Journal for Nature Conservation 79 (2024) 126621

Contents lists available at ScienceDirect

Journal for Nature Conservation

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

EU2030 biodiversity strategy: Unveiling gaps in the coverage of ecoregions and threatened species within the strictly protected areas of Italy

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ARTICLE INFO

Keywords:
Conservation
Gap analysis
IUCN red list
2030 target
Protected areas

ABSTRACT

About 19 % of the Italian territory is covered by protected areas (PAs), 5.1 % of which fall in IUCN categories Ia and II, which can be considered strictly protected areas (StPAs). The 2030 EU Biodiversity Strategy sets a target of 30 % coverage for PAs (of which 10 % should be StPAs). We assessed the area coverage of StPAs, for the territory of Italy, with respect to biogeographical regions, ecoregions, elevation range, habitats, and the distribution of species threatened with extinction according to the IUCN Red List (Vulnerable, VU; Endangered, EN; or Critically Endangered, CR). We found that most of the StPAs are located in the Mediterranean biogeographical region, followed by the Alpine and Continental regions, and that the spatial distribution of such protected areas is biased towards higher elevation. Moreover, we found that three of the fourteen terrestrial ecoregions of Italy are not protected at all by StPAs (i.e., Illyrian, Ligurian-Provencal, and Central-Adriatic), while the Po Plain and the Sicilia Sections are only marginally protected. Moreover, nine habitats are not covered by any StPAs including one priority habitat (Inland salt meadows). Finally, we found unprotected species among freshwater fish (21), amphibians (3 VU, 3 CR), reptiles (1 CR), birds (2 NE), mammals (1 VU), and plants (20 VU, 14 EN, 21 CR). Our findings suggest that the current amount and spatial distribution of StPAs of Italy are far from the targets of the EU Biodiversity Strategy and needs improvements.

1. Introduction

Biodiversity is facing an unprecedented crisis often referred to as the sixth mass extinction (Brondízio et al., 2019; Cowie et al., 2022; Díaz & Malhi, 2022; Shivanna, 2020). Ecosystems have been consistently altered by human activities. Notably, 75 % of the global land surface has been significantly altered, 85 % of wetlands have been removed and around 25 % of assessed plant and animal species are under threat with one million risking global extinction (Brondízio et al., 2019; IUCN, 2023). Moreover, extinction rates may be even higher as known species represent only a minimal fraction of total species richness. Some drivers of biodiversity loss can be identified in land use changes causing natural habitat loss and fragmentation, direct exploitation of natural resources, invasion of alien species, climate change and pollution, with the first two being the most detrimental (IPBES, 2019; Jaureguiberry et al., 2022). Protected areas (PAs) are considered essential for conservation because they can be employed to achieve a wide variety of biodiversity and ecosystem conservation goals, as well as social and economic objectives (Watson et al., 2014), including augmenting local biodiversity and hampering land cover change (Geldmann et al., 2013; Gray et al., 2016).

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https://doi.org/10.1016/j.jnc.2024.126621
Received 11 July 2023; Received in revised form 24 January 2024; Accepted 18 April 2024
Available online 21 April 2024

Coherently with the global biodiversity strategy and the Kunming-Montreal biodiversity framework's 2030 mission of taking urgent action to halt and reverse the loss of biodiversity (CBD, 2022); and recognising that biodiversity in the EU is still declining and such trend will continue without further implementation of existing policies (EEA, 2019) the European Community launched the 2030 EU Biodiversity Strategy (EC, 2021; EC, 2022). The strategy has the aim to extend protected areas to 30 % of land and sea surface in the whole Union, with efforts shared by every member state, within a policy frame to reverse ecosystem degradation and biodiversity loss, as well as improve society's resilience against climate change, forest fires, food insecurity and disease outbreaks. The Strategy also indicates that one-third of this area, corresponding to 10 % of the EU area, should be under strict protection (EC, 2021; EC, 2022). Strictly protected areas (StPAs) are defined as "fully and legally protected areas designated to conserve and/or restore the integrity of biodiversity-rich natural areas with their underlying ecological structure and supporting natural environmental processes" (EC, 2022). Natural processes are left undisturbed by human pressures and threats to the area's overall ecological structure and functioning, regardless of whether those pressures are located inside or outside the strictly protected area (EC, 2022). Such a definition aligns with the IUCN Protected Area classification of category Ia (strict nature reserve) and Ib (wilderness area), respectively. It is debated whether national parks (category II of IUCN classification, hereafter "NP") may be counted as StPAs since the designation of NP allows for a zonation process in which strict protection does not apply to the whole area (Dinerstein et al., 2019) and where different socio-economic activities, including forestry or agriculture practices, are allowed. This is particularly important in some countries, like Italy, with a long history of human transformation of landscapes and ecosystems (Nazari et al., 2023). The types of permitted management practices interact with natural processes and, therefore, limit the concept of "undisturbed by human pressures" areas. For the type II PAs, the IUCN guiding principle indicates a minimal management intervention to guarantee ecological functions and processes and this varies significantly across European countries. Furthermore, the regulations for each zone within NPs also vary according to the legislation of the country where the area is located and with the single NP's management plan (in Italy core Zone A within each NP is strictly protected by the law and no land use change is allowed, whereas in other zones B, C, and D increasing human activities are allowed but with limited impact on biodiversity). A recent study showed that, even considering all the PAs belonging to the IUCN category II, and with few exceptions, the amount of strictly protected areas across EU countries and biogeographical regions remains very limited, much lower the 10 % EU target, and their spatial distribution is greatly biased towards higher elevation sites (Cazzolla Gatti et al., 2023).

In this study, our goal was to conduct a spatially explicit assessment of Italian terrestrial StPAs (as IUCN categories Ia, Ib, and II, after Cazzolla Gatti et al., 2023) to evaluate their coverage of biogeographical regions, ecoregions, elevation range, habitats and endangered species distribution included in the global Red List. We aim to assess the Italian StPAs' network contribution to the protection of biodiversity on a higher scale (particularly for the EU 2030 biodiversity stragy) and to provide a basis for further studies on the expansion of the Italian StPAs network towards the EU 2030 biodiversity target.

2. Methods

2.1. Study area

According to the EU Biogeographical Map (EEA, 2021, Cervellini et al. 2020), the Italian territory falls into the alpine, continental and mediterranean regions (see Supplementary Fig. 2). Thanks to its position, with a North-South extension from 47° 29′ N to 35° 29′ N, it covers a wide range of ecological and biogeographical gradients, as shown, for example, by the number of endemic species, which reaches 4,777 for animals species and accounts for more than 15 % of vascular plant species (ISPRA, 2023), or the differences in forest types (Chiarucci et al., 2019). Topographically, the country is dominated by mountains and, especially hills, with an average altitude of about 537 m a.s.l. Mountain ranges cover important parts of the national territory, including a large part of the Alps (for about 1,000 km in length), with some of the highest mountains of Europe (such as Mont Blanc, 4,810 m; Monte Rosa, 4,634 m; Cervino, 4,478 m), and the Apennines chains, ranging through the entire peninsula, from Liguria to Sicily (the highest peak being Gran Sasso, 2,912 m).

