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Effectiveness of the Natura 2000 network to cover threatened species

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Abstract

The world's biodiversity is currently in rapid decline - Europe being no exception - with as principal cause a human-mediated global change. The Natura 2000 network is an important conservation tool for European biodiversity; it is a network of natural and semi-natural sites within Europe with high heritage values due to the exceptional flora and fauna they contain. Here, we evaluated the coverage of 300 threatened species by the Natura 2000 network, and determined potential factors influencing the designation of sites and the structure of the network within a country (social, ecological and demographic national factors). Our analysis was based on a coverage ratio between the Natura 2000 sites and distribution maps of threatened European species. We showed that the distributions of a large proportion of threatened species of mammals, birds and reptiles considered in our study were highly covered (above 90%) by the current Natura 2000 network, demonstrating that the Natura 2000 network also covers species not listed in the annexes of the Nature Directives. However, our results confirm that a large proportion of threatened species (some of them listed on the European annexes), especially fishes, are currently poorly covered by the Natura 2000 network. The coverage of species likely seemed to be highly related to national demographic factors, i.e. the proportion of the national urban population. Our analysis also suggested that the designation of sites depends too strongly on governmental politics, economic and cultural criteria, and interactions between society and the environment. A more effective process might be necessary to ensure the Natura 2000 network reaches its potential as the most important and comprehensive network of protected areas intended to halt the loss of biodiversity in Europe in the near future.

Keywords

Reserve sites, threatened species, biodiversity loss, conservation tools

Introduction

The world's biodiversity is currently in rapid decline. In recent decades, this trend has accelerated globally, Europe being no exception. The international community reacted by adopting the Rio de Janeiro Convention on Biological Diversity (CBD) in 1992 (Balmford et al. 2005; Vié et al. 2008), which the European Community ratified in 1993. The CBD recommends that strategies that aim to ensure the conservation and sustainable use of biodiversity by anticipating and preventing significant reduction in or loss of biodiversity (for Europe see DG Environment 2002) need to be adopted. In response to the CBD, Europe established a network of protected sites called Natura 2000. The Natura 2000 network is governed by the Directive 79/409/EEC, adopted in April 1979 for the conservation of wild birds (also called "Birds Directive") and the Directive 92/43/EEC, adopted in May 1992 for the conservation of natural habitats, wild fauna and flora (also called "Habitats Directive"). Even if the Natura 2000 network is a European network of natural and semi-natural sites with high heritage values due to the exceptional flora and fauna they contain, the effectiveness of this network still remains unclear (Gruber et al. 2012).

The goal of the Natura 2000 network is to maintain the biological diversity of environments, while taking into account economic, social, cultural and regional logic of sustainable development. Compared to other nature conservation programs (Ramsar (www.ramsar.org) and MedWet (www.medwet.org), the Natura 2000 network can be considered as the main contribution by the European Union (EU) to fulfil the recommendations of the CBD, aiming to establish regional and national systems of protected areas on land (by 2010) and sea (by 2012). Currently, the Natura 2000 network covers almost 18% of the area of the 27 member states (more than 26,000 sites; European Commission 2010), covering all biogeographical regions of Europe, each site with its own characteristic blend of vegetation, climate and geology.

The Natura 2000 network comprises two major site categories, Special Protection Areas (SPAs) and Special Areas for Conservation (SACs). SPAs are sites of conservation value for rare and threatened European bird species designated internationally under the Birds Directive (DG Environment 1979). Special Areas for Conservation (SACs) are sites to protect plants, animals and wildlife habitats of EU importance as designated by the Habitats Directive (DG Environment 1992). For SPAs and SACs, the percentage of national territory designated to the Natura 2000 network ranges from 3% in Ireland to 25.1% in Slovakia and from 6.8% in the United Kingdom to 31.4% in Slovenia respectively (DG Environment 2010; but see also Evans 2005). Both SPAs and SACs can overlap, but differ in their designation processes.

While the designation of SPAs is based on the presence of bird species listed in the annexes of the Birds Directive, including a validation stage of the EU, SACs designation (Habitats Directive) is more complex and involves several stages (Evans 2012). Nationally, Natura 2000 sites are selected on the basis of national lists proposed by the member states. For each biogeographical region, the European Commission adopts a list of Sites of Community Importance (SCI) which then become part of the network.

Finally, the SCI are designated at the national level as Special Areas of Conservation (SAC) which subsequently undergo implementation measures. Faced to this complex method of establishment, the European Directives did not specify the method of consultation to be followed for reserve site selection. Therefore, management of the Natura 2000 network and the responsibilities of member states remain unclear, and so far have not followed a standardized framework (DG Environment 2002). Procedures have varied considerably between member states according to their administrative system. The detailed work involved is often delegated to various national agencies or, in the case of federal states, to regions. Several studies (Alphandéry and Fortier 2001, Pinton 2001, Mischi 2009) focused on problems in the identification of sites (SACs and SPAs) at the national level (in France), corresponding to the first phase of implementation guidelines. Similar problems, e.g. administrative, scientific (lack of data and tools) and social, were also encountered in other countries (in UK: Ledoux et al. 2000; in Greece: Apostolopoulou and Pantis 2009; in Finland: Björkell 2008, Hiedanpää 2002; in Germany: Stoll-Kleeman 2001a, b; in Ireland: Bryan 2012) and at the European scale (Keulartz 2009; Julien et al. 2000; Jackson 2011). Many environmental diagnoses were questioned, notably for potentially unreliable methods due to insufficient financial and human resources and a lack of data control, which slowed the implementation of new Natura 2000 sites at local level.

