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Towards the application of EU Habitats Directive to a non-EU country: the case of San Marino

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ABSTRACT

In the European Union, biodiversity conservation is guided by the Birds Directive and the Habitats Directive (HD), which provided the foundational policy for Natura 2000, the World's largest coordinated network of protected areas. The Republic of San Marino, a European non-EU microstate enclaved within Italy, has ratified the UN Convention on Biological Diversity, but does not have a formalised area-based conservation strategy. In this study we test the adoption of the HD to the Republic of San Marino, by producing a formalised list of habitat types and a map of their distribution. We created a list of potential habitat types present in the country by extracting those located in a 10 km radius of the Italian prtoected areas surrounding San Marino. To verify their presence in the country, we actively surveyed vegetation plots in the period 2019–2022. We used non-metric multidimensional scaling to provide an ordination of the plots and analyse gradients in habitats at the country scale. We confirmed the presence of 9 habitat types and excluded 22 additional types. Despite the relatively small cover of confirmed habitat types (2.71 km^2; 4.4 % of the country territory), some of them are quite rare in the surrounding areas, highlighting the importance of local conservation measures and integration of the San Marino policy with Italian policies. The adoption of HD by non-EU states such as the Republic of San Marino could be a simple but valuable step to develop an area-based conservation strategy at the country level, aligned with the surrounding context.

1. Introduction

Conserving biodiversity is an urgent concern, given the multiple human pressures on natural habitats (IPBES, 2019), leading to consistent decline and extinction of species' populations (Briggs, 2017; Dirzo et al., 2014; Hallmann et al., 2017). Although the efficacy of some conservation actions has been questioned (e.g. Chen et al., 2023), protected areas remain a key measure to guarantee the persistence of many species, and to limit human impacts on natural habitats (cfr. e.g. CBD, 2020; Maxwell et al., 2020).

In the European Union (EU), biological conservation is guided by the Birds Directive (BD; EC, 1979) and the Habitats Directive (HD; EC, 1992). Whereas BD has a specific conservation focus on birds, HD aims at preserving natural habitats and wild fauna and flora in the EU territory. Moreover, with HD the EU introduced the valuable concept of conservation at the habitat rather than at species level, ensuring protection even for taxa not indicated in its annexes (see e.g., Chiarucci et al., 2008; Evans, 2012; Spiliopoulou et al., 2020).

According to HD, member countries set out Sites of Community Importance, which are converted into Special Areas of Conservation (SACs) once they are legally recognised. The site selection is based on the presence of one or more habitat types or species, indicated in annexes I and II respectively. The term "habitat type" in the context of the HD means an area where biotic and abiotic factors are constant and ecological conditions remain uniform (EC, 1992). As a consequence, habitat types can be mapped (Angelini et al., 2016) and identified on the basis of typical species (Bonari et al., 2021), i.e. species exclusive of peculiar vegetation units (Evans & Arvela, 2011). To assist in the identification and classification of habitat types, the European Commission (EC, 2013) has provided a European interpretation manual, which has been adapted locally by some nations (Evans, 2010), with Biondi et al. (2010) proposing the Italian version. Each habitat type is given a 4-digit unique code, marked by an asterisk to indicate the habitat should be prioritised (e.g., 6110* - Rupicolous calcareous or basophilic

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grasslands of the *Alysso-Sedion albi*).

BD and HD led to the creation of Natura 2000 (N2K), a network of protected areas outlined in accordance with the two EU Directives, constituting the Union response to the Council of Europe's (CoE) Bern Convention (Council of Europe, 1979). N2K has proven to be an effective way to standardise the site selection process across different countries and biogeographical regions, as well as to manage them accordingly (Campagnaro et al., 2019). Recent evidence also suggests its efficacy in safeguarding the biodiversity of some biological groups (Ricci et al., 2024). This network extends to the territories of the 27 EU Member States on 767,885 km^2 of land area (EEA, 2024) and it is the World's largest network of this type (EC, 2024a). Outside the EU, the Emerald Network of Areas of Special Conservation Interest (Council of Europe, 1989) gathers the sites outlined in accordance with the Bern Convention, constituting a complementary network to N2K.

