Identification of areas of very high biodiversity value to achieve the EU Biodiversity Strategy for 2030 key commitments. A case study using terrestrial Natura 2000 network in Romania

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Abstract

European Union seeks to increase the protected areas by 2030 to 30% of the EU terrestrial surface, of which at least 10% of areas high biodiversity value should be strictly protected. Designation of Natura 2000 network, the backbone of nature protection in the EU, was mostly an expert-opinion process with little systematic conservation planning. The designation of the Natura 2000 network in Romania followed the same non-systematic approach, resulting in a suboptimal representation of invertebrates and plants. To help identify areas with very high biodiversity without repeating past planning mistakes, we present a reproducible example of spatial prioritization using Romania's current terrestrial Natura 2000 network and coarse-scale terrestrial species occurrence.

The planning exercise uses 371 terrestrial Natura 2000 Sites of Community Importance (Natura 2000 SCI), designated to protect 164 terrestrial species listed under Annex II of Habitats Directive in Romania. Species occurrences in terrestrial Natura 2000 and Natura 2000 sites were aggregated at a Universal Traverse Mercator spatial resolution of 1 km2. To identify priority terrestrial Natura 2000 sites for species conservation, and to explore if the Romanian Natura 2000 network sufficiently represents species included in Annex II of Habitats Directive, we used Zonation v4, a decision support software tool for spatial conservation planning. We carried out

the analyses nationwide (all Natura 2000 sites) and separately for each biogeographic region (i.e., Alpine, Continental, Pannonian, Steppic and Black Sea).

The performance of national-level planning of top priorities is low. On average, when considering 10% of the landscape of Natura 2000 sites as protected, 20% of the distribution of species listed in Annex II of Habitats Directive are protected. As a consequence, the representation of species by priority terrestrial Natura 2000 sites is reduced when compared to the initial set of species. When planning by taxonomic group, the top-priority areas include only 10% of invertebrate distribution in Natura 2000. When selecting top-priority areas by biogeographical region, there are significantly fewer gap species than in the national level and by taxa scenarios; thus, the scenario outperforms the national-level prioritization. The designation of strictly protected areas as required by the EU Biodiversity Strategy for 2030 should be followed by setting clear targets for the representation of species and habitats at the biogeographical region level.

Introduction

Protected areas, a critical tool for nature conservation strategies, are intended to ensure the long-term persistence and viability of biodiversity. They should ideally support as many as possible rare, threatened, or endemic taxa, particularly those with low mobility and high sensitivity to environmental alterations (Geldmann et al. 2013; Gray et al. 2016; Possingham et al. 2006; Rodrigues et al. 2004). When planning protected areas, states around the world are guided by supranational policies such as Convention on Biological Diversity and EU Biodiversity Strategy for 2030, which issue ambitious targets to increase the extent of protected areas. For example, Convention on Biological Diversity (CDB) Aichi Target on Protected Areas calls for protection of 17% of world terrestrial and inland water areas in key regions for biodiversity and ecosystem services (UNEP 2011), while the EU Member States seek to increase the Natura 2000 network by 2030 to 30% of EU terrestrial surface and designate the strict protection of areas of very high biodiversity and climate value (European Commission 2020).

A promising tool to help to build an ecologically-sound network of protected areas meeting the CDB or EU targets is systematic conservation planning (Margules & Pressey 2000). Systematic conservation planning maximizes conservation benefits while minimizing impacts on other resources, such as the availability of productive land. Spatial conservation prioritization, as a part

of systematic conservation planning, mostly relies on the complementarity concept (i.e., selection of complementary areas to avoid duplication of conservation effort) and is considered an efficient instrument for identifying spatial priorities and achieving conservation goals (Margules & Pressey 2000; Pressey et al. 2007).

One of the most extensive networks of conservation areas in the world is the Natura 2000 network, which has been created to operationalize EU Birds (Directive 2009/147/EC) and Habitats Directives (Council Directive 92/43/EEC). To date, Natura 2000 covers 18% of EU terrestrial areas, thus meeting the CDB Aichi Target on Protected Areas (UNEP 2011). The effectiveness and representativity of Natura 2000 were evaluated for different taxonomic groups and geographic areas, and except for an agreement on better than random planning performance, the conclusions tended to highlight suboptimal planning (D'Amen et al. 2013; Dimitrakopoulos et al. 2004; Kukkala et al. 2016; Lisón et al. 2013; Müller et al. 2018; Müller et al. 2020; Votsi et al. 2016). The suboptimal planning of Natura 2000 at the EU and member states level originates from an uncoordinated designation process (Apostolopoulou & Pantis 2009; Ioja et al. 2010; Lisón et al. 2017; Orlikowska et al. 2016), which was partially solved by selecting new sites after expert-opinion evaluations during the Natura 2000 biogeographical seminars (Kenig-Witkowska 2017; Manolache et al. 2017). Furthermore, the efficacy of the Natura 2000 network was extensively evaluated from other perspectives, for example, for understanding the effect of climate change on representativity (Araújo et al. 2011; Popescu et al. 2013) and for coordinating conservation investments (Hermoso et al. 2017; Nita et al. 2016).

The designation of the Natura 2000 network in Romania followed the same non-systematic approach. The process began between 2007 and 2009 with designating 316 Sites of Community Importance covering Habitats Directive, Special Protection Areas, and Birds Directive. This process has continued to today; there are 606 designated Natura 2000 sites that encompass 23% of the total country's area (54214 km^2) (DG Environment 2020; Manolache et al. 2017). Of these, 426 are terrestrial Natura 2000 Sites of Community Importance, covering 40310 km^2 (17% of Romania's terrestrial surface) (DG Environment 2020; EIONET 2020). During the first two designation stages, the process was highly biased towards overlapping existing national protected areas (Ioja et al. 2010; Manolache et al. 2017), and thus, even if the 17% targets are met, the effectiveness of Natura 2000 in representing habitats and species is questionable. For example, Ioja et al. (2010) confirmed that overlapping existing national protected areas resulted in a

suboptimal representation of plants and invertebrates; Miu et al. (2018) highlighted underrepresentation of agricultural landscape in Dobrogea, while Manzu et al. (2013) and Popescu et al. (2013) found that the Natura 2000 network will not protect plants, reptiles, and amphibians if species ranges shift under climate change scenarios.