Species listed in the annexes of the European Directives depend on the criteria from the European and Member state's scales. Consequently, several species listed in these annexes are not mentioned on the IUCN Red List and vice versa. However, despite not being the primary aim, the Natura 2000 network might help to protect all threatened species. Here, we were interested in the effectiveness of the Natura 2000 network to cover also non-target, but threatened species [IUCN Red List categories: vulnerable (VU), endangered (EN) or critically endangered (CR)]. We were especially interested in the following questions: Are there differences in the coverage related to countries, taxonomic groups or biogeographical regions? Can the differences between countries be explained by national indicators such as population density, gross domestic product, etc.? Because an arbitrary threshold, such as 10 % of the area, is often assumed to assure an efficient protection to a species (Rosati et al. 2008), we also focused our analysis on species with a coverage of less than 10% by the Natura 2000 network.

Methods

The distribution areas of threatened species as listed on the IUCN Red List were studied within the Natura 2000 network at the national scale, at the scale of biogeographical regions and at the European scale. For abbreviations of each member state from the European Union we followed the two-letter nomenclature established for internet resources (i.e. FR = France, DE = Germany, etc.). Biogeographical regions were abbreviated as follows: Alpine (ALP), Atlantic (ATL), Black Sea (BLA), Boreal (BOR), Continental (CON), Macaronesian (MAC), Mediterranean (MED), Pannonian (PAN), Steppic (STE).

Data collection

As marine sites have been implemented very recently, we decided to focus on terrestrial and freshwater Natura 2000 sites. The database from the IUCN Red List (IUCN 2007) was used to obtain a list of all threatened [vulnerable (VU), endangered (EN) or critically endangered (CR)] terrestrial and freshwater plant and animal species in the European Union (see Appendix 1). In total, 707 terrestrial and freshwater species fall into these categories. For our analysis on the representation of threatened species in the Natura 2000 network, we used distribution maps in Image Bitmap format (sources: http://www.iucnredlist.org/; EIONET 2009 available on http://biodiversity.eionet.europa.eu/). We were able to obtain distribution maps in Image Bitmap files for 300 threatened species (amphibians: n = 17; birds: n = 20; fishes: n = 124; insects: n = 26; mammals: n = 20; molluscs: n = 13; plants: n = 61; reptiles: n = 19). The distribution maps from the IUCN website used numerous information sources and high data quality (IUCN 2007) suggesting that map precision was relatively high. Because distribution maps from spatial data of member state reports (EIONET 2009; ETC/BD 2008) were built using different approaches and data were captured at a variety of resolutions, they were re-projected by the European Topic Centre on Biological Diversity (ETC/BD) to a standard projection and were harmonised to give range and distribution on a 10 km × 10 km or equivalent grid (ETC/BD 2008). Of these 300 species, 43.6% were VU, 26.7% were EN and 29.7% were CR. More than half (54.8%) were included in the annexes II, III or IV of the Habitats Directive or the Birds Directive. The Natura 2000 network map, the biogeographical regions map and the member states map were available in Image Bitmap format (EEA 2010) through the European Commission.

Among all species, distribution maps are prone to errors. The maps used from the IUCN website (n = 145) are depending on how a species present in a given site when underlying distributional maps was considered. Indeed, because information of species abundance was not available yet from the distribution maps of the IUCN website, the species present in a given site could be constantly present, or promptly present (for example present during the migration, for reproduction access, or accidently present). These map limitations could be a potential source of bias (Alagador et al. 2011; Araújo 2004). Moreover, the distribution maps (n = 155) from EIONET (2009) have a relatively low resolution (10 km × 10 km) and are harmonised depending on the resolution of the method used in each member state (ETC/BD 2008). For instance, French Article 17 report maps were built at a very coarse resolution compared to the neighbouring countries. Overall, the currently available data has certain limits, likely introducing a not quantified bias in our analysis.