To date, few non-EU European countries are not hosting Emerald Network sites. Some of them (namely, Albania, Bosnia and Herzegovina, Iceland, Montenegro, North Macedonia, and Serbia) are waiting for the adoption of their official candidate sites (Council of Europe, 2024), whereas others (namely Monaco, San Marino, Turkey, and Vatican City) have not joined the network yet. The Republic of San Marino joined the CoE in 1988 (Council of Europe, 1988) as the 22nd member state, but nevertheless it did not ratify the Bern Convention, taking part in its standing committee as an observer. In 1995 it ratified the Convention on Biological Diversity (UNEP, 1992), while, in recent times, began negotiations for an association agreement with the EU (Council of the European Union, 2014), which arrived at a conclusion in late 2023 (EC, 2024b).

Promoting conservation measures in accordance with continental guidelines could be beneficial for San Marino, aiding its ongoing internationalisation process. Moreover, given its enclaved position within the territory of Italy, a full member of EU, adopting the Habitats Directive would be fruitful to align the area-based conservation policy of San Marino within the frame of EU and Italy actions. Up to now, this approach has never been formally explored.

With this study, we propose for the first time the application of Habitats Directive guidelines to the Republic of San Marino, a non-EU country. By providing the list of habitat types found in the small country, together with their distribution, we pursue to aid conservation actions within it and to set a reference for other non-EU states to set out protected areas according to the Habitats Directive.

2. Methods

2.1. The study area

The Republic of San Marino is a European microstate, enclaved in central Italy, between the administrative regions of Emilia-Romagna and Marche (Fig. 1a), with a surface area of 61.19 km^2 and a minimum distance of around 10 km from the Adriatic coastline.

Large part of the territory is occupied by clay sediments on middle slope hills and has an active human use as cropland (41 %) or hosts artificial surfaces (20 %; Santolini, 2009). Badlands are also present (4 %), as a result of deforestation and soil overexploitation during the past centuries (Suzzi Valli, 1993). In the south-eastern part of the territory, several calcareous outcrops lay on the silt sediments (Fig. 1b), leading to the occurrence of cliffs, with the Mount Titano reaching the maximum altitude (738 m a.s.l.). The harshness of some of these sites has also enabled the persistence of natural habitats, such as small patches of woodlands, rocky vegetation, xeric grasslands. Gypsum sediments are also present in some locations (Guerra, 2008), hosting distinctive vegetation types.

Pesaresi et al. (2017) defined the temperate macrobioclimate for San Marino, with mean monthly temperature ranging from 4.1 °C (January) to 23.5 °C (July and August) in the 1991–2011 period. There was also a trend of increasing temperature over this period (Guerra, 2012). Mean annual precipitation was 767.3 mm in the 1990–2011 period, with winter and summer as the driest seasons. Cumulative values for