2.2. Source data

To reach the goal of the study, we considered the area covered by StPAs (as IUCN categories Ia – Strict Nature Reserve, and II – National Park, Ib – Wilderness Reserve not being present in Italy) across biogeographical regions, ecoregions, habitats and distribution of species classified in the IUCN Red List in Italy we used the most updated available data sources. In Italy, StPAs of category Ia largely correspond to State Nature Reserves and Integral Nature Reserves, while category II protected areas correspond to National Parks. The spatial layers of StPAs were obtained from the 2022 update of the WDPA, available on the Protected Planet website (Protected Planet, 2022), by selecting Italian areas of all IUCN categories, both terrestrial and marine, note that WDPA data don't consider some areas such as regional PAs of core areas of parks without an approved plan, a clear perimeter and zones. Therefore results might be underestimated. The boundaries of each administrative region were obtained from the layers available on the Italian National Institute of Statistics website (ISTAT, 2022). We used the official delineations of the biogeographical regions of Europe as used in the Habitats Directive (92/43/EEC) as provided by the European Environmental Agency (EEA, 2021), which divides the Italian territory into Alpine, Continental and Mediterranean biogeographical regions (see Supplementary Fig. 2).

For the ecoregions, we used the classification by Blasi and Capotorti (2018), based on four nested hierarchical levels (divisions, provinces, sections and subsections; see Supplementary Fig. 3). Divisions are obtained by the combination of macroclimatic zones and biogeographical regions and divide Italy into two units: Temperate (1) and Mediterranean (2) Division (see Supplementary methodology and Supplementary Fig. 2). Provinces are the lower division level of divisions and correspond to prevailing potential vegetation physiognomies, with respective dominant species. They are defined on the basis of bioclimates, orographic systems and biogeographical regions. Ecoregional Provinces of Italy are 7: 1A (Alpine), 1B (Po Plain), 1C (Apennine), 1D (Illyrian), 2A (Ligurian-Provencal), 2B (Tyrrhenian), 2C (Adriatic) (Supplementary Fig. 3). The last level we analyzed is the Sections, which divide the national territory into 14 homogenous parts (Supplementary Fig. 3) and can be further divided into Subsections according to lithological and morphological systems (see Supplementary methodology and Supplementary Fig. 4).

The layer of the altitudinal range was extracted from the EU-DEM v.1.1 raster (Copernicus, 2021b) in relation to the polygonal layers of the protected areas (Ia and II).

The layer with the habitat cover (Ercole et al., 2021) was obtained from the database of Reporting Direttiva Habitat (isprambiente.it, consulted July 2023), while the distribution ranges referred to the global Red List species (IUCN and BirdLife International, 2022–2), although not available for all the species assessed in the Italian Red List (Rondinini et al., 2022; Rossi et al., 2013; 2020). Whenever possible, we manually added the missing species by searching for the specific material in the IUCN Red List of Threatened Species website (IUCN, 2023). It was possible to integrate the polygonal shapefiles of the distribution ranges of 5 freshwater fish species (i.e., Lampetra fluviatilis, Lampetra planeri, Lampetra zanandreai, Petromyzon marinus, Silurus glanis), all derived from global and/or European assessments.

2.3. Data analysis

Details of our workflow are reported in Fig. 1. The layers were first imported either in QGIS 3.22.13 or in R 4.2.2 (R Core Team, 2023) and reprojected in EPSG: 32,632 – WGS 84 / UTM zone 32 N. First we filtered the WDPA layer by keeping only areas of IUCN category 'Ia' or 'II' – areas of category Ib are not present in Italy– (step 1.1). Then to avoid double counting if StPAs were overlapping on the same area, which was often the case as in the WDPA layer core areas of national parks are classified as Ia, we cut them keeping the strictest level (i.e., Ia > II), thus obtaining the StPAs layer (step 1.2).

Subsequently, red list species layers were imported and cut using Italian national borders with a 600 m buffer (step 1.3). The reason for using such a buffer is that StPAs polygons downloaded from the WDPA database do not match perfectly with the italian boundaries so it was used to include all portions of the PAs. On the contrary, Ecoregions, biogeographical regions and habitats, being land-focused products that coincides with national borders have just been imported directly without masking.

Later, we overlaid administrative regions, biogeographical regions, ecoregions (hereafter referred collectively as 'land products'), with the StPAs Ia and II layer obtaining a new layer with the intersection of the StPAs and the land products for which it was possible to calculate the area of all the intersections (step 1.4). We further overlaid the habitat and cut red list species layers with the StPAs layer (step 1.5) but without computing the area of the intersections as we were interested only in the presence or absence of the said species or habitat inside the StPAs network.

To check for the missing species and habitats we extracted the attribute table of the layer obtained in step 1.5 in R, obtained a unique list of species and habitats present in the StPAs network (step 2.1) and confronted them with the complete lists obtained from the attribute table of the habitats and cut red list species, respectively (step 2.2). Since the bird range layer provided by BirdLife International lacked information on IUCN risk categories, we checked and manually added this information (using the IUCN global database) only for the 11 species whose range was not found to fall within any StPAs.

For the calculation of the percentage area of administrative regions, biogeographical regions and ecoregions falling into StPAs of category Ia or II we firstly aggregated all the intersections between StPAs Ia or II and the land products and computed the total area of the StPAs for every zone of the land products (step 2.3) then we divided it for the total area of every zone of the land products and obtained the percentage of the protected area (step 2.4).

Finally, for the altitude analysis the altitude raster and the StPAs layer were imported in R (step 3.1; packages raster (Hijmans, 2023),