Data processing

To estimate the coverage of the Natura 2000 network in regard to the distribution of threatened species in Europe, we used an image processing protocol employing

ADOBE PHOTOSHOP CS v8.0 (Adobe Systems Incorporated 2003). By overlaying distribution maps of species and Natura 2000 maps, we were able to calculate the ratio at which a species distribution falls within sites of the Natura 2000 network. The first step consisted of overlaying the Natura 2000 network map with a distribution map of a species. When the maps were overlaid, the distribution map of the species was modified in transparency, in order to highlight the Natura 2000 sites covered by the distribution map. Through transparency, several colours were obtained on the screen. For example, we had red pixels for Natura 2000 sites included in the distribution of the given species and grey pixels for the rest of the distribution map (not covered by the Natura 2000 network). Consequently for each coloured area, all pixels were selected and the number of pixels was obtained. Coverage was then obtained as follows: the proportion of the distribution of a given species in the Natura 2000 network within a member state/biogeographical region (number of pixels corresponding to the overlay between the distribution map and the Natura 2000 network map; i.e. the number of red pixels) divided by the distribution of the given species within a member state/biogeographical region (sum of grey and red pixels corresponding to the global distribution map). The cover ratios per species were then obtained 1) per country, 2) per biogeographical region, and 3) at the European scale (by adding the total number of pixels included in the Natura 2000 network divided by the total distribution map pixels). To validate the method using Image Bitmap files, we also obtained cover ratios from GIS data (polygon vector files) for species groups for which such data was available (mammals, birds, reptiles and amphibians). The comparison of the two approaches revealed a non-significant difference (Mann-Whitney test: $W = 1995.5$, $n = 64$, $P = 0.959$).

In order to determine if country and Natura 2000 parameters could explain the coverage of threatened species by a national Natura 2000 network, we calculated the average coverage by country and compared it to seven socio-economic parameters of countries and three Natura 2000 indicators (Table 1; Appendix 1).

Statistical analysis

For each species, coverage could range between 0 and 1, following a Poisson distribution. Therefore, we used a non-parametric Kruskal-Wallis ANOVA to test for differences between different species groups, member states and biogeographical regions. For refinement of the ANOVAs we employed the Tukey's honestly significant difference (HSD) posthoc test to compare member states/biogeographical region where significant differences were found with the ANOVA. We also used a non-parametric ANOVA to test if the surface of biogeographical regions is correlated to the mean coverage, to the number of threatened species present within and to the proportion of Natura 2000 network per region.

We then determined an arbitrary threshold of 10% of coverage to detect threatened species for which the Natura 2000 network has a poor coverage. This threshold

Table 1. Details of all national indicators used with definition, abbreviations and units. Abbr. = abbreviation.

Class	Indicator	Abbr.	Definition	Unit	*Ref.*
Economic indicators	Gross domestic product	GDP	market value of all final goods and services made within the borders of a country/year	Million €	*1*
Demographic indicators	Total population	TP	all persons residing in the country	Inhab.	*1*
	Population density	PD	number of individuals per surface units	Inhab./km²	*1*
	National surface	NS	total surface of a country	km²	*1*
	Urban population	UP	number of individuals residing in cities compared to the total population	% of total population	*1*
Ecological indicators	Ecological footprint	FP	amount of biologically productive land and sea area needed to regenerate the resources a human population consumes and to absorb and render harmless the corresponding waste	ha/person	*2*
	CO_2 consumption	CO_2	weighted emissions of greenhouse gas emissions	Million tonnes of CO_2	*1*
Natura2000 indicators	Number of sites	NS	Number of Natura2000 sites	Number of sites	*3*
	Total area of sites	TA	Total area of all Natura2000 sites	km²	*3*
	Natura2000 surface	%size	National network surface compared to total national surface	% of total surface	*3*

References: 1: UNDP (2006); 2: EEA (2008); 3: DG ENVIRONMENT (2010).

of 10% is assumed to be the minimum of coverage to assure an efficient protection to a given species (Rosati et al. 2008). Under this threshold, the representation of the species may be defined as an under-protection ("total gap", see Rosati et al. 2008). But we can suggest that an effective coverage ratio (sufficient for a good protection) for a small insect may be low in areas with high densities, whereas we could imagine that a similar ratio should be not sufficient for mammal or bird species. Hence, the arbitrary threshold of 10% determined in this study was not used to highlight threatened species not correctly protected by the network, but only used to see how the Natura 2000 network overlaid the distribution of threatened species at the European scale. In parallel to a low coverage of the network (10% or less), we also detected high coverage using a threshold of 90%.

We used linear models to analyse the extent country and Natura 2000 indicators (Table 1) explain the variation in coverage of threatened species by Natura 2000 (dependent variable 'coverage') per country (average of coverage ratios from all species living within the country) and the number of species with a coverage of less than 10% (dependent variable 'Nspecies<10%') using a Gaussian distribution and an identity link function. Because fishes were numerous in our database and poorly covered by the Natura 2000 network, we also conducted the same analysis only with these species to

see if the national indicators could explain their specific coverage. Data were not available for Cyprus and Luxembourg, which were therefore excluded from this analysis. The best model among all possible sub-models was then selected using the corrected Akaike's information criterion (AICc = 2 * [model performance log-likelihood + number of parameters estimated]): models explaining the most variation with the fewest predictors have the lowest AICc and were considered the 'best models'. With a selection by AIC, one best model can be selected (if the difference of their respective AICc is < 2; Anderson et al. 1994). All statistical analyses were performed with the software R (R Development Core Team 2008).