With the latest extensions, the Romanian Natura 2000 network covers all species and habitats listed in Habitats and Birds Directives (DG Environment 2020; Manolache et al. 2017); however, the new EU Biodiversity Strategy for 2030 requires an expansion from 23% to 30% of the total country's area and the strict protection designation for areas with very high biodiversity and climate value within the network (European Commission 2020). To help identify areas with very high biodiversity and to provide an example of systematic planning of a protected area network, we present a reproducible example of spatial prioritization using Romania's current terrestrial Natura 2000 network and coarse-scale terrestrial species occurrence. The objectives of this study are (1) to identify areas of very high biodiversity within the Romanian terrestrial Natura 2000 network at national and biogeographical levels, (2) to evaluate the effectiveness of the network in covering Habitats Directive Annex II species when areas of very high biodiversity are strictly protected at national and biogeographical region levels, and (3) to investigate the extent to which the Natura 2000 network covers the species listed in Annex II of Habitats Directive at national and biogeographical region levels. The European Union assesses the effectiveness of Natura 2000 network in protecting species and habitats listed Birds and Habitats Directives at the Member State level but also at the biogeographic level (Evans 2012); thus, we performed our analyses at both administrative levels.

Methods

Natura 2000 sites and species

The dataset includes 371 terrestrial Natura 2000 Sites of Community Importance (Natura 2000 SCI), designated to protect 164 terrestrial species listed under Annex II of Habitats Directive in Romania. Raw data is available at Zenodo repository (https://zenodo.org/record/3931434). The initial database included 426 Natura 2000 SCI and 166 species (EIONET 2020), from which we excluded 7 sites with a very small surface area (>1 km^2), 48 terrestrial sites designed only for habitat protection, and 2 marine species (the common bottlenose dolphin - *Tursiops truncatus*, and the harbor porpoise - *Phoecena phoecena*) (Data S1). Of the 164 species, 26 are mammals, 6

are reptiles, 6 are amphibians, 26 are fish, 54 are invertebrates, and 46 are plants. The number of species protected within a Natura 2000 site varies between 1 (46 sites protect only 1 species) and 62 (ROSCI0206 Iron Gates). The terrestrial sites with the largest number of protected species (>40 species) are ROSCI0206 Iron Gates, ROSCI0069 Domogled - Valea Cernei, ROSCI0019 Calimani - Gurghiu, ROSCI65 Danube Delta, ROSCI0031 Cheile Nerei – Beusnita, ROSCI0122 Fagaras Mountains, and ROSCI0214 Tur River. The largest Natura 2000 sites in terms of surface area (>1200 km^2) are ROSCI0065 Danube Delta, ROSCI0122 Fagaras Mountains, ROSCI0085 Frumoasa, ROSCI0019 Calimani – Gurghiu, and ROSCI0206 Iron Gates (Rozylowicz et al. 2019).

To map species occurrences in terrestrial Natura 2000, we used site-level occurrence records data included in the Natura 2000 Standard Data Forms (EIONET 2020). Site-level occurrence records were aggregated at a Universal Traverse Mercator spatial resolution of 1 km^2 (UTM 1 × 1 km). If a species was included in the Standard Data Form for a given site, it was considered as present in all UTM 1 × 1 km overlapping the respective site. We followed this approach due to the lack of finer scale species distribution data in Romania for most of Natura 2000 taxa. The spatial resolution was also used by Romania for biogeographical assessments of conservation status of species and habitats under Article 17 of the Habitats Directive (EIONET 2020).

The analyzed Natura 2000 sites and species were further sorted by biogeographic region. Because Romania lies at the geographic center of Europe (Rey et al. 2007) Natura 2000 network overlap five terrestrial biogeographical regions, out of the nine regions recognized by the European Union, i.e., Alpine, Continental, Pannonian, Steppic and Black Sea (Rozylowicz et al. 2019). Due to its small size, the terrestrial Black Sea region was merged with the Steppic biogeographic region (Steppic and Black Sea region in our analysis). Of the 164 terrestrial species, 110 species are found in the Alpine Biogeographic Region, 143 species in the Continental Biogeographic Region, 76 species in the Pannonian Biogeographic Region, and 78 species in the Steppic and Black Sea Biogeographic Region. Several species were found in 2 or 3 biogeographic regions due to their wide geographic range (e.g., *Bombina bombina, Bombina variegata, Emys orbicularis)* or because they inhabit a large variety of habitats (e.g., *Lutra lutra*) (Data S1).

Spatial conservation planning of terrestrial Natura 2000 sites

To identify priority terrestrial Natura 2000 sites for species conservation, and to explore if the Romanian Natura 2000 network sufficiently represents species included in Annex II of Habitats Directive, we used Zonation v4, a decision support software tool for spatial conservation planning (Lehtomäki & Moilanen 2013; Moilanen 2007). We carried out the analyses nationwide (all Natura 2000 sites) and separately for each biogeographic region (i.e., Alpine, Continental, Pannonian, Steppic and Black Sea).

Zonation eliminates grids cells within the existing Natura 2000 networks (species occurrences) with the lowest total marginal loss in biodiversity while accounting for distribution of total and remaining characteristics of the analysis (Moilanen et al. 2014). At each iteration, the biodiversity features (species occurrences as UTM 1 × 1 km) are normalized by maintaining the size of their categories, which means that if occurrences of a species become less frequent during the cell removal process, its relative significance increases. Repeated normalization of the category size leads to maintaining a balance between the characteristics of all iterations (Moilanen et al. 2014). At the end of the analysis, Zonation heuristically ranks all the Natura 2000 sites according to its conservation priority. We analyzed the dataset by using the additive benefit function with exponent $z = 0.25$, which is a default value representing the exponent of the species-area curve (Moilanen 2007; Moilanen et al. 2005). In this prioritization model, the function sums the loss across features, converted via feature-specific benefit functions, giving priority to the cells containing multiple species (Arponen et al. 2005). The outputs of the analyses are the ranking of sites according to their contribution in covering protected species at the national and biogeographical level. Zonation outputs are hierarchies of cells with conservation ranking between 0 (lowest value) and 1 (top priorities). The scores have a uniform distribution; thus, the top spatial conservation priorities (e.g., top 10% of the landscape) have a Zonation ranking of ≥0.90. The ranking maps are paired with the performance curves that describe the extent to which each species is retained in any given high-priority or low-priority fraction of the Natura 2000 network (Moilanen et al. 2005; Moilanen et al. 2011). The uniform distribution of the conservation ranking has the advantage of providing flexibility when identifying top areas for conservation. We considered all grid cells falling in the top 10% of the predicted priority ranks, a proportion that maximizes species representation within Natura 2000 sites, as high-priority areas for conservation (Moilanen et al. 2005).