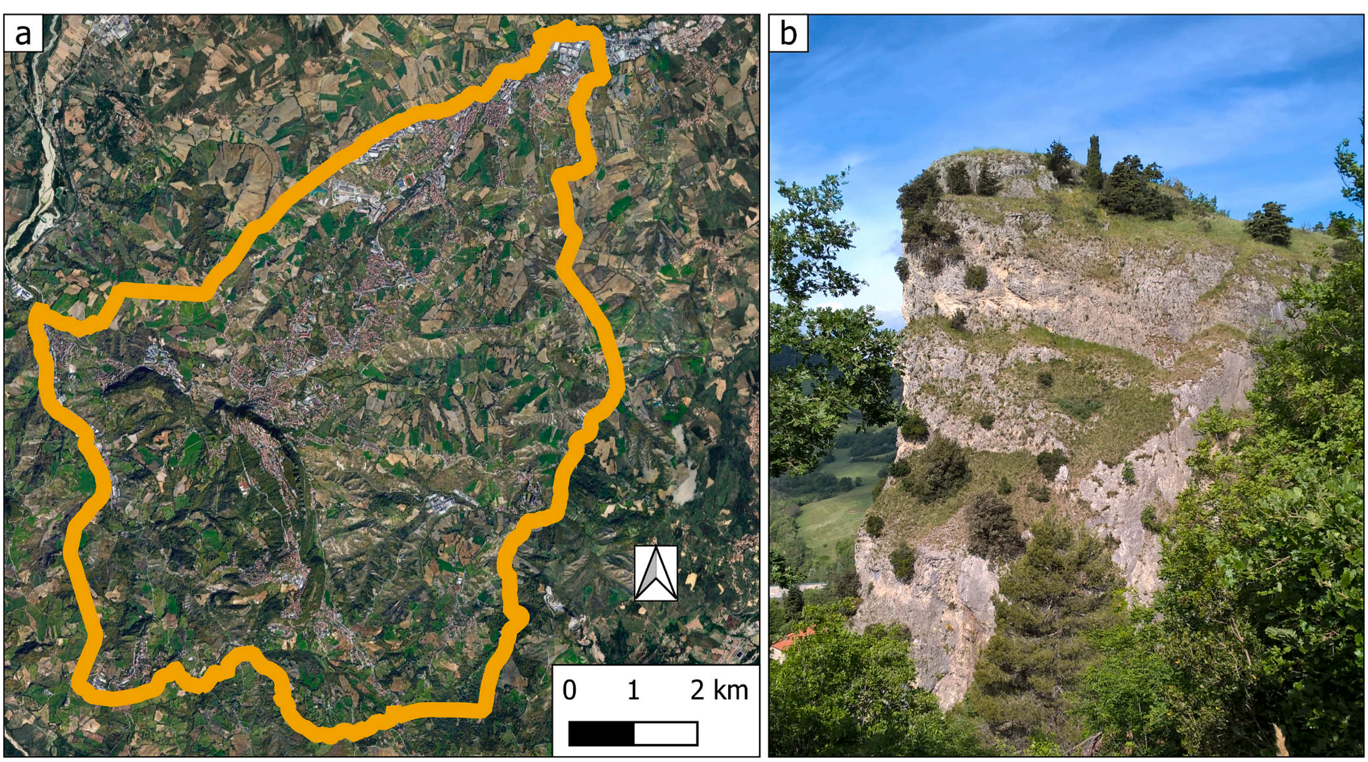

Fig. 1. a) A satellite image of the territory of the Republic of San Marino (gold boundary). The heterogeneous colours of land cover underline the high degree of human transformation of the territory. Map lines delineate study area and do not necessarily depict accepted national boundaries; b) A view of the Monte Cucco outcrop. Calcareous outcrops are a common geomorphological unit in the Southern part of the territory.

precipitated rain are decreasing, as are snowfalls (Guerra, 2012).

Despite the reduced size of the country, San Marino's vascular flora is particularly rich in species, with almost 1,000 taxa found in recent times (Alessandrini et al., 2022; Bruschi et al., 2024). Several taxa have a notable biogeographical interest, e.g. *Ephedra nebrodensis*, with its northernmost location in the Italian peninsula (Pignatti et al., 2017–2019), *Ulex europaeus*, *Brassica montana*, or Italian endemics such as *Crocus biflorus*, *Erysimum pseudorhaeticum*, and *Artemisia caerulescens* subsp. *cretacea*.

Biondi & Vagge (2004) outlined the main vegetation types, which include *Quercus pubescens* woods, xeric grasslands, and rocky vegetation.

2.2. Study design

As a starting point to look for habitat types potentially present in San Marino, we selected the 8 SACs with borders closer than 10 km to the study area. We then listed the habitat types reported within their perimeter and calculated their frequency in terms of number of sites, to set a probability score in finding such habitat types (*improbable*: 1–2 sites; *scarcely probable*: 3–4 sites, *probable*: 5–6 sites; *highly probable*: 7–8 sites).