Results

European scale

The global mean ratio of threatened species coverage was 0.359 ± 0.255 (mean ± SD; median = 0.304). Depending on the taxonomic group, the global mean ratio varied from 0.292 ± 0.159 in insects (median = 0.261) to 0.452 ± 0.239 in reptiles (median = 0.412; see Fig. 1) but differences between taxonomic groups were statistically not significant ($F_{8,294}$= 0.936, P = 0.487). For only 6.6% (n = 20) of the analysed species, 90% of their distribution was covered by the Natura 2000 network. While 12% (n = 36) of the analysed species had only 10% of their distribution covered. The taxonomic group the least covered by Natura 2000 were fishes [22 (17.8%) threatened fish species]. Seven of these fish species are currently listed in the annexes of the Habitats Directive. In birds, only one species had a coverage of less than 10% in the Natura 2000 network. Overall, 42% (15 out of 36 species) of threatened species with a low coverage and 30% (6 out of 20 species) of threatened species with a high coverage by Natura 2000 were listed on the annexes I, II or V of the European Directives (see Appendix 1). However, comparing the coverage of threatened species listed by the European Natura Directives (0.339 ± 0.210) with the coverage of threatened species from the IUCN Red List (0.359 ± 0.255) did not reveal a significant difference ($F_{1,299}$= 2.512, P = 0.114).

Biogeographical regions scale

The mean coverage across biogeographical regions was 0.352 ± 0.244. We did not detect any difference in the coverage at the taxonomic group level ($F_{8,483}$ = 1.601, P = 0.122; Fig. 2a) in regard to the biogeographical regions, but found a significant difference at the species level ($F_{8,483}$ = 7.01, P < 0.001). Threatened species were best covered in the Black Sea (0.587 ± 0.300; median = 0.602), compared to the mean coverage of the Continenal (0.271 ± 0.203; median = 0.244), Atlantic (0.282 ± 0.269; median = 0.194), Boreal (0.191 ± 0.156; median = 0.146), Mediterranean (0.354 ± 0.254;

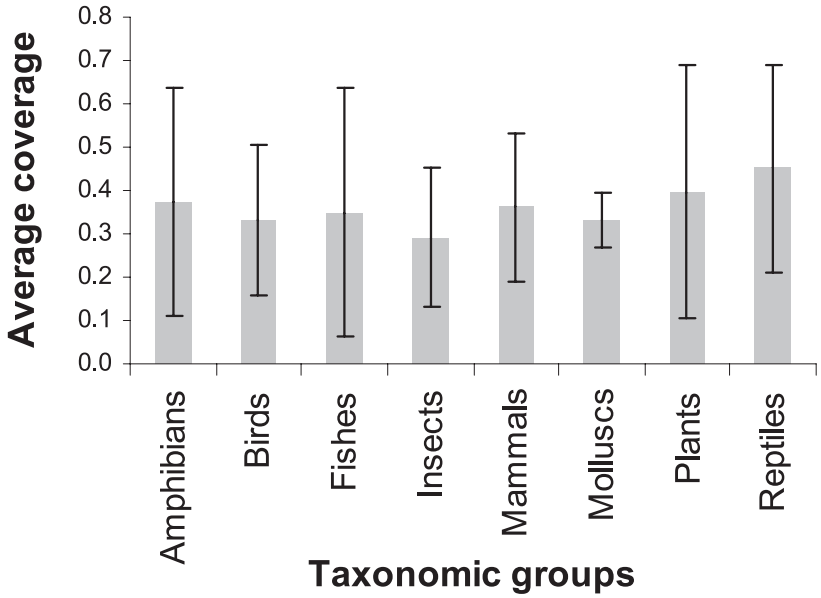

Figure 1. The average Natura2000 coverage of threatened species by taxonomic group.

median = 0.279) and Pannonian (0.287 ± 0.106; median = 0.270) regions (all Tukey's HSD tests: $P < 0.001$). Threatened species were also well covered in the Alpine region (0.451 ± 0.210; median = 0.409), compared to the mean coverage of the Atlantic (Tukey's HSD test: $P = 0.004$), Boreal (Tukey's HSD test: $P = 0.004$) and Continental (Tukey's HSD test: $P < 0.001$) regions. We found a poor coverage of threatened species in the Atlantic (17 out of 54 species = 31.5%), Boreal (26.7%) and Continental regions (14.7%; Fig. 2b and 2c).

We did not find a size effect between the mean coverage and the surface of biogeographical regions ($F_{1,7} = 2.036$, $P = 0.197$). We also did not find a relationship between the surface of biogeographical regions and the number of threatened species present within ($F_{1,7} = 2.41$, $P = 0.164$), whereas we found a correlation between the surface of biogeographical regions and the proportion of the Natura 2000 network per region ($F_{1,7} = 6.06$, $P = 0.043$).

Member states scale

The mean coverage across countries was 0.323 ± 0.225 (median = 0.282). Our comparison of the coverage of threatened species by a country's Natura 2000 sites revealed significant differences at the taxonomic group level ($F_{8,583} = 2.929$, $P = 0.003$). Insects appeared to be much less covered by the national Natura 2000 networks (0.242 ± 0.169) compared to reptiles (0.435 ± 0.229; Tukey's HSD test: $P = 0.034$) and plants (0.388 ± 0.29; Tukey's HSD test: $P = 0.057$).