Raw data is available at Zenodo repository (https://zenodo.org/record/3931434).

Results

Prioritization of Natura 2000 sites at national level

Of 241759 1 × 1 km grid cells covering Romania, 53874 grid cells (~23% of Romanian territory) are overlapped by Natura 2000 sites. Of protected grid cells, Zonation retained 48954 planning units (20.24% of Romanian territory) and 4920 planning units overlapping less than 5% with the respective protected area.

The high-priority protected Natura 2000 sites overlap Western Carpathians and Transylvania (Fig. 1). Outside of Carpathians, the top-priority Natura 2000 sites were mostly rivers. The largest sites with areas identified as priority for conservation are: ROSCI0355 Podisul Lipovei - Poiana Rusca, ROSCI0406 Zarandul de Est, ROSCI0407 Zarandul de Vest, ROSCI0328 Obcinele Bucovinei, ROSCI0376 Raul Olt intre Maruntei si Turnu Magurele, ROSCI0354 Platforma Cotmeana, ROSCI0381 Raul Targului Argesel Rausor, and ROSCI0357 Porumbeni. Isolated hotspots are represented by sites in the eastern and southern parts of Romania: ROSCI0434 Siretul Mijlociu, ROSCI0335 Padurea Dobrina – Husi, ROSCI0399 Suharau – Darabani, ROSCI0389 Saraturile de la Gura Ialomitei - Mihai Bravu, ROSCI0353 Pestera – Deleni, ROSCI0359 Prigoria – Bengesti, and ROSCI0343 Padurile din Silvostepa Mostistei (Fig. 1, Data S2).

National level top-priority sites cover 17% of Natura 2000 protected grid cells in the Steppic and Black Sea biogeographic region, 9% in Pannonian biogeographic region, 6% of Natura 2000 protected grid cells in Alpine biogeographic region, and 3% of protected grid cells in Continental biogeographic region (Fig. 1, Data S2).

The performance of national-level planning of top priorities is low. On average, when considering 10% of landscape of Natura 2000 sites as protected, 20% of distribution of species listed in Annex II of Habitats Directive are protected (Fig. S1). As a consequence, the representation of species by priority terrestrial Natura 2000 sites is reduced when compared to the initial set of species, with 51 species (31%) not covered by top 10% of planning units. The missed species include plants (23 species), invertebrates (15 species), fish (6 species), mammals (5 species), and reptiles (2 species) (Table 1, Data S3).

Table 1 Representation of Natura 2000 species by the top 10% priority 2000 sites (most represented and gap species).

Taxonomic group	**Species**	**Number of top 10 % Natura 2000 sites covering the species**
Plants	*Pulsatilla grandis, Dicranum viride, Pulsatilla patens, Campanula romanica, Aldrovanda vesiculosa, Potentilla emilii-popii, Centaurea jankae, Moehringia jankae, Syringa josikaea, Pulsatilla pratensis ssp. hungarica, Colchicum arenarium, Draba dorneri, Dracocephalum austriacum, Galium moldavicum, Paeonia officinalis ssp. banatica, Astragalus peterfii, Centaurea pontica, Ferula sadleriana, Gladiolus palustris, Saxifraga hirculus, Stipa danubialis, Thlaspi jankae, Tulipa hungarica*	0
	Echium russicum	7
Invertebrates	*Pilemia tigrina, Cucujus cinnaberinus, Paracaloptenus caloptenoides, Gortyna borelii lunata, Pseudogaurotina excellens, Rhysodes sulcatus, Carabus zawadzkii, Cucullia mixta, Buprestis splendens, Glyphipterix loricatella, Graphoderus bilineatus, Vertigo moulinsiana, Isophya harzi, Oxyporus mannerheimii, Stenobothrus eurasius*	0
	Lucanus cervus	22
Fish	*Umbra krameri, Alosa tanaica, Leuciscus souffia, Cobitis elongata, Romanichthys valsanicola, Rutilus pigus*	0
	Rhodeus sericeus amarus	41
Amphibians	-	-
	Bombina variegata	56
Reptiles	*Vipera ursinii, Vipera ursinii rakosiensis*	0
	Emys orbicularis	24
Mammals	*Sicista subtilis, Rhinolophus mehelyi, Microtus tatricus, Bison bonasus, Mustela lutreola*	0
	Lutra lutra	60