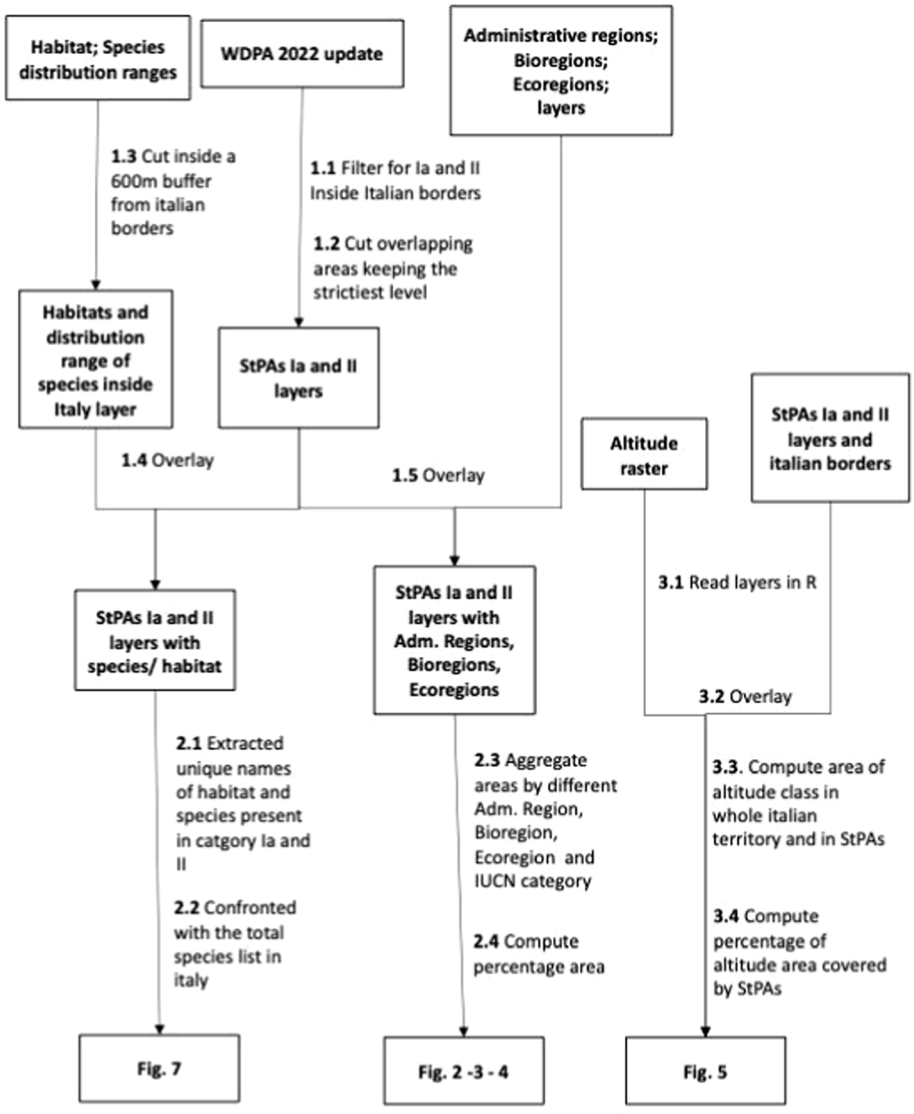

Fig. 1. The figure describes the workflow of the analysis from the starting layers to the final results and figures expliciting the different steps adopted.

rgdal (Bivand et al., 2023), sf (Pebesma, 2018; Pebesma & Bivand, 2023)). Subsequently we overlaid the altitude raster with the StPAs layer (step 3.2, package exactextractr (Baston, 2023)) and computed the area occupied by StPAs for each altitude class (step 3.3). We later divided such areas for the total area of Italy by altitude class —obtained in the same way but using the Italian borders layer— to compute the percentage of area under strict protection for altitude range (step 3.4).

For all data manipulation in R we used the package tidyverse (Wickham et al., 2019), and magrittr (Bache & Wickham, 2022).

3. Results

We recorded 141 StPAs with a cumulative area of 16,054.56 km^2, corresponding to 5.3 % of the terrestrial area of Italy. Among these, 116 StPAs belonged to IUCN category Ia (613.23 km^2, 0.20 % of the terrestrial area), and 25 were IUCN category II (15,441.33 km^2, 5.1 %; Supplementary Figure 1).

3.1. Strictly protected areas across administrative regions of Italy

The area under strict protection across regions varies from 0.05 % in Friuli Venezia Giulia to more than 14.2 % in Abruzzo, Molise and Calabria (Fig. 2). The regional area protected by category Ia StPAs was lower than 1 % for all regions except Veneto and ranges from 0 % of Sardegna, Umbria and Valle d'Aosta up to 1.14 % of Veneto. The regional protected area by category II StPAs varies from 0 % of Friuli Venezia Giulia to 21.2 % of Abruzzo.

3.2. Strictly protected areas across biogeographical regions of Italy

The amount of StPAs is higher in the Alpine region (Fig. 3), with 34 StPAs covering 4,468.52 km^2 (8.77 %). Among them, 27 StPA were of category Ia (290.39 km^2, 0.57 % of the region) and 7 of category II (4,178.13 km^2, 8.20 %). The Mediterranean region has an intermediate value, with 84 StPAs covering 9,044.58 km^2 (5.58 %), 65 of category Ia (214.12 km^2, 1,32 %) and 19 for category II (8,830.46 km^2, 5.45 %). The Continental region shows the lowest coverage, with 32 StPAs covering 1906.21 km^2 (2.16 %), 27 of category Ia (119.13 km^2, 0.13 %) and 5 of category II (1787.08 km^2, 2.03 %).

3.3. Strictly protected areas across ecoregions of Italy

The temperate division of Italy has a StPAs cover of 9,515.40 km^2 (5.03 %), made up by 61 category Ia StPAs (438.02 km^2, 0.23 %) and 13 category II StPAs (9,077.38 km^2, 4.80 %). The Mediterranean Division has a StPAs cover of of 5,904.77 km^2 (5.23 %), made up by 56 Category Ia areas (185.70 km^2, 0.17 %) and 14 Category II areas (5,719.07 km^2, 5.07 %) (Supplementary Fig. 4).

The StPAs cover across ecoregional provinces and sections was very variable, showing high values in some provinces and sections of the southern Apennines and Alps and extremely low values or total lack of StPAs in the plain and most densely populated areas of the country (Fig. 4 and supplementary Figs. 3-4-5-6 and Supplementary Table 1).

3.4. Distribution of StPAs across elevation range

The overall distribution of StPAs showed a significantly different distribution with respect to the country's elevational range (average altitude 537 m a.s.l.) as shown by a Wilcoxon test (p-value < 2.2e-16). Furthermore, category Ia PAs were mostly distributed between 700 and 1,700 m a.s.l., with a secondary peak at low elevation, due to the presence of category Ia StPAs in islands and some coastal areas. The type II StPAs were more distributed between 400 and 1,500 m a.s.l. (Fig. 5).