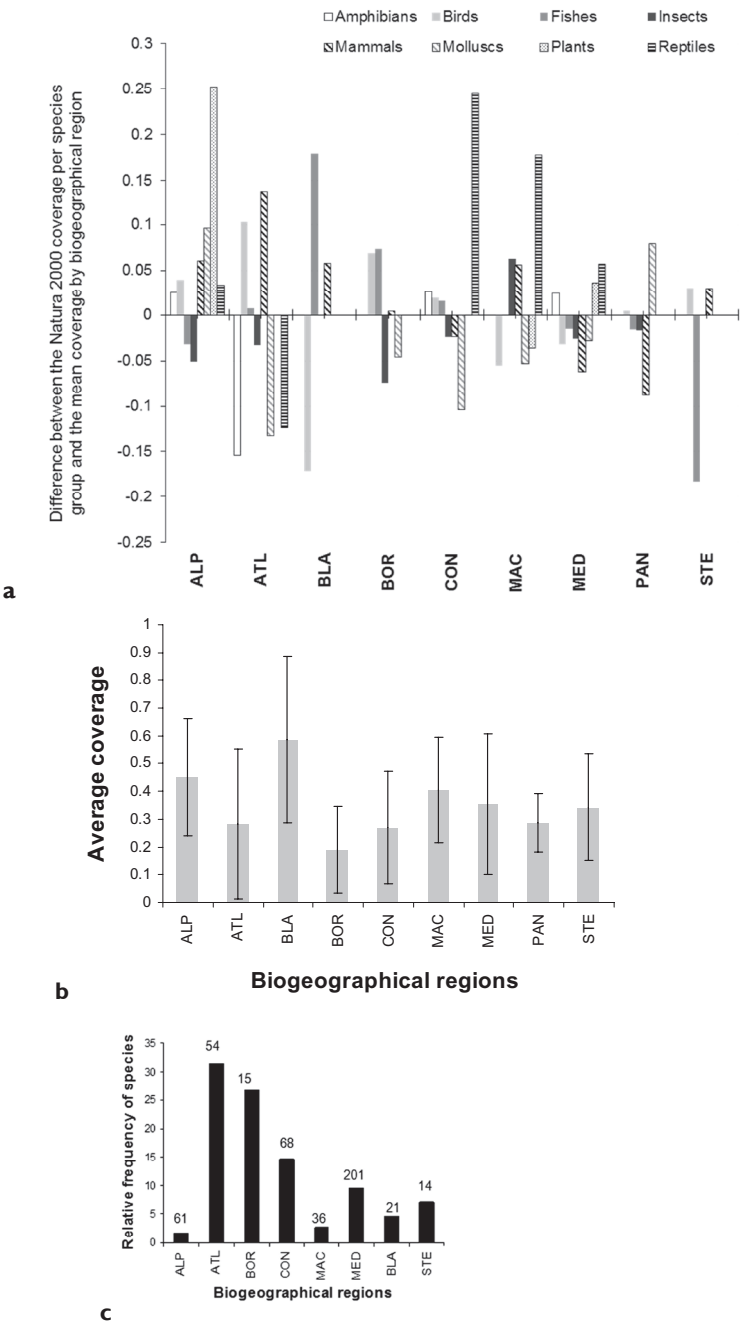

Figure 2. a Difference between the Natura2000 coverage per species group and the mean coverage by biogeographical region (when positive, the coverage of the groups is better than the mean coverage of a region) **b** mean coverage by biogeographical region and **c** relative frequency of threatened species with a coverage below 10% by biogeographical regions. The number on top of the bars indicates the total number of threatened species studied per biogeographical region. The Pannonian region has no species falling in this category.