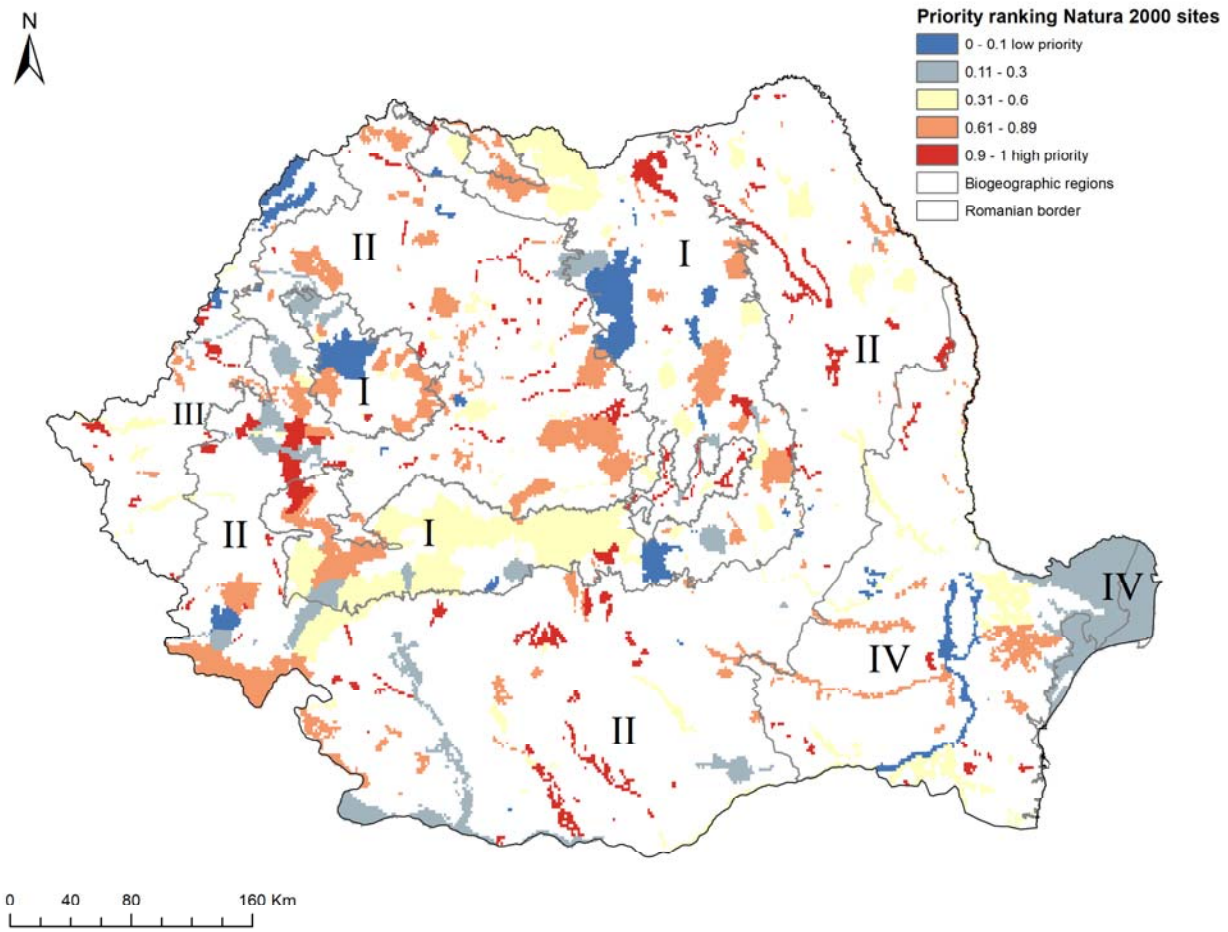

Fig. 1 National level prioritization scenario. Sites have been graded according to their priority, with the highest-priority sites (top 10%) shown in red. Biogeographic regions are numbered I (Alpine), II (Continental), III (Pannonian), IV (Steppic and terrestrial Black Sea).

Prioritization of Natura 2000 sites at national level by taxonomic group

When priority ranking maps are organized by taxonomic group, the top-priority sites are dissimilar to the results of national level prioritization (Fig. 2). For amphibians, the ranking map (Fig. 2B) indicates that sites with high priority for conservation are spatially grouped in the western and central parts of Romania, while reptiles were clustered in the southwestern and southeastern part of Romania (Fig. 2B). For mammals, invertebrates, fish, and plants, most of the high-priority species are spatially grouped in the Carpathians and Dobrogea areas, regions with large protected areas and high species richness (Fig. 2C-F).