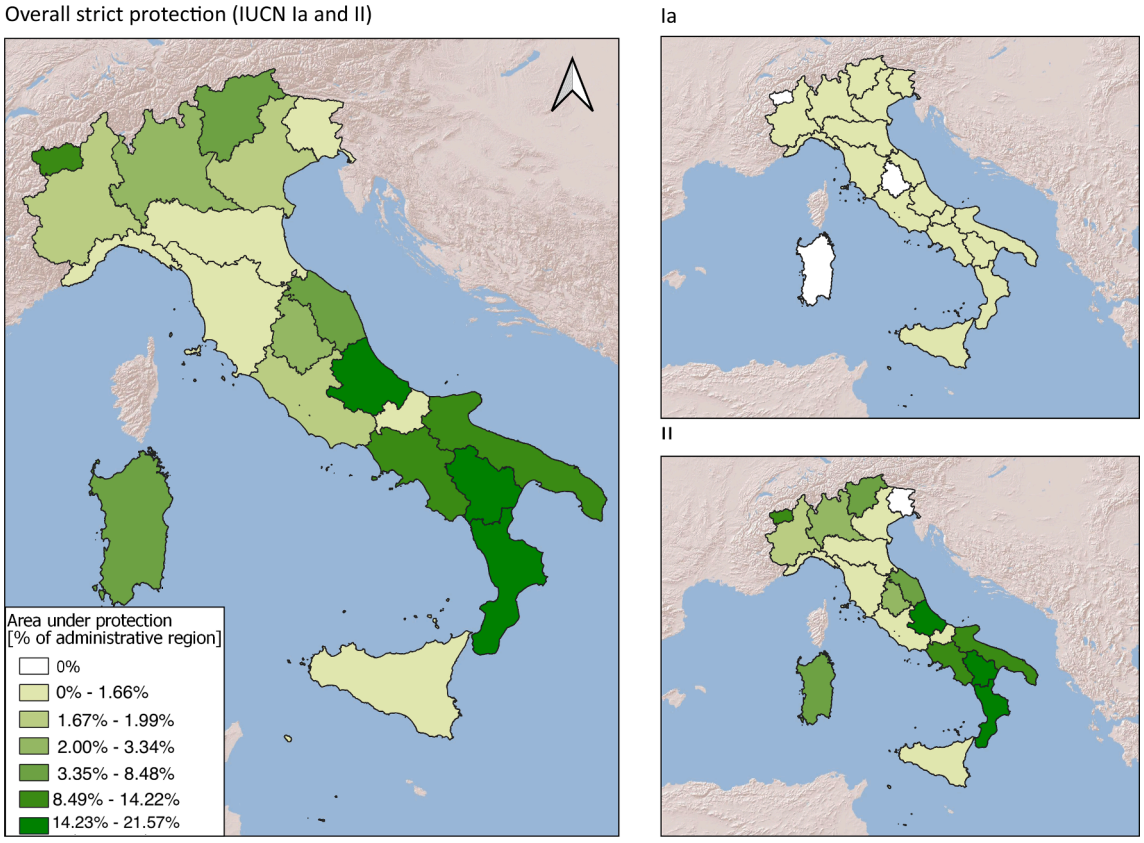

Fig. 2. Cumulative percentage of area under strict protection across italian administrative regions in cumulative sense (left panel), for IUCN category Ia (right up) and II (right down).

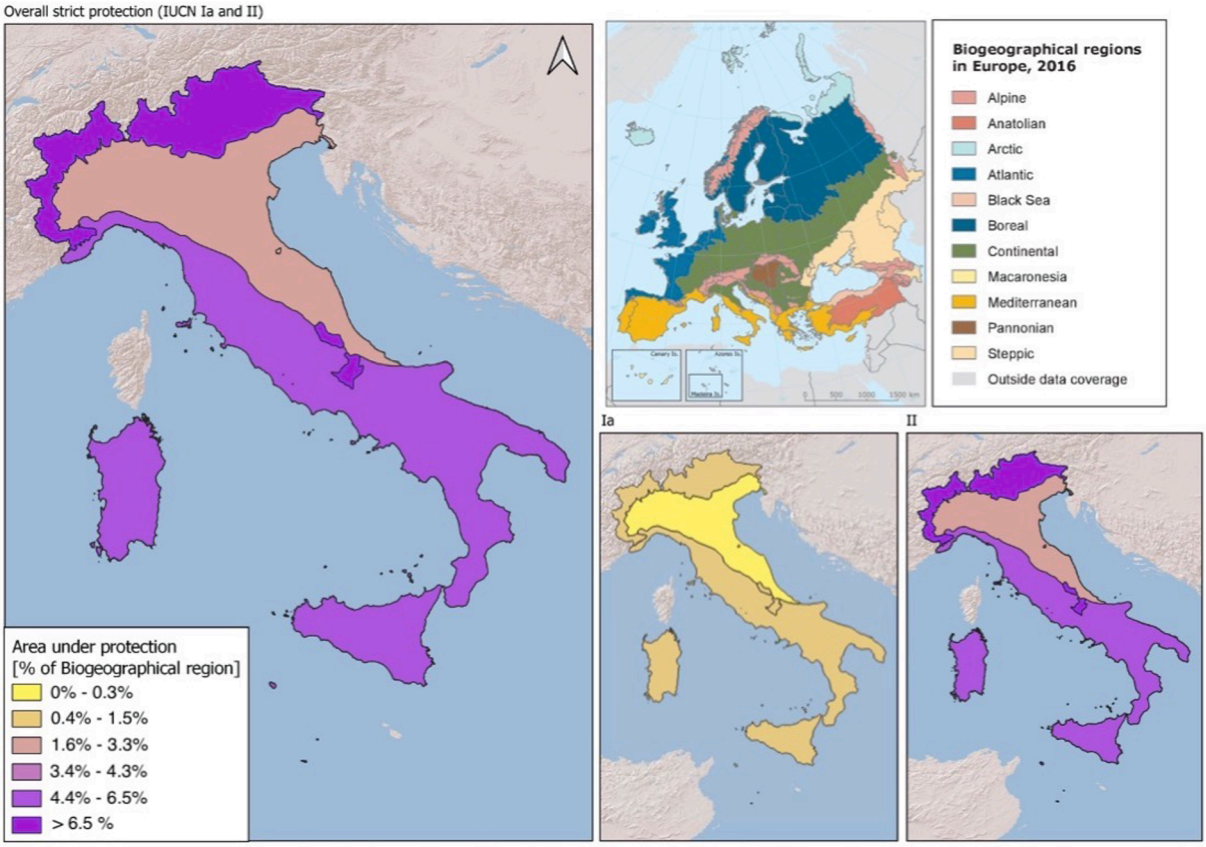

Fig. 3. Percentage of biogeographical regions covered by StPAs: Area under protection (%) is shown for all StPAs in the left panel and for the 2 different IUCN categories (Ia and II) in the bottom right panels. The map at the top right shows the European biogeographical regions (EEA, 2021).

3.5. Habitats of the 92/43/EEC Directive

Among the 132 terrestrial habitat types of the EU Habitats Directive (92/43/EEC) reported for the national territory, 122 habitats are present in, at least one, StPA, while 10 habitat types are not included in any of the StPAs (Table 1).