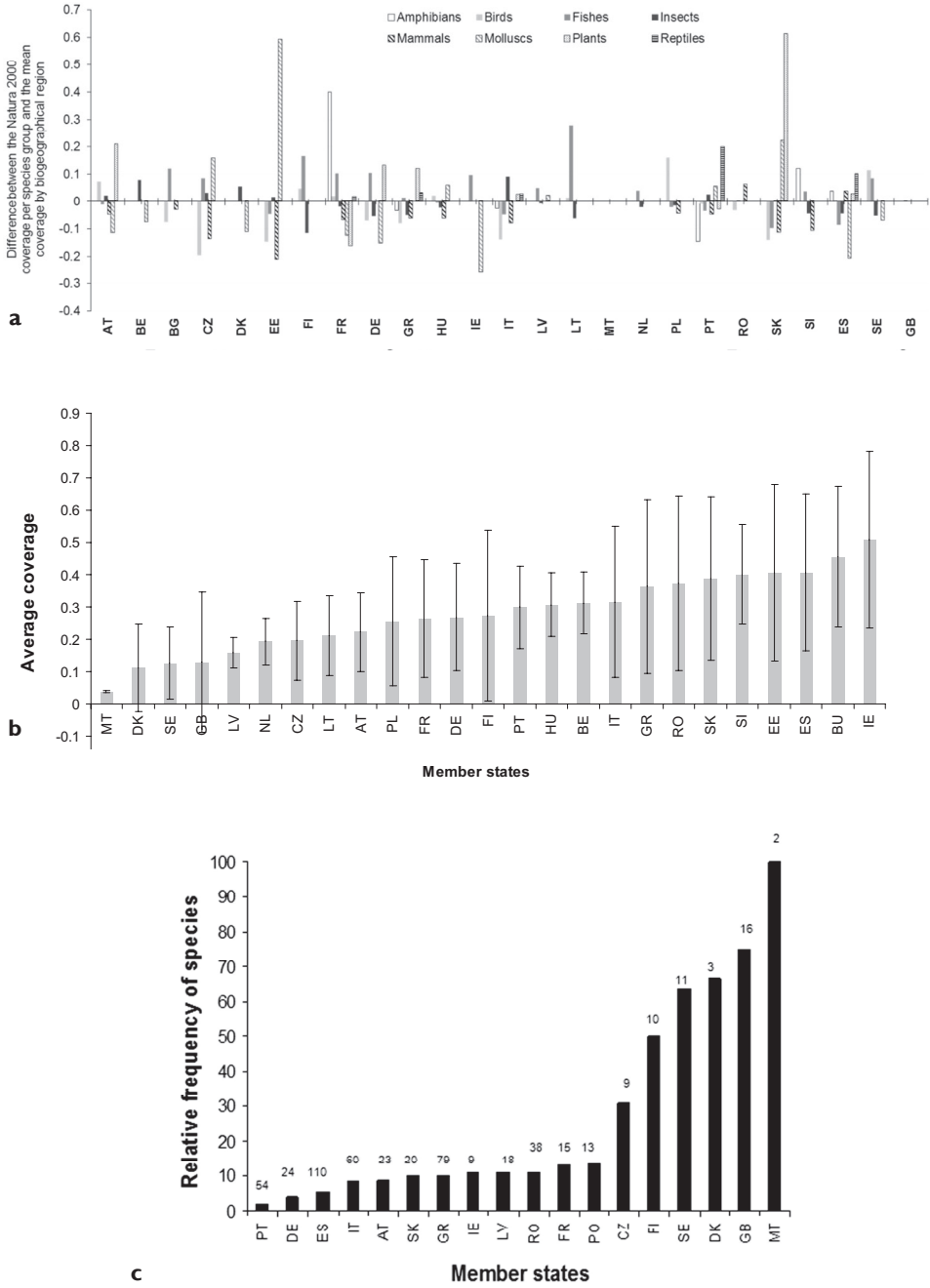

Figure 3. a Difference between ratio per species group and mean ratio by Member State (when positive, the coverage of the groups is better than the mean coverage of a country) **b** mean coverage of threatened species and **c** relative frequency of threatened species with a coverage below 10% by Member State. The number on top of each bar represents the total number of studied threatened species by Member State. The Natura 2000 network from non represented countries had no threatened species with a coverage of less than 10%.

Across species groups, the average coverage of threatened species by country showed significant differences ($F_{24,567}$ = 3.9596, P < 0.001). Notably, the United Kingdom (0.131 ± 0.218; median = 0.031) and Sweden (0.127 ± 0.113; median = 0.072) had a low coverage compared to the mean across countries, while Spain (0.407 ± 0.244; median = 0.333; Tukey's HSD tests: P < 0.001) and Bulgaria (0.457 ± 0.218; median = 0.402; Tukey's HSD tests: P < 0.001 and P = 0.014 respectively) generally showed a high coverage of threatened species. In the United Kingdom, 11 of 16 threatened species, all of them fish species and three listed on the annex II of the Habitats Directive, have less than 10% of their distribution covered by the Natura 2000 network (Fig. 3c). The Greek Natura 2000 sites cover 8 of 79 threatened species (1 amphibian, 7 fishes) with less than 10% (i.e. low coverage), while two of these species (2 fish species) are listed on the annex II of the Habitat Directive (Fig. 3c). In Spain only 5% of threatened species had a coverage of their distributions of less than 10% by the Natura 2000 network.

Relationship between coverage and national indicators

The best model explaining the mean national coverage of threatened species (dependent variable 'coverage') consisted of the variable population density (PD) and the national network surface compared to total national surface (%size; $F_{2,22}$ = 13.12; P < 0.001; AICc = -46.7160; Table 2, Table 3 and Appendix 2). The variable %size had a higher explanatory power (t_{22} = 3.924; P < 0.001) than PD (t_{22} = -2.334; P = 0.029). Another model explaining the mean national coverage of threatened species included the percentage of national urban population (UP) and %size ($F_{2,22}$ = 11.75; P < 0.001; AICc = -45.2501; Table 2 and Table 3).