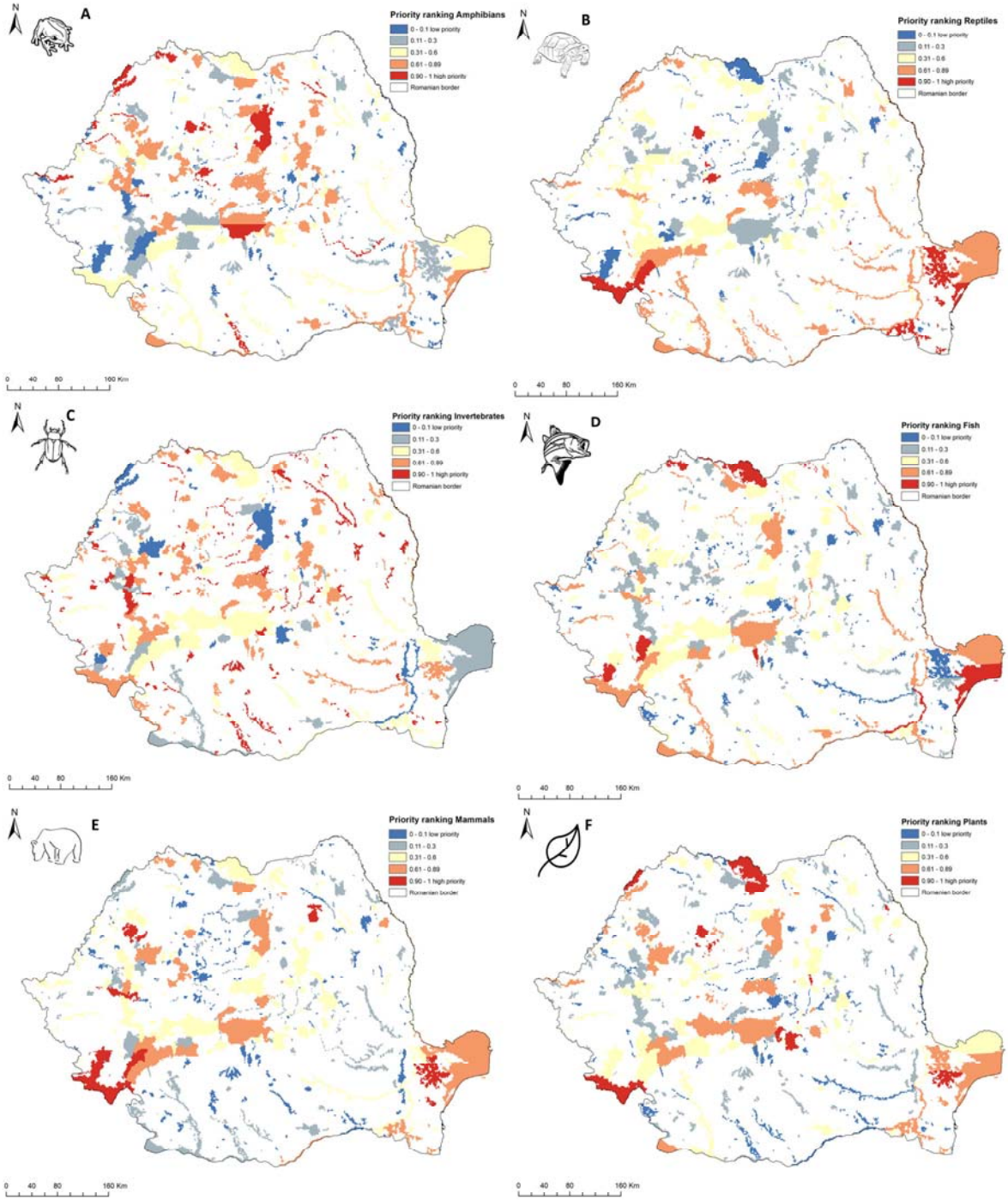

Fig. 2 Taxonomic group prioritization scenario. Sites have been graded according to their priority rank, with the highest priorities (top 10%) shown in red. (A) Amphibians. (B) Reptiles. (C) Invertebrates. (D) Fish. (E) Mammals. (F) Plants.

The performance of top-priority Natura 2000 sites in covering species distribution varies by taxonomic group (Fig. S2). When considering invertebrates, the prioritization exercise indicates that if the top 10% of the landscape included in Natura 2000 sites is strictly protected, only 10% of the invertebrate distribution in Natura 2000 is also protected; this is followed by the amphibian group, with 35% of the amphibian distribution in Natura 2000 protected. For reptiles, Natura 2000 performs better, with 90% of the distribution of reptiles in Natura 2000 strictly protected. For mammals, fish, and plants, the Romanian Natura 2000 network performs well, with more than 50% of distribution of the respective species strictly protected when the identified top-priority 10% of Natura 2000 area is protected.

Prioritization of Natura 2000 sites for species conservation at biogeographical level

When the Alpine biogeographic region is considered, the high-priority areas are in Western Carpathians (Natura 2000 sites overlapping Trascau and Apuseni Mountains), Southern Carpathians (Natura 2000 sites overlapping Piatra Craiului Mountains), and Eastern Carpathians (Natura 2000 sites overlapping Gurghiu Mountains) (Fig. 3A, Data S2). When the Continental biogeographic region is analyzed, the main hotspots overlap Natura 2000 site in Iron Gates (SW Romania), Dealurile Clujului de Est (center of Romania) and Tur River (northwest of Romania) (Fig. 3B, Data S2). In the Pannonian region, the main hotspot is in the Lower Mures Floodplain (western-most part of Romania) (Fig. 3C, Data S2). In the Steppic and terrestrial Black Sea biogeographic regions, the high-priority areas are Macin Mountains, Canaralele Dunarii, and Padurea si Valea Canaraua Fetii – Iortmac and Dumbraveni - Valea Urluia - Lacul Vederoasa Natura 2000 sites (Fig. 3D, Data S2).

The performance of Natura 2000 by biogeographical region is similar for Alpine, Steppic-Terrestrial Black Sea and Pannonian. In these regions, when the top 10% of the respective region is strictly protected, between 40% and 50% of the distribution of covered species is protected. The Continental biogeographic region performs better when considering 10% of landscape of Natura 2000 sites as protected, almost 60% of distribution of species listed in Annex II of HD are protected (Fig. S3).

The biogeographical level planning scenario produced fewer gap species than the national level scenario when selecting top priorities (Fig. 5, Data S3). Out of 118 species included in Alpine EBR, 55 are gap species if planning is done at the national level and 8 if planning is done at the

biogeographical level. Of 149 species in Continental EBR, 53 are gap species when prioritization is done at the national level and 19 when it is done at the biogeographical level. Furthermore, out of 75 species represented in Pannonian EBR, 32 are gap species in national-level scenarios and only 17 in biogeographical level scenarios. Also, the number of gap species is reduced when planning is done at Steppic and Black Sea EBR level, with 58 gap species out of 79 in national-level scenarios and only 12 species in biogeographical level scenarios.