We used the spatial resources published in Santolini (2009) as a basis for estimating the spatial distribution of the vegetation types in our study area. Based on our knowledge of the territory, we refined the polygons and selected the vegetation types to be surveyed, to verify the presence of the potential habitat types previously identified. To survey and characterise the vegetation types, we used vegetation plots, according to the common practice adopted for these tasks (e.g., Agrillo et al., 2018).

We selected random points inside polygons as sampling sites, keeping a minimum distance of 20 m from the polygon edges, to avoid edge effects. This threshold of 20 m was chosen due to the generally small surface area of habitat patches which did not enable us to keep a larger threshold distance. During field surveys, we also recorded when we noted some punctual vegetation units potentially attributable to one of the HD types, and not identifiable by satellite images. Moreover, we accounted for any habitat type which can be identified by geomorphological features (e.g., 8310 – Caves not open to the public), by referencing previous literature.

We surveyed a total of 60 vegetation relevés in the 2019–2022 period, by performing (i) 10 m × 10 m squared plots in xeric grasslands and wood stands, (ii) 1 m × 1 m plots for pioneer vegetation on calcareous outcrops and (iii) 5 m × 5 m plots and rectangular plots (2 m × 10 m) for surveying riverside vegetation. We also evaluated the presence of other habitat types not included in the potential list. Spatial operations were carried out using QGIS software (3.30.2 version; QGIS Development Team, 2023). Within each plot, we recorded all vascular plant species (shoot presence), quantifying their cover abundance based on the Braun-Blanquet scale (Braun-Blanquet, 1932). Plant nomenclature followed Pignatti et al. (2017–2019). The data were stored and made available in the AMS-VegBank database (GIVD code EU-IT-021; Alessi et al., 2022).

To differentiate the composition of the surveyed vegetation units, we performed an ordination of all the plot data via a Non-Metric Multidimensional Scaling (NMDS) approach, based on presence/absence data (Jaccard distance), considering the first two dimensions of the ordination. All performed statistical analyses were carried out using R software (4.3.3 version; R Core Team, 2024).

We considered a habitat type as valid for San Marino if at least three different plots were referable to that type. This threshold takes into account both the need for recording some species variability and the reduced extension of natural habitats in San Marino, which limits survey possibilities. However, the threshold was not considered for punctual habitats with clear identity, but not allowing larger samples, such as 7220* – Petrifying springs with tufa formation (*Cratoneurion*). This is also justified by several habitat types being found together in a few square metres or composed in a mosaic with other habitat types or vegetation units, because of their characteristics. We based data comparison on the physiognomic reference composition reported by Biondi et al. (2010) and Emilia-Romagna (2015) for each habitat type. In particular, we qualitatively assessed that at least one of the typical species (Bonari et al., 2021) reported in the manual was present in our plot data. We excluded any potential habitat types that had no supporting evidence for their attribution.

For each identified habitat type, we reported a description sheet that summarised its features in the Republic of San Marino. We also provided a summary for the sampled habitats not associated with a directive's type, and notes for the excluded types.

We finally produced the San Marino habitat map, pointing out the distribution of the identified HD habitat types across the country.

3. Results

We found a list of 30 potential habitat types, summarised in Table S1. 17 habitat types are listed as *improbable* (1–2 frequency score), 5 as *scarcely probable* (score: 3–4), 4 respectively as *probable* (score: 5–6), and *highly probable* (score: 7–8).

We recorded 415 plant taxa, with 398 of them identified at the species or subspecies level (see Appendix 1 for the summary matrix of plot data); the recorded data were also useful to improve the San Marino flora (Alessandrini et al., 2022), since we detected 6 species not previously reported for the country (*Allium ursinum*, *Cleistogenes serotina, Lathyrus setifolius*, *Parapholis incurva*, *Pistacia terebinthus*, and *Vicia loiseleurii*).

NMDS ordination showed a marked distinction among the surveyed vegetation types (Fig. 2), except for *Quercus ilex* woodland which appeared to be inside the xeric grassland group, due to the presence of species linked to open habitats. Grasslands on badlands were highly differentiated from those on calcareous outcrops.

