes would clearly be a very political process and should be done very carefully as it may also open the way to proposals weakening the protection regime provided by Article 6 in the Habitat Directive. Furthermore, especially if one considers plants and insects, the list of taxa and species to include would be extremely long and basically impossible to draft based on current taxonomic and biogeographical knowledge. However, the level of knowledge we currently have on distribution, systematics, and ecology for terrestrial vertebrates in Europe clearly calls for an update of the annexes at least for these species.

Our results demonstrate that the Natura 2000 network represents at continental level an important network of PAs and provides a good complement to existing national PAs. First, when both networks are considered almost one-third of EU28 is under some form of protection, providing one of the largest networks of PAs in the world. Second, the coverage offered to single species is generally very good. One key result of our analysis is the almost complete absence of total gap species inside the Natura 2000 network, with only one exception. Furthermore, the Natura 2000 network provides overall a reasonable representation to most terrestrial vertebrates in Europe. When national PAs and the Natura 2000 network

are taken as a consolidated system, the results are even more encouraging; only 14% of all species would be considered partial gap species given our representation targets. Furthermore, on average, more than 50% of the representation target is also covered for partial gap species, a percentage that is closely approached for the least protected taxa (i.e., amphibians and reptiles). Moreover, the consolidated network provides more reachable habitat than the PAs alone and Natura 2000 alone for species dispersing long distances. This indicates that Natura 2000 sites act as stepping stones, reinforcing the connectivity of the entire system.

Our results clearly differ from previously published analyses focused on nation-wide systems (e.g., Maiorano et al. 2007), but this is not surprising because a species that may be a total gap species in Italy may at the same time be well protected elsewhere. Furthermore, our results on connectivity suggest that the Natura 2000 network presents a unique opportunity to contribute to the ecological linkages necessary for a substantial portion of biodiversity in the EU and that there is room for improvement particularly for the less mobile species that depend on fine-scale landscape features and the proximity of protected habitat at relatively short distances. The Habitat Directive (Article 10) already provides the framework within which management and conservation measures outside of Natura 2000 areas can be implemented, and other EU initiatives (e.g., the Green Infrastructures strategy adopted in 2013) can help.

However, the two networks are not managed under the same political and technical vision. While Natura 2000 responds to the policies of the European Parliament, national PAs respond to national policies. Past and recent events show that tensions between the two levels can easily occur and disrupt the necessary coordination in managing the various networks (EEA 2012).

Maintaining these vast systems of PAs is economically and politically costly, and one might ask what is the level of redundancy of the overall system and how can it be reduced to improve its efficiency? However, there are no studies, to our knowledge, on the possible level of redundancy of the individual and combined networks; moreover, having a certain amount of redundancy appears the most prudent approach against the uncertainty of the predicted global changes (Mumby et al. 2011).

Future efforts in terms of new areas being established should be focused primarily on the only total gap species, on those taxa currently less well protected (reptiles and amphibians), and on enhancing connectivity for the largest number of taxa and dispersal ranges. However, the EU is characterized by extremely high human population density and pervasive human influence even in the most remote areas, and the establishment of new PAs is difficult. Further subtraction of productive land for conservation is likely to be socially, economically, and politically costly. Therefore, any further conservation effort should prioritize management on the ground to achieve a favorable conservation status for all species and habitats inside PAs. At the same time, it is important to focus on the habitat matrix outside PAs. It has been clearly demonstrated that PAs cannot fulfill their conservation objectives if they are small and are islands in a human dominated landscape (Maiorano et al. 2008). However, the EU potentially has the political power and the economic and technical tools to make a real impact on biodiversity conservation in unprotected areas. For example, agri-environmental policy has been implemented with increasing conviction and economic support in the last decades (Batary et al. 2015 [this issue]).

Obviously, the good representation that we measured for terrestrial vertebrates does not guarantee representation of other taxa or other biodiversity features. Yet the literature provides good support of the contention that broad taxonomic groups generally can represent the majority of species (Moore et al. 2003; Di Minin & Moilanen 2014). In this sense, our analyses should be fairly robust because we have included species as different (in ecology, morphology, physiology) as large mammalian carnivores and as salamanders.

Our results should be considered with a number of caveats. A major caution is linked to the representation targets we considered. We used a widely applied approach to set species-specific targets (Rodrigues et al. 2004; Venter et al. 2014) that is based on the assumption that species with restricted ranges require a stronger conservation effort. We recognize, however, that even a species-specific representation target can represent a problem, with inequitable assessments of PAs coverage (Santini et al. 2014). One possible solution would be to explicitly recognize the existence of spatial structuring in the populations of each species, but this is not feasible for the number of species and the study area we considered.

A second important caveat is linked to data quality. The species distribution database we used is updated, and more than 44% of the distribution maps have been positively evaluated against independent field data (Maiorano et al. 2013). Moreover, models of species distribution based on habitat suitability represent one possible solution to minimize commission errors that often plague maps of extent of occurrence (Gaston 2003). However, even if we decreased the amount of commission errors in species distributions, we could not exclude the presence of omission errors, which could have influenced our results.

The main problem linked to data quality resides, however, in the PA and Natura 2000 layers. We selected PAs on the basis of the IUCN categories and, following the approach adopted by Venter et al. (2014), we included all areas in categories I to VI. The assumption for this choice is that even multiple-use areas (such as categories V and VI) can support species conservation, but we recognize that the IUCN PA categories can potentially foster a

number of problems (Boitani et al. 2008). Furthermore, both the World Database on Protected Areas and the Natura 2000 database may have spatial errors as well as errors in their attributes. We made every effort in the initial selection of areas to correct these problems (e.g., excluding one PA in Sardinia because it was actually a Tunisian PA erroneously mapped in Italy), but other errors may have remained undetected.

The EU has initiated in 2014 a process called Fitness Check on EU Nature Legislation (Birds and Habitats Directives) aimed at assessing the effectiveness, efficiency, coherence, relevance, and EU added value of the Birds and Habitats Directives in contributing to the EU Biodiversity Strategy. Because the Natura 2000 network is central to the effort to meet the 2020 European conservation targets, our results contribute to the assessment and suggest the system is largely effective but would benefit from further updating and maintenance.

Comparing the Natura 2000 network with other PAs at the global level, the EU is clearly advanced from a conservation point of view. Watson et al. (2014) proposed a change in PA policies at the global level, a focus on expansion, management, investment, and enforcement of existing PAs. While many countries are still short of what they formally agreed to do in the 2020 CBD strategic plan (Watson et al. 2014), considering more options for expansion of the PA system in the EU is not the main issue (and could be difficult considering the level of protection already reached and the level of human pressure on the landscape). However, the EU should focus on the other aspects, particularly on management (both in and outside PAs) and enforcement (particularly inside Natura 2000). Further investments in conservation are urgently needed, and a focus on ecosystem services and the costs of habitat degradation inside PAs is particularly important.

Supporting Information

A description of the study area and the spatial distribution of national PAs and the Natura 2000 network (Appendix S1) and a list of all species considered in the analyses (Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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