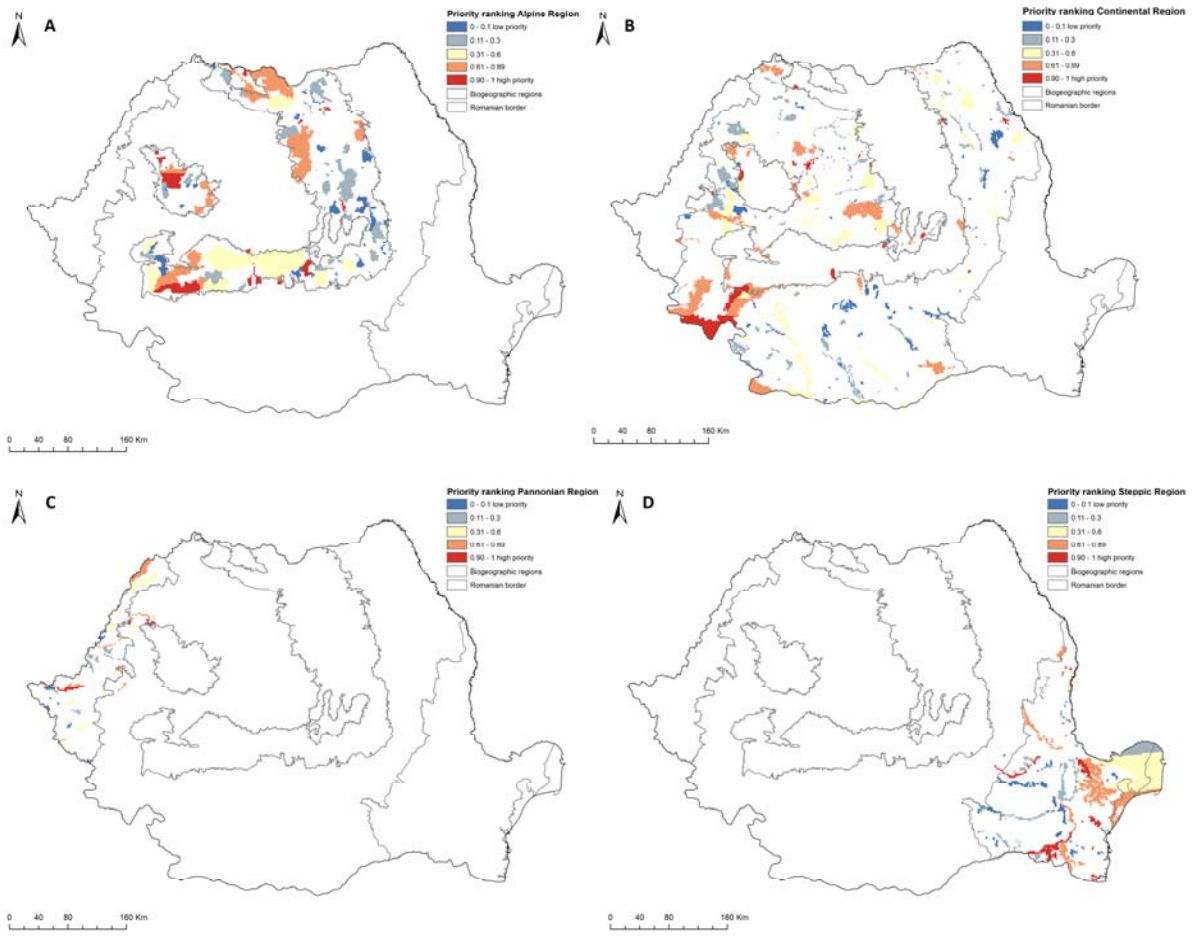

Fig. 3 Biogeographical level prioritization scenario. Sites have been graded according to their priority rank, with highest priorities (top 10%) shown in red.(A) Alpine biogeographic region. (B) Continental biogeographic region. (C) Pannonian biogeographic region. (D) Steppic and terrestrial Black Sea biogeographic region.

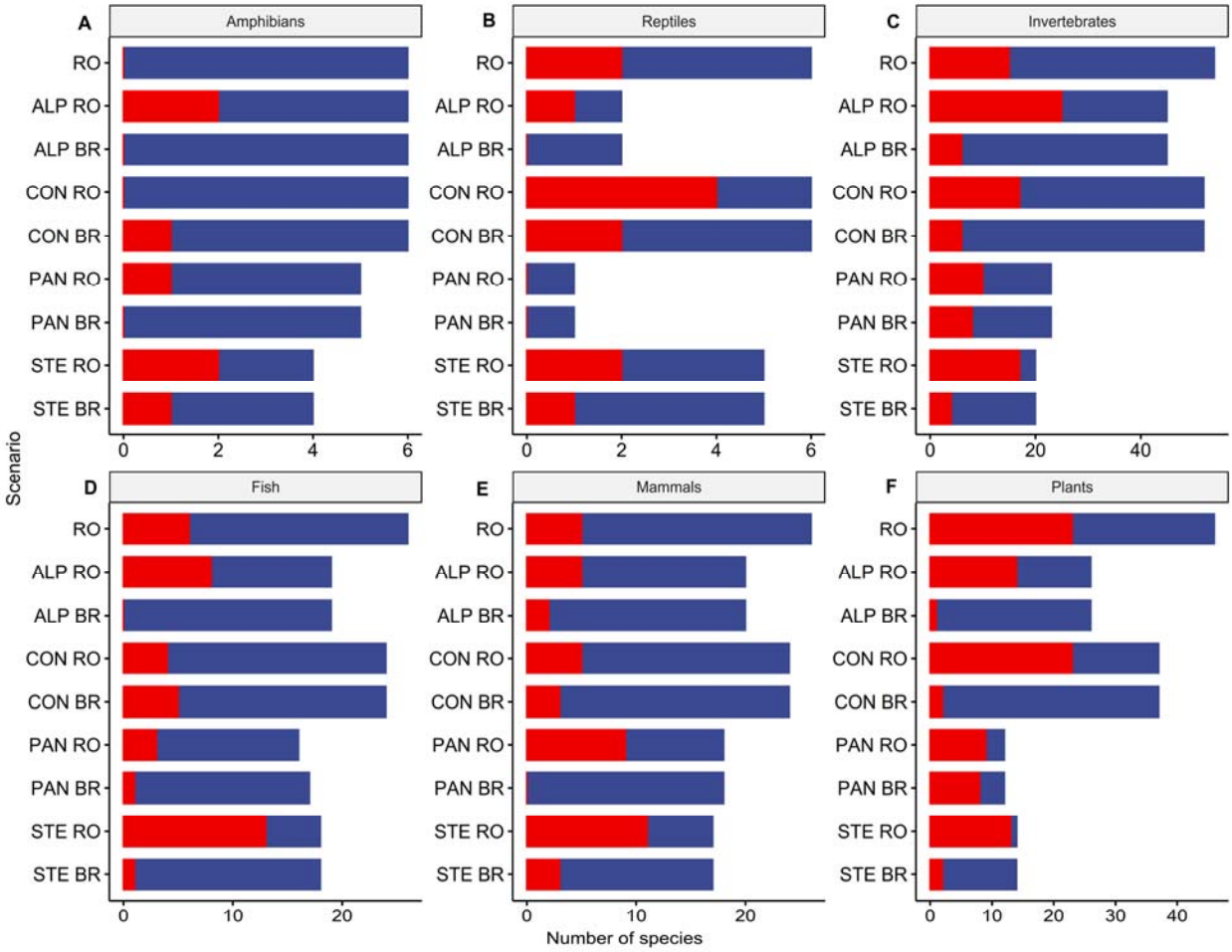

Fig. 4 Species representation in the top 10% planning units by prioritization scenarios. Red = gap species, Blue = covered species. RO = national level scenario. ALP RO = Alpine EBR in national level scenario. ALP BR = Alpine EBR in biogeographical level scenario; CON RO = Continental EBR in national level scenario. CON BR = Continental EBR in biogeographical level scenario; PAN RO = Pannonian EBR in national level scenario. PAN BR = Pannonian EBR in biogeographical level scenario; STE RO = Steppic and terrestrial Black Sea EBR in national level scenario. STE BR = Steppic and terrestrial Black Sea EBR in biogeographical level scenario.