3.6. IUCN Red List species

The general picture of all the Italian species for which it was possible to obtain the distribution range from the IUCN global database is shown in Table 2, divided by taxonomic groups and risk categories, the latter also reported as a percentage of the total species in the table. The 339 bird species assessed in the analysis are not reported in Table 2 because the data provided by BirdLife International provided us with a dataset that lacked information on the associated risk categories. The most represented risk category is LC for 72.96%, while the least represented is EW for 0.09%, represented by *Huso huso* (Adriatic sea subpopulation), a species belonging to the Actinopterygii. With regard to the major risk categories (VU, EN and CR), the most represented taxonomic groups, from the most to the least numerous, are Magnoliopsida, Liliopsida, Actinopterygii and Amphibia. Three species of amphibians classified as VU and three as CR in the IUCN Red List, out of the 43 included, have not been observed in any StPAs, category Ia or II, if considering only category Ia one VU and three more EN species result not protected. As regards to reptiles, one endemic species, *Podarcis raffonei*, listed as CR among the 51 species assessed is not protected in any area of category Ia and/or II (Fig. 6). In the Italian Red List, of the 120 species of freshwater fish, 21 species are excluded from any strict protection. Among them five VU, two EN, two CR are not included in any Ia StPA (Fig. 6) and of them three VU, one EN (*Hucho hucho*), and one CR (*Thymallus aeliani*) are completely excluded from any strict protection, category Ia or II. We further evaluated 131 species of mammals, two VU and one CR (*Mustela lutreola*) species are not present in Ia areas and of them one species (*Arvicola sapidus*) listed as VU shows a distribution that is not included in any StPAs (Fig. 6). We also discovered that one bird species classified as VU (*Clangula hyemalis*) out of the 274 in the Italian Red List and the 339 listed by BirdLife International in Italy are not strictly protected (Fig. 6). Finally, we found that 26 VU, 28 EN, 25 CR plant species distribution is not by any Italian StPAs of category Ia and of them 20 VU, 14 EN, and 21 CR are not present in any Italian StPAs (Fig. 6). The complete list of species without strict protection in Italy is shown in Supplementary Table 2.

4. Discussion

4.1. Strictly protected areas across Italy

The number of strictly protected areas within the Italian territory is quite high (i.e., 141 StPAs), but their cumulative area is low with respect to the land surface of the country, and they are unequally distributed through administrative regions, biogeographic regions, ecoregions and elevation range. Only 5.31 % of the country is presently covered by StPAs (IUCN categories Ia and II), meaning that an additional area of the same extension (around 16,000 km^2) should be added to this network to achieve the 10 % area target of the EU Biodiversity Strategy for 2030 (Cazzolla Gatti et al., 2023). However, two contrasting points should be taken into account when calculating the suggested enlargement: the first point is that large parts of the area here used to calculate the StPAs belong to national parks (IUCN category II), a type of PAs which are not strictly protected over their entire surface, but only within the so-called zone A of the park (which often is classified as Ia). The other zones, in

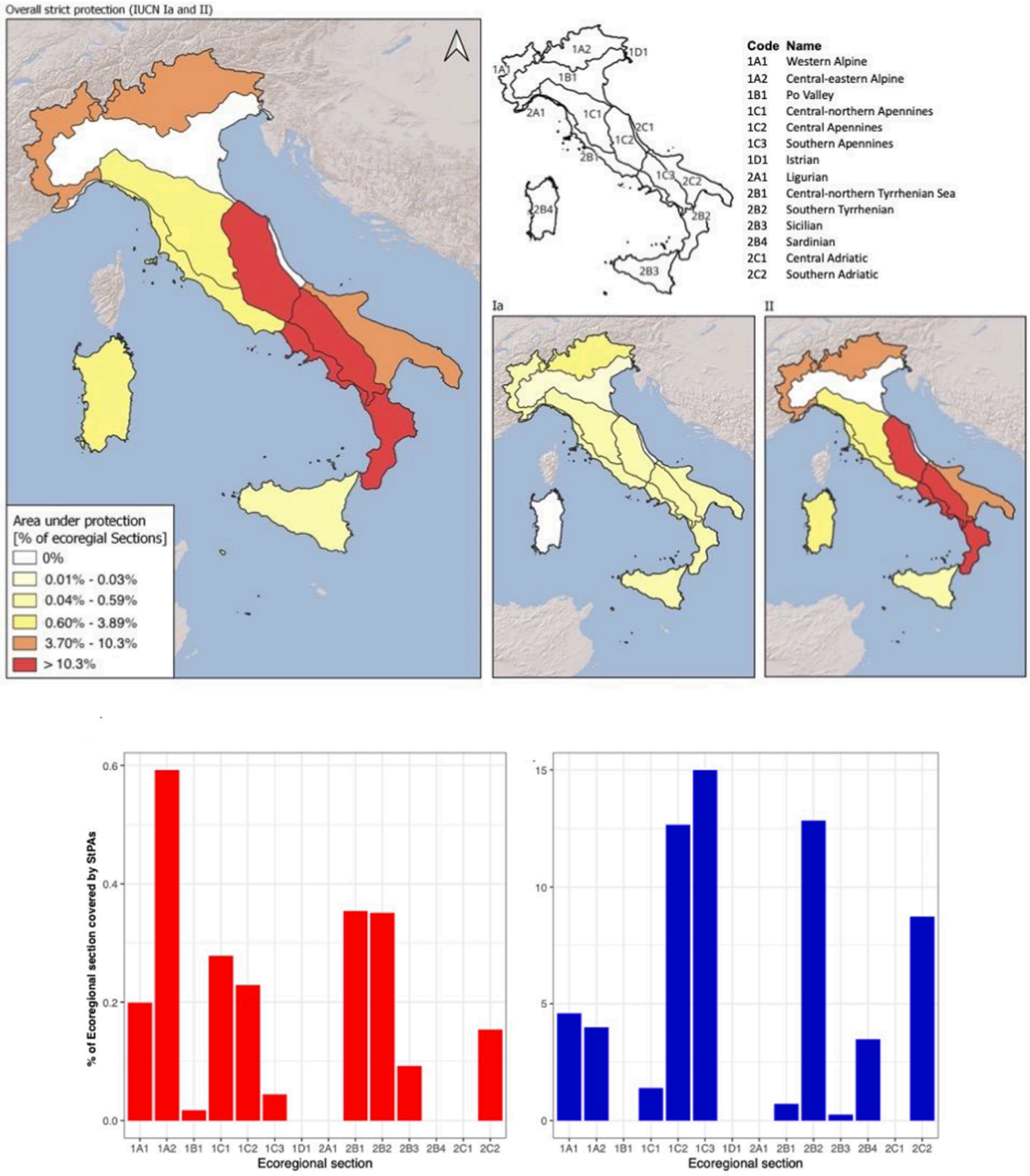

Fig. 4. Percentage of ecoregion sections covered by StPAs: Area under protection (%) is shown for all StPAs in the left panel and for the 2 different IUCN categories (Ia and II) in the right panels. The map at the top right shows the Italian ecoregion sections and the related codes. Barplots of Area under protection (%) are shown for IUCN categories Ia (bottom left) and II (bottom right). See Supplementary Fig. 3 to see the four complete Italian ecoregional levels.