Using the results of the ordination analysis and active search in the field for punctual habitats, we identified 9 HD types for the Republic of San Marino (Table 1; see Appendix 2 for their detailed description) and excluded the other 21 habitat types and an additional one (4030 – European dry heaths; see Table S2 for the complete list, reporting reasons for exclusion). The total area occupied by the identified habitat types reached 2.71 km^2, corresponding to 4.4 % of the country territory. Their distribution map is presented in Fig. S1.

Thermophilous woodlands referred to 91AA* habitat type covered the largest area (Tables 1, S1). They mainly occurred on southern and western exposed sides of calcareous outcrops and were dynamically linked to xeric grasslands of the 6210 habitat type (Fig. S2), as grasslands tend to be colonised by shrub and tree species in the absence of grazing or mowing (Appendix 1). On calcareous outcrops, vegetation was also composed of patches of pioneer rocky vegetation of the 6110* habitat type. Notably, Pennarossa location hosted a *Quercus ilex* wood referable to 9340 habitat type (Fig. S3) which is a valuable vegetation unit, given its rarity in the nearby territories (Table S1; Alessandrini et al., 2022). Other rare habitat types included 3140 – Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp. (Fig. S4) and 7220* – Petrifying springs with tufa formation (*Cratoneurion*) (Fig. S5), whose persistence is directly related to the constant availability of water during the year. We attributed the 6430 habitat type to few patches of riverside vegetation dominated by nitrophilous tall herb communities (Fig. S6), and the 9260 habitat type to old *Castanea sativa* plantations, not actively managed at the present time. Finally, we attributed the 8310 habitat type to the cave systems found within the Mount Titano outcrop (Suzzi Valli, 1993) and we excluded badland vegetation from any habitat type attribution, due to the absence of typical species.

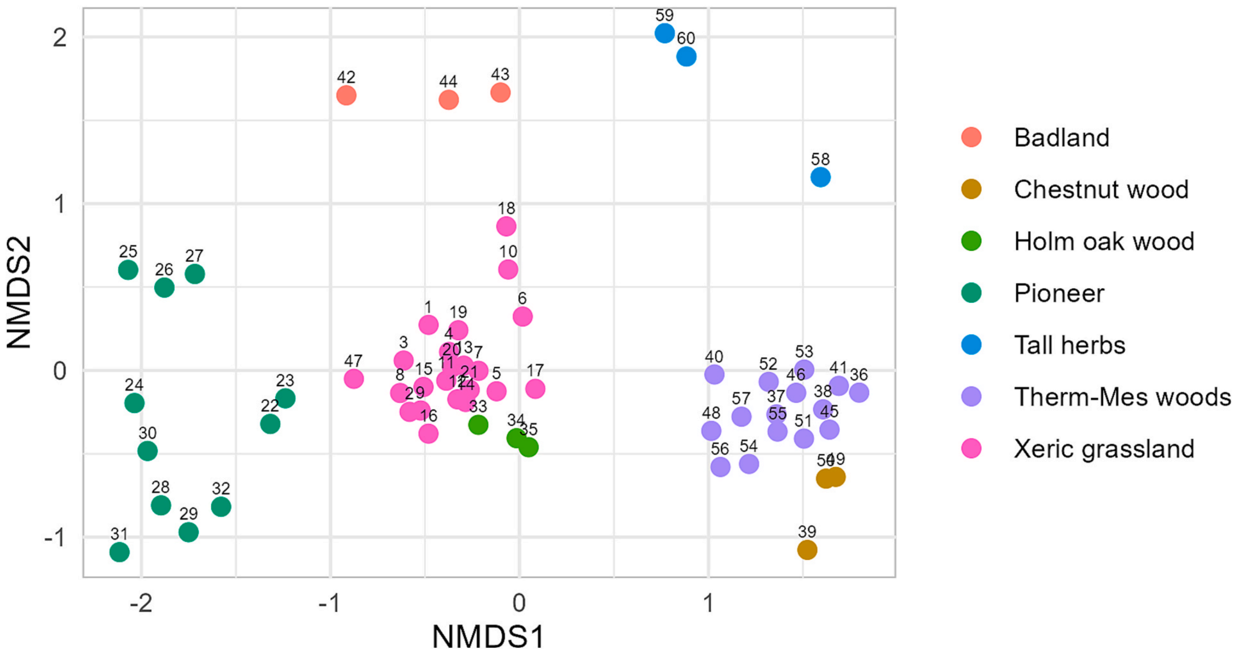

Fig. 2. Non-Metric Multidimensional Scaling (NMDS) ordination of vegetation plot data based on presence/absence data and Jaccard distance. The numbers over each dot represent the plot ID.