Discussion

The EU Biodiversity Strategy for 2030 set new ambitious targets for the Member States, such as enlargement of protected areas to at least 30% of land in Europe, of which 10% should be strictly protected (European Commission 2020). The goal of the Natura 2000 network is to ensure the

long-term survival of species and habitats listed in Birds and Habitats Directives (Evans 2012); hence, strictly protected areas within the existing network should also cover most of the species and habitats protected by the two Directives. Here we provide an evaluation of the effectiveness of spatial conservation prioritization in the identification of strictly protected areas within the existing Natura 2000 network using Romanian terrestrial Natura 2000 network as a case study. Selecting strictly protected areas within the existing Natura 2000 network using spatial conservation prioritization at the European Biogeographical Region level performs better than nationwide or taxa-specific planning both in terms of species representation and spatial evenness.

When spatial conservation prioritization is done at the national level, the top 10% grid cells contributing to representation of Habitats Directive species covers 8.17% of the existing Natura 2000 network (see Fig. 1, Data S2). Priority areas overlap 119 Natura 2000 sites of which only 28 sites include strictly protected areas > 50 km^2. The largest high-priority areas are included in ROSCI0355 Podisul Lipovei Poiana Rusca (423 km^2), ROSCI0376 Olt River between Maruntei, and Turnu Magurele (248 km^2). Areas selected as important for Natura 2000 network coherence are located mostly on Continental EBR (71% of priority areas and 14.53% of Continental EBR). Sites in Steppic and terrestrial Black Sea EBR were also selected in a large proportion relative to the size of the region (14.45% of the Steppic EBR). The Alpine and Pannonian biogeographic regions contributed less to high-priority areas (3.05% of Alpine EBR and 2.86% of Pannonian EBR) (see Data S1). In national-level prioritization scenarios, 37% of sites with high-priority planning units (44 Natura 2000 sites) are rivers. The biased selection of rivers and sites in Continental EBR resulted in missing 51 out of the total 164 species (e.g., the meadow viper *Vipera ursinii*, Danube feather grass *Stipa danubialis*, the European mudminnow *Umbra krameri*, see Data S3). Covering all species would require priority areas in 31 new sites (e.g., Danube Delta, Iron Gates), increasing the number of Natura 2000 sites with priority areas to 150. The suboptimal performance of high-priority areas in covering species included in Annex II of Habitats Directive is also confirmed by other prioritizations exercises (Kukkala et al. 2016; Mikkonen & Moilanen 2013). Continental EBR, which in this scenario would constitute the backbone of strictly protected areas, include many common species when compared to other EBRs (Gruber et al. 2012; Rozylowicz et al. 2019); thus, rare species inhabiting Alpine and Pannonian EBRs would be missed without a significant extension of high-priority areas. In a previous analysis of key sites within the Romanian Natura 2000 network, we found that more

than 50% of sites from Alpine, Steppic, and the Black Sea EBRs are important for network cohesion at the national level (Rozylowicz et al. 2019); thus, the national level spatial conservation prioritization will miss most of these sites.

The lower coverage of species by the top 10% priority areas in the national-level spatial conservation prioritization is also evident when conservation prioritization is done at the national level by taxonomic group (see Fig. 2, Fig. S2, Data S2). In this taxa specific scenario, the top 10% priority areas overlap 170 Natura 2000 sites, of which 119 sites include priority areas for invertebrates, 19 sites for amphibians, 18 sites for plants, 16 sites for reptiles, 13 sites for mammals, and 10 sites for fish species. This suggests that the high number of sites with priority areas is mostly due to poor coverage of invertebrates. Invertebrates are overlooked due to insufficient search efforts and a lack of taxonomists (Brodie et al. 2019; Cardoso et al. 2011; D'Amen et al. 2013); thus, there are fewer Natura 2000 sites per species in most cases.

When selecting top-priority planning units within each biogeographical region, the cumulated surface of the top 10% grid cells contributing to covering Habitats Directive Annex II species represents 9.16% of Natura 2000, thus outperforming planning at the national level (8.17%). Also, the number of sites with planning units in the top 10% is reduced (68 Natura 2000 sites when planning region by region, 8 sites belong to two EBRs), and the location is more evenly distributed across Romania (see Fig. 3, Data S2). The most numerous sites with top-priority planning units are in the Alpine EBR (28 sites) and the Continental EBR (23 sites), followed by the Steppic and terrestrial Black Sea EBR (15 sites), and the Pannonian EBR (4 sites). Planning by biogeographical unit scenarios also perform better in terms of species representation, with only 10 species not covered by top-priority planning units (i.e., *Centaurea pontica*, *Pulsatilla pratensis* subsp. *hungarica*, *Carabus zawadzkii*, *Graphoderus bilineatus*, *Lycaena helle*, *Rutilus pigus*, *Cobitis elongata*, *Microtus tatricus*, *Mustela lutreola*, *Vipera ursinii rakosien*sis) (see Data S3). Covering these species would require at least 7 new sites, increasing the number of sites to 77 (e.g., of new sites ROSCI0065 Danube Delta, ROSCI0031 Cheile Nerei – Beusnita, ROSCI0214 Raul Tur, ROSCI0187 Pajistile lui Suciu, ROSCI0020 Campia Carei, ROSCI0124 Muntii Maramuresului, ROSCI0125 Muntii Rodnei). The performance of this prioritization scenario is confirmed by other studies done at the EU level. For example, Kukkala et al. (2016) found that selection of Natura 2000 by biogeographical unit at the EU level covers a greater range of species than national level or administrative level selection.

Our prioritization exercise is constrained by the limited availability of distribution data for most of Annex II Habitats Directive species. With few exceptions such as reptiles, amphibians, mammals in the Dogrobea region, large carnivores (Birsan et al. 2017; Cogălniceanu et al. 2013a; Cogălniceanu et al. 2013b; Cristescu et al. 2019; Miu et al. 2018) species distribution data are available as the extent of occurrence (EIONET 2020). To overcome this shortcoming we used Natura 2000 Standard Data Form, the technical documentation of a Natura 2000 that includes species for which it was designated (Lisón et al. 2017), and the grid size reported by Romanian authorities for biogeographical assessments of the conservation status of species and habitats under Article 17 of the Habitats Directive (EIONET 2020). The surrogate for species distribution overestimate the range of rare species; thus, we did not interpret species representation as distribution covered but the number of sites captured by priority areas. Hence, before planning strictly protected areas, Member States should invest in obtaining robust species distribution data, especially for overlooked species such as invertebrates.