The best model explaining the mean national coverage of species with a low coverage (dependent variable 'Nspecies<10%') included the national network surface compared to total national surface (%size), the gross domestic product (GDP) and the weighted emissions of greenhouse gas emissions (CO_2; $F_{1,13}$ = 13.92; P < 0.001; AICc = -99.3453). The mean national coverage of species with a low coverage was negatively correlated to CO_2 (t_{13} = -3.901; P = 0.002) and positively correlated to %size (t_{13} = 3.268; P = 0.006) and GDP (t_{13} = 2.452; P = 0.029). Another good model explaining the mean national coverage of species with a low coverage included TP (total population) instead of GDP ($F_{3,13}$ = 12.7; P < 0.001; AICc = -98.1737; Table 2 and Table 3).

With only fish species and after model selection, 6 different models were retained. Within these 6 models, the percent of total Natura 2000 surface (%size), the population density (PD) and the percent of urban population (UP) have a significant effect on the coverage. As the retained explicative predictors were the same than in the global model (with all species) demonstrating a similar analysis, we did not show this specific result.

Table 2. Results of the linear models showing the relationship between ratios of coverage and the extent national and Natura2000 indicators. Models with the dependent variable 'coverage' are models taken into account all threatened species. Models with the dependent variable 'Nspecies10%' are models taken into account only threatened species with a coverage <10%. All models with a ΔAICc < 2 are represented.

Variables	RSS	R^2	AICc	ΔAICc
Coverage ~ %size + PD	0.1514	0.5025	-46.7160	0.000
Coverage ~ %size + UP	0.1606	0.4725	-45.2501	1.4659
Nspecies10% ~ CO2 + GDP + %size	0.0012	0.7078	-99.3453	0.000
Nspecies10% ~ CO2 + %size + TP	0.0012	0.6869	-98.1737	1.1716

Table 3. Results of the best linear models selected by AICc values. (a) models with the independent variable 'coverage' and (b) models with the dependent variable 'Nspecies10%'.

Variables	**Estimates for variables**				
(a) Models with the dependent variable 'coverage'					
Model 1	**Estimate**	**DF**	**F**	**P**	**AdjR^2**
Int.	0.1465 **	2, 22	13.12	< 0.001	0.5025
%size	9.286x10-3 ***				
PD	-1.627x10-4 *				
Model 2	**Estimate**	**DF**	**F**	**P**	**AdjR^2**
Int.	0.3807 *	2, 22	11.75	< 0.001	0.4725
%size	0.0075 *				
UP	-0.0033				
(b) Models with the dependent variable 'Nspecies10%'					
Variable	**Estimate**	**DF**	**F**	**P**	**AdjR^2**
Int.	0.0335 ***	3, 13	13.92	< 0.001	0.7078
CO2	-1.0381x10-4 **				
GDP	1.73x10-8 *				
%size	1.381x10-3 **				
Variable	**Estimate**	**DF**	**F**	**P**	**AdjR^2**
Int.	0.0371 ***	3, 13	12.7	< 0.001	0.6869
CO2	-1.384x10-4 **				
TP	1.017x10-9 *				
%size	9.679x10-4 *				

Discussion

Here, we analysed the coverage of 300 threatened IUCN red listed species by the European Natura 2000 network. Our analysis showed that a large proportion of threatened species of mammals, birds and reptiles showed a high coverage (≥ 90%) by the current Natura 2000 network. Hence, the Natura 2000 network also covers species not listed in the annexes of the Nature Directives. However, our results revealed that a large proportion of threatened species, some of them even listed on the annexes of the Habitats Directive and especially fishes are currently poorly covered (≤ 10%) by the Natura 2000 network. Factors explaining the coverage of threatened species included national

network surface compared to total national surface (%size), national proportion of urban population (UP), national population density (PD), gross domestic product (GDP) and weighted emissions of greenhouse gas emissions (CO_2).

Our analysis showed an especially low coverage of threatened fish species by the Natura 2000 network (especially in the United Kingdom). Of the 124 fish species considered, 22 species had a range coverage of less than 10% by the Natura 2000 network, despite the fact that seven are listed in the annexes (II, IV and/or V) of the Habitats Directive [in United Kingdom: *Coregonus clupeoides* (La Cepède 1803), *Coregonus pennantii* (Valenciennes 1848) and *Coregonus stigmaticus* (Regan 1908); in Austria: *Coregonus danneri* (Vogt 1908); in Greece: *Barbus euboicus* (Stephanidis 1950), *Eudontomyzon hellenicus* (Vladykov, Renaud, Kott & Economidis, 1982) and *Acipenser naccarii* (Bonaparte 1836); see Appendix 1]. Concerning amphibians, three species (*Speleomantes flavus*, *Rana latastei*, *Pelophylax epeiroticus*) are weakly covered by the Natura 2000 network, of which two are listed in annex II and annex IV of the Habitats Directive. *S. flavus* (Stefani 1969) is endemic to Sardinia (Italy). This species is also listed in Appendix II of the Bern Convention but no conservation program is known at the moment, despite a need for close monitoring of the population status of this species (Lecis et al. 2008). *R. latastei* (Boulenger 1879) has a low coverage by the Natura 2000 network, but benefits from national protection in Italy, Switzerland and Slovenia. However, generally we did not find any difference between the coverage of IUCN threatened species and species listed on the European annexes.