fact, show a lower level of protection and can allow different types of exploitation, such as grazing and forestry management, which are not in line with the indication of IUCN, according to which category II PA should aim to protect the majority of naturally-occurring ecosystem functions. The maintenance of cultural landscapes is certainly important but makes some of these PAs more similar to a category IV. The other point related to the fact that in Italy there is a high number of protected areas established by the regional governments (namely, regional parks and similar) which in some cases are comparable to category II PAs and sometimes include core zones comparable to StPAs of category Ia. The lack of recognition of these PA as national parks and the variety of regional management practices limits the capacity to make country scale analysis. It should be noted that most of the Ia strictly PAs are strict reserves, owned by the state and managed by the Forest carabinieri (https://rgpbio.it/ consulted June 2023), such as the iconic case of the Montecristo island in which the oldest known individuals of *Quercus ilex* are preserved (Filibeck et al., 2023).

4.2. *Area coverage of strictly protected areas across administrative regions, biogeographical and ecological regions*

Though several administrative regions (Abruzzo, Basilicata,

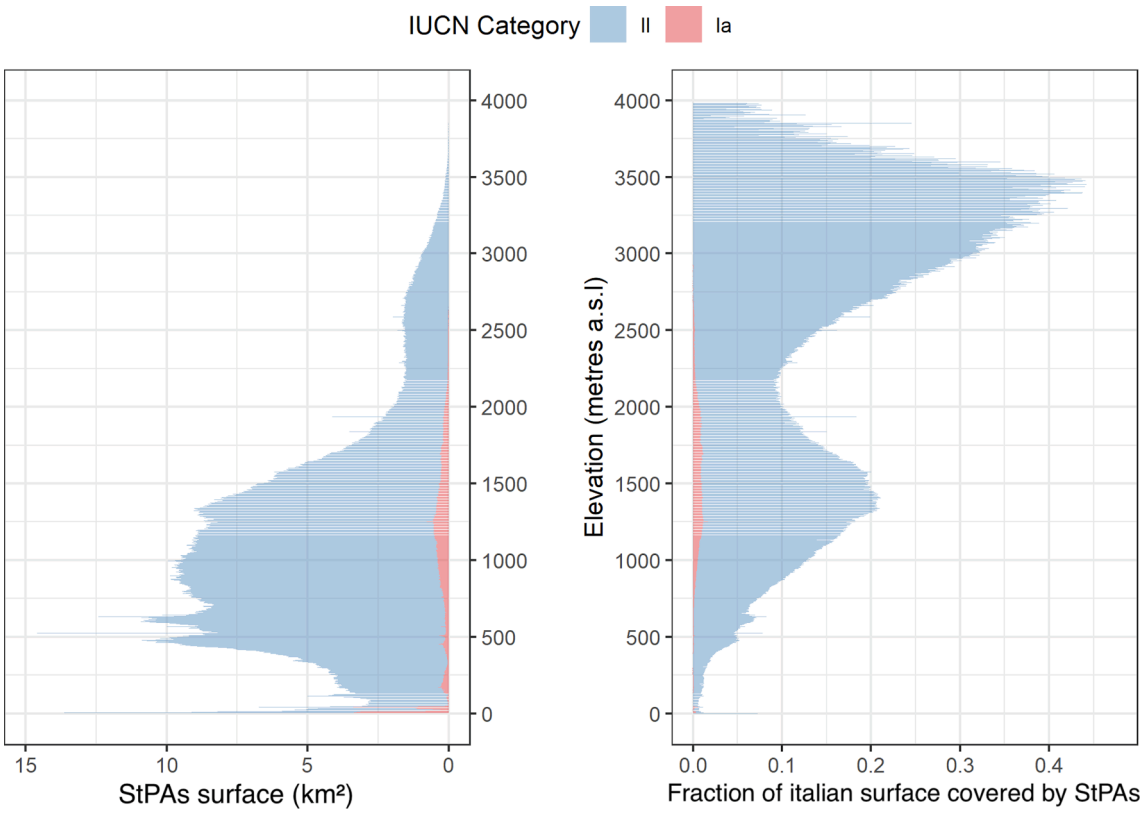

Fig. 5. Distribution of StPAs surface (in km^2) and fraction of the Italian surface area at the related altitude covered by StPAs across the elevation range (in m a.s.l.) for Ia and II areas.

Table 1
Habitats not included in any strictly protected area of category Ia or II:

EU Habitat code	Habitat group	Annex I priority	Description
7120	Bogs, mires & fens	NO	Degraded raised bogs still capable of natural regeneration
9170	Forests	NO	Galio-Carpinetum oak-hornbeam forests
9350	Forests	NO	*Quercus macrolepis* forests
5310	Sclerophyllous scrubs	NO	Laurus nobilis thickets
9120	Forests	NO	Atlantic acidophilous beech forests with Ilex and sometimes also Taxus in the shrub layer (Quercion robori-petraeae or Ilici-Fagenion)
1340	Coastal habitats	YES	Inland salt meadows
9190	Forests	NO	Old acidophilous oak woods with Quercus robur on sandy plains
2330	Dunes habitats	NO	Inland dunes with open Corynephorus and Agrostis grasslands
3110	Freshwater habitats	NO	Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae)

Calabria, Campania, Valle d'Aosta and Puglia) have a relatively high level of land area protected as STPAs, all the other regions display very limited protection, with the regional cover of StPAs far below the 10 % target. Moreover, except for Veneto, all regions of Italy show less than 1 % of the area protected by PAs of category Ia. This suggests a certain imbalance of representativeness between the two categories across regions.

However, this different representation may be consistent with some characteristics of national parks, which make them easier to establish and more accepted by the population, such as, for example, the presence of many areas in which it is permitted to build, cultivate, raise livestock, keep pastures, fishing, forestry activities, etc. In fact, as already mentioned, the level of protection in national parks is different from that in areas Ia, with many management activities (e.g., hunting, agriculture, forestry, building) often allowed in non-core zones. It is therefore obvious that the amount of area covered by many national parks is not comparable, in terms of protection to that achieved by the StPAs that are dedicated to the conservation of natural processes.