Conclusions

Our planning exercise highlighted that the scale of planning is important. Thus, when EU Member States start the designation of strictly protected areas as required by the EU Biodiversity Strategy for 2030 (European Commission 2020), they should set clear targets for the representation of species and habitats at the biogeographical region level.

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Supplementary figures

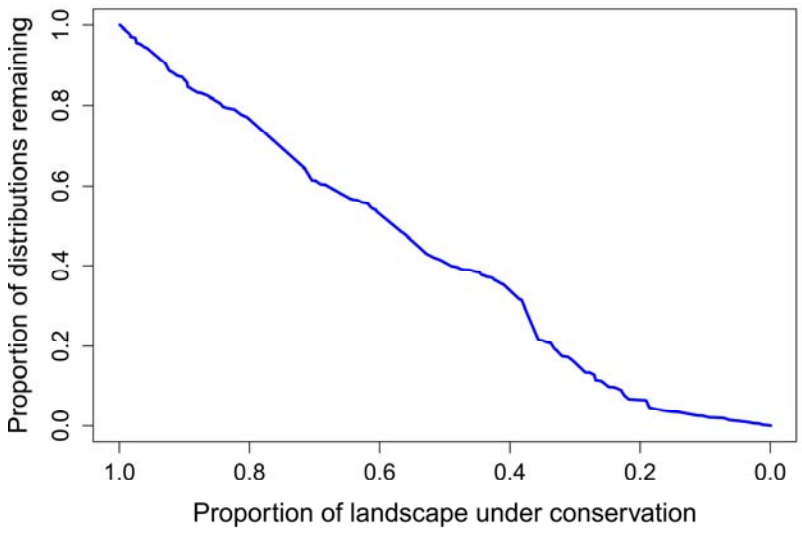

Fig. S1 Coverage of species distribution within Romanian terrestrial Natura 2000 network at various proportions of strictly protected landscape. National level prioritization scenario. The curve represent mean coverage achieved across all species.

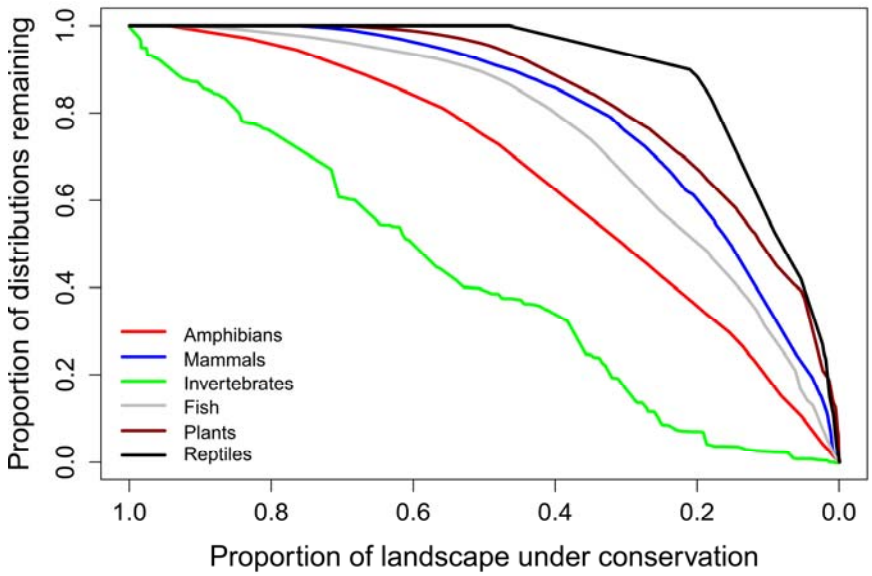

Fig. S2 Coverage of taxonomic group distribution within Romanian terrestrial Natura 2000 network at various proportions of strictly protected landscape. Taxonomic group level

prioritization scenario. The curves represent mean coverage achieved across all species of the respective taxonomic group.

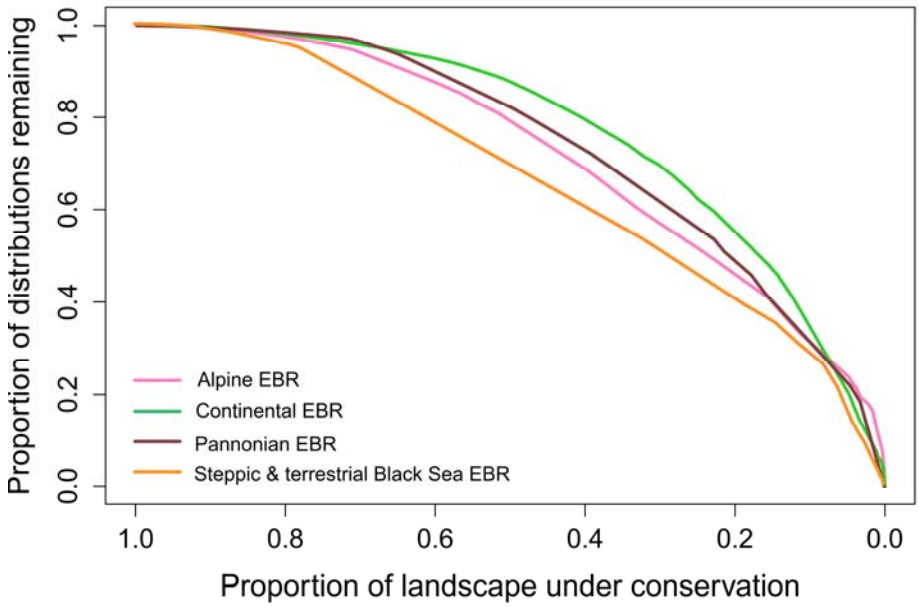

Fig. S3 Coverage of species distribution within biogeographical regions overlapping Romanian terrestrial Natura 2000 network at various proportions of strictly protected landscape. Biogeographical level prioritization scenario. The curves represent mean coverage achieved across all species.