Our analysis also showed that the region with the best average coverage of threatened species was the Black Sea region, covering 58.7% of the distribution ranges of threatened species. Although we did not find a size effect between the mean coverage and the surface of biogeographical regions, we want to stress that the Black Sea region is the smallest European biogeographical region (9705 km²) and has only 21 threatened species (7% of all species analysed here), while the total area of all Natura 2000 sites in this region represent 71.8% of the terrestrial surface (negative relationship between the surface of biogeographical region and the proportion of Natura 2000 network per region; see EEA 2010). In addition, the Black Sea region contains a low proportion of poorly covered species (4.76%; Fig. 2c). In contrast, the Alpine region is the region with the lowest proportion of poorly covered species (1.64%, or 1 of 61 species) and also the region with the highest proportion of terrestrial surface cover by Natura sites. In contrast, the Atlantic, Boreal and Continental biogeographical regions have a high proportion of poorly covered species (31.48%, 26.67% and 14.71% respectively; Fig. 2c). Our analysis suggests that the difference between biogeographical regions with good coverage and the ones with poor coverage could be resulting from industrial occupation, with industrial areas invoking difficulties for Natura 2000 site establishment. Moreover, in these large biogeographical regions, the increase in urbanisation and tourism development have generated fragmentation and habitat loss (especially in the Mediterranean region; EEA 2010). Further, our analysis on the national scale showed that the mean coverage of the species with a Natura 2000 coverage of less than 10% and an overall low national mean coverage of all species was largely explained by

a high population density and a low Natura 2000 surface. That result suggests that the establishment of new sites within urbanized countries was difficult and an adaptation of the site designation process and conservation policy might be needed in the future.

Globally, our analysis confirmed that the Natura 2000 network, despite the huge efforts of the EU Member States, may have shortcomings in protecting some of the threatened species, also suggested by earlier studies on national (Dimitrakopoulos et al. 2004, Maiorano et al. 2007) and European scales (Jantke et al. 2011). Based on a gap analysis using modelling tools for conservation planning, Jantke et al. (2011) recommended significantly increasing the Natura 2000 area to achieve complete coverage of all considered species. Instead, we recommend to increase the number of Natura 2000 sites, because we also tested that an increasing of Natura 2000 site's surface did not significantly increased the coverage of threatened species, even with an increasing of 10% of surface (data not shown). For the Greek island of Crete, the network was characterised as an inadequate protection for endangered species (Dimitrakopoulos et al. 2004). In addition, Maiorano et al. (2007) have shown that despite significant efforts in establishing new sites and an annual expansion of the Italian network, some areas with high species richness currently have no coverage. These areas contain endemic and rare species with limited distribution ranges. The same authors outlined that objectives and measures proposed for site designation were clearly insufficient to safeguard the many species and habitats present within the network. This was further supported by the European Commission assessment (European Commission 2007) that 16.4% of the 712 annex II species were not represented at all in Natura 2000 sites. However, despite implementation problems, conservation programs such as Natura 2000 do bring measurable benefits to wildlife (Donald et al. 2007).

Recommendations and perspectives

In order to improve the management of Natura 2000 sites (with a high efficiency), a common and standardized management of the Natura 2000 network with a uniform framework among member states needs to be established. Natura 2000 sites should be under continuous observation and evaluation, to determine their importance for the conservation of biodiversity in a biogeographical region, either using site selection algorithms as implemented in the programs ZONATION (Moilanen et al. 2005) or MARXAN (Watts et al. 2009) or by determining the international importance of the sites for the global survival of a species (Schmeller et al. 2008a, b). Such an approach would improve efficiency and create importance categories for each Natura 2000 site, as well as providing a basis on which to determine appropriate resource allocation. These approaches will help with the selection process, and may decrease the impact of the political agenda, as currently observed (Mathevet and Mauchamp 2005). We further recommend developing public awareness and participation to increase the ecological conscience (Stoll-Kleemann et al. 2010). The involvement of local people in conservation strategies has been shown to be highly efficient (e.g. Schmeller et al. 2012). For example, in the United States, bird protection has been recently modified and improved by

crediting landowners who have adapted their land to migratory and threatened species (recovery credit trading), and by establishing a Farm Bill, a law encouraging farmers and ranchers to protect important habitats through the Conservation Reserve Program (U.S. Department of Agriculture, Farm Service Agency 1997). Our recommendations should increase the efficiency of Natura 2000 network by avoiding the establishment of ineffective sites (with a low number of protected species), as observed in several member states with a high Natura 2000 surface coverage but with a low number of protected species.

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Appendix I

Summary of all threatened species studied with their IUCN status and their global ratio of coverage (next to each taxonomic group: mean + SD). (doi: 10.3897/nature-conservation.4.3626.app1). File format: MS Word Document (doc).

Explanation note: The species listed on the annex of the Habitats Directive or Birds Directive have across in the relevant columns. An asterisk (*) before the species names indicates that the species is a priority species.

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Appendix II

Principal component analysis of socio-economic, national indicators and parameters describing the Natura2000 network (see also Table 1). (doi: 10.3897/natureconservation.4.3626.app2). File format: MS Word Document (doc).

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