At the biogeographical scale, all three Italian biogeographical regions show less than 10 % of their surface strictly protected. Only the Alpine region shows the highest percentage of protection (i.e., 8.77 % of the relative area), while the least protected is the Continental one (i.e., 2.16 % of the area). The high value recorded for the Alpine area can be explained by the characteristics of this biogeographical regions: due to the harsh climate, access difficulties and short vegetative periods, the mountain ranges have always been sparsely populated and not subject to intensive agriculture. As a result, there were many free spaces left in which to establish larger protected areas at the opposite of the Continental biogeographic region, in which the overexploited and highly anthropized Po Valley has left no much space for wilderness. Finally, the Mediterranean region is part of one of the world's biodiversity hotspots (Hrdina & Romportl, 2017) but, despite the high number of StPAs present in there (i.e., 84 out of 141), it is scarcely protected (i.e., 5.58 % of the relative area), especially regarding the major islands (Sicily and Sardinia) and the smaller archipelagos. The situation changes when considering only StPAs of category Ia. in this case the mediterranean region results the most protected (1,32 % of the relative area) due to the high number of areas, the alpine and the continental region results less protected with 0.57 % and 0.13 % of the relative area under Ia StPAs, respectively. The difference between biogeographical regions ranking when considering both Ia and II StPAs or only Ia is may be attributed to

Table 2
Number of species in various taxonomic classes in Italy, categorized according to their IUCN global Red List status.

	DD	LC	NT	VU	EN	CR	EW	Tot. species
ANDREAEOPSIDA	1	0	0	1	0	0	0	2
BRYOPSIDA	5	15	2	8	4	1	0	35
JUNGERMANNIOPSIDA	0	3	0	1	0	2	0	6
LILIOPSIDA	13	230	20	13	17	5	0	298
LYCOPODIOPSIDA	0	2	0	1	0	3	0	6
MAGNOLIOPSIDA	17	250	29	13	18	20	0	347
MARCHANTIOPSIDA	0	0	0	1	0	0	0	1
PINOPSIDA	0	9	0	0	0	1	0	10
POLYPODIOPSIDA	1	9	4	0	1	0	0	15
ACTINOPTERYGII	2	85	5	9	6	8	1	116
PETROMYZONTI	0	4	0	0	0	0	0	4
AMPHIBIA	0	29	1	5	5	3	0	43
MAMMALIA	2	104	9	10	5	1	0	131
REPTILIA	2	37	6	3	1	2	0	51
Percentage (%)	4.04	72.96	7.14	6.1	5.35	4.32	0.09	1,065

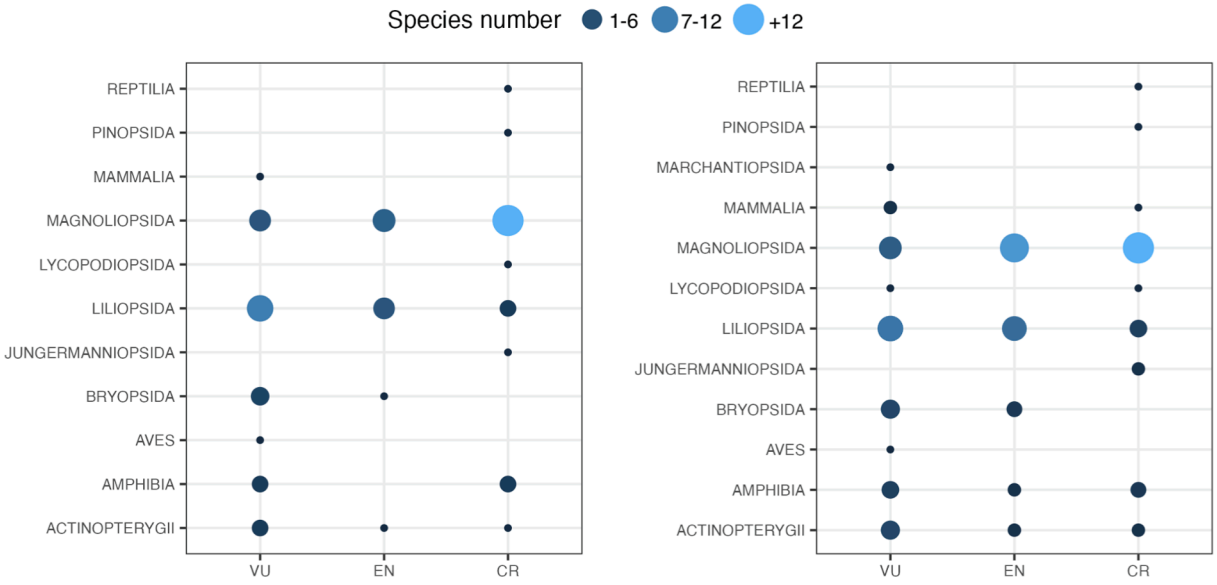

Fig. 6. Number of species and categories of risk of IUCN Red List species excluded from strict protection from both category Ia and II (left), and for category Ia only (right) in Italy per taxonomic group. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the characteristics of the Mediterranean region: being both a biodiversity hotspot and a productive region establishing a high number of small StPAs is probably the best strategy in terms of conflict avoidance. These results lead us to suggest that more attention must be paid to the strict protection of the Mediterranean and Continental biogeographical regions and Italian lowlands but with consideration of the peculiarities of those areas.

Similarly, regarding ecoregions our findings show that the distribution of strict protection is not homogeneous across the most detailed levels: sections and subsections.

Out of the 14 sections four presents either a total lack of StpAs or a coverage under 0.05 % (Supplementary table 1), Such sections are located in plain and densely populated areas of the country and two of them (i.e., 2C1 Central Adriatic, 1B1 Po valley) are of particular concern as highlighted as environmentally fragile (Mastronardi et al., 2022). If referring to the areas Ia only the number of sections that doesn't reach 0.05 % of protection increases to six.

Looking at the most detailed level we identified six out of thirty-three subsections with a surface under strict protection exceeding 10 % as well as seven completely unprotected by any StPAs and 12 unprotected by any Ia area (supplementary table 1) to which more attention should be devoted for strict conservation in the years to come.

4.3. Bias in the distribution of strictly PAs across the Italian elevation range

The biases detected in the distribution of StPAs at the regional, biogeographical and ecoregional levels are not the only ones. In fact, a non-homogeneous distribution has also been recorded across the entire Italian altitudinal range. Italy has a heterogeneous altitudinal profile, which includes the mountain chains of the Alps and the Apennine, as well as the extensive Po Valley. The mean altitude value was found to be 537 m a.s.l. and our analyses show that the StPAs are not distributed homogeneously across this range. In fact, strictly protected areas are more frequent at medium–high altitudes, with a slight peak of Ia areas in low-altitude locations. It is evident that StPAs concentrate at high elevations due to higher biodiversity of these areas related to the lower human pressure compared to highly anthropized areas at low altitudes in which establishing a StPA may create conflict with human activities insisting on the territory. The result is consistent with numerous studies (Barr et al., 2011; Margules & Pressey, 2000), which show that PAs networks and IUCN category I and II in particular (Joppa & Pfaff, 2009) are located at higher elevations and far from anthropized, productive areas.

This is illustrative of the fact that the StPAs within national borders fail to protect a representative portion of lowland Italian biodiversity

and habitats, which consequently remain exposed to greater direct and indirect anthropic impacts (e.g., fragmentation and degradation of habitats, and land use change).

4.4. Habitats and threatened species not strictly protected in Italy

According to the IV Italian Report (2013–2018) of the Habitats Directive, in Italy there are 132 habitats and our analysis shows that most of these (i.e., 122) are protected by at least one area of category Ia or II. However, nine terrestrial habitats (and one partly marine), including one priority habitat (i.e., 1340 Inland salt meadows), are excluded from strict protection. Although the habitats that are not strictly protected are fewer than those conserved within StPAs, they still do need attention to preserve the important ecological and biodiversity role they play. In order not to negatively impact and/or lose the important ecological processes and species typical of these habitats, in the coming years it will be needed to implement actions towards their inclusion under a rigorous level of protection, particularly because habitat quality is found to be sensitive of protection level (Sallustio et Al., 2017) and in consideration of the EU2023 target.

Similarly, among the species evaluated in the IUCN Red Lists, we found that 3 critically endangered and 3 vulnerable species of amphibians, one critically endangered reptile, 3 vulnerable, one endangered (*Hucho hucho*) and one critically endangered (*Thymallus aeliani*) freshwater fish species, one vulnerable mammal, one vulnerable bird species (*Clangula hyemalis*), and 20 vulnerable, 14 endangered, and 21 critically endangered plant species are not strictly protected. We found that the most strictly protected taxonomic group is that of plants, whose good conservation status, among other factors, largely depends on the establishment and presence of protected areas, while for vertebrates the effect of StPAs is less direct. For instance, for the most threatened group of vertebrates, the amphibians, the mere establishment of protected areas seems insufficient to improve their conservation status, since we found high-risk categories even within the PAs. Our results confirm what was already observed by D'Amen et al. (2011) who assessed the efficacy of the whole Italian PAs network in protecting amphibians.

Moreover, the poorly strictly protected Mediterranean area, in which Italy is located, represents one of the global biodiversity hotspots and among the threatened species analyzed, many of these are Italian endemisms, often with distribution ranges restricted to one or a few small localities.

Our results confirm the need for more attention on the needs of threatened species when establishing new StPAs, i.e., by targeting areas with concentrations of threatened species even in low elevation agricultural landscapes (Venter et al., 2018).

4.5. Limitation of the methodology and future perspective

We acknowledge that some data used in this study have not a high resolution and lack some details. In particular, the distribution ranges of Red List species available from the IUCN database may contain some missing records or report species distribution on a larger scale than real. Similarly, the best available resolution for the habitat distribution map (which is the one we used) has a 10 km spatial resolution. This not very detailed resolution can constitute a source of overestimation of species and habitat distribution ranges. However, both datasets are the best available at the moment and represent the most updated scientific knowledge so far before new, more defined products (e.g. the expected maps of the Associazione Teriologica Italiana, ATIt, or finer resolution national habitat maps), will be available.

In this study we focused our attention to Italy where the system of environmental protected areas is formed by the integration between the protected areas, regulated by the national framework law (L. 394/91) and listed in the official list (i.e., "VI Elenco Ufficiale delle Aree Naturali Protette", EUAP), and sites belonging to the Natura 2000 network. Both the EUAP and Natura 2000 areas are listed in The World Database on Protected Areas (WDPA) which includes the IUCN classification of each listed PA, making it a powerful tool for research (UNEP-WCMC, 2019). However, the level of protection is highly variable across PAs and, to achieve the goal of 10 % PAs in Europe, an analysis of what can be considered strictly protected is needed across political and biogeographical partitions of the national territory. In this regard, it should be emphasized that Man and Biosphere and regional reserves include core areas of strict reserve not yet classified as such in the databases we used.

Due to limitations in data sources and legal definitions of StPAs, although detailed spatial tools for ecological classification of the national territory are available, before the present study, assessments of the representativeness of the Italian territory from a multi-scale perspective (i.e., bioregional, ecoregional) of StPAs, and the Italian network contribution to broader scale species conservation objectives (particularly for the EU 2030 biodiversity strategy) was lacking. With the current analysis, our goal is to lay the first stone, even if still rough, to build a structure of more detailed knowledge that will guide the national conservation policies towards EU27 biodiversity strategy.

5. Conclusions

The present analysis shows how the distribution of StPAs across administrative regions, biogeographical regions, ecoregions as well as altitude, temperature, and precipitation ranges, is extremely unbalanced across the whole national territory. In many cases, the surface of StPAs does not reach the 10 % of the relative surface of the analyzed geographic level (i.e., administrative regions, bio-ecoregions), and consequently they are still very far from reaching the European 2030 Biodiversity targets (i.e., protect at least 30 % of the land and sea surface of each Member State, allocating a one-third of this to a rigorous level of protection). Moreover, we found that about 85 threatened species reported in the IUCN Red List as critically endangered, endangered, and vulnerable have a distribution in national areas not strictly protected. This evidence, together with the fact that category II areas (National Parks) are considered strictly protected but the zoning of their territory according to the national legislation is not everywhere effectively strict because a wide range of anthropic activities is often permitted, calls for urgent legislative actions for an effective nature conservation policy at country level. For instance, there is an urgent need to promote a law for the establishment of strict reserves and also to give national parks a new profile in nature conservation in implementation of the operational principles and criteria of the IUCN category IIa.

In order to respond to the EU Biodiversity Strategy to 2030, this analysis aims to provide the best available updated picture of the current Italian situation, laying a useful basis for further studies and conservation planning actions in order to meet the need to expand the network of strictly protected areas of our country.

CRediT authorship contribution statement

Roberto Cazzolla Gatti: Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Jacopo Iaria:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Gloria Moretti:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Valerio Amendola:** Data curation, Formal analysis. **Francesca Maura Cassola:** Writing – original draft, Writing – review & editing. **Pierfilippo Cerretti:** Visualization, Writing – original draft, Writing – review & editing. **Michele Di Musciano:** Supervision, Visualization, Writing – original draft, Writing – review & editing. **Luana Francesconi:** Visualization, Writing – original draft, Writing – review & editing. **Anna Rita Frattaroli:** Visualization, Writing – original draft, Writing – review & editing. **Martina Livornese:** Visualization, Writing – original draft, Writing – review & editing. **Matilde Martini:** Visualization, Writing – original draft, Writing –

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We are grateful to the European Union - NextGenerationEU through the Italian Ministry of University and Research under PNRR - M4C2-I1.4 Project code: CN00000033, Title: NBFC - National Biodiversity Future Center, CUP: J33C22001190001, CUP: J83C22000860007, and CUP B83C22002950007.

Funding

This research has received funding from the Italian Ministry of University and Research (MUR) under the PRIN Project entitled “Identification of priority sites for the conservation of terrestrial animal and plant diversity to meet European and CBD 2030 targets” 2022C8E2F4_001 - CUP J53D23006530006.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2024.126621.

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