4. Discussion and conclusions

This work not only revises the extent of natural vegetation across the landscape of San Marino in view of the HD but is also an important step in the eventual adoption of its policies. Although the total area of natural vegetation in San Marino is relatively small, several of the habitats are classed as rare in the broader region. Alignment of San Marino with the HD will improve conservation outcomes for these rare habitats across the landscape of northern Italy. Moreover, it could represent a simple step for the N2K network to expand its coverage and management to other countries, as well as a simple method for those new countries to plan an area-based conservation approach.

We identified 9 habitat types for the San Marino territory, encompassing 4.4 % of its surface. This number is notably lower than in several neighbouring SACs (Table S1), as a consequence of urbanisation and human disturbance: we recall that 61 % of the territory is covered by agricultural areas or artificial surfaces (Santolini, 2009). Due to the same anthropogenic context, San Marino is unlikely to reach an extension of N2K sites comparable to that of two small EU countries as Malta and Luxembourg, where N2K sites cover 13.3 % and 27.1 % of the land territory respectively (EEA, 2024). Nevertheless, the relevant presence of habitat types rare in nearby SACs (e.g., 3140, 7220*, 9340) underlines the importance of adopting conservation measures, to halt San Marino habitat loss and preserve its considerable species diversity (Alessandrini et al., 2022; Londi et al., 2011; Rezbanyai-Reser et al., 2016; Scaravelli et al., 2015; Tedaldi et al., 2014). The 9 habitat types are also the result of a strict selection, as illustrated before. Since their attribution is widely based on expert assessment (Bonari et al., 2021), we preferred a more selective method, to include only those surely present in the considered territory. Some habitat types that are widespread in the Apennines (5130 – *Juniperus communis* formations on heaths or calcareous grasslands, 6220* – Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*, 6510 – Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis*), etc.), were not listed in this study, despite the fact that their presence could not be excluded *a priori*, given the existence of many of the guide species in the Republic territory (Biondi et al., 2010; Emilia-Romagna, 2015; Alessandrini et al., 2022; Santi et al., 2022). The conservative estimate of 9 habitat types is also justified by the reduced extent of the Republic itself and the notable urban sprawl, which does not allow for habitat patches to extend over large areas as is the case in the less densely populated surrounding landscape. Smaller habitat patches close to urban areas lead to obvious consequences for floristic composition (increase of the edge belt at the expense of the core area), number of relevés which is reasonable to perform to characterise the vegetation in the polygons chosen, and interpretation of the habitats represented by these relevés. Not by chance, many of the other habitats which are plausible for the Republic territory were excluded principally for the absence of the guide species or the typical vegetation (see Table S2), as a probable consequence of the intense landscape fragmentation and human pressure. In the other SACs considered the number of habitat types is surely much higher, but their surface is much less impacted by man's activities, apart from few and circumscribed cases.

Further habitats could also be present in very limited surfaces or inaccessible places (e.g. 8210 – Calcareous rocky slopes with chasmophytic vegetation): in the first case, they are difficult to interpret because of the too small extent, which does not allow the vegetation to develop with a clear syntaxonomical physiognomy; in the other, they cannot be detected for the difficulty to study the flora of these places (rock walls, the sides of a gorge…). Another issue is the notable landscape fragmentation, which frequently causes a mixture of diverse species and habitats in the same place: such a confused situation is often impossible to ascribe to one or more habitat types that is clearly identifiable. Finally, we recall that some particular practices of territory management typical of San Marino, such as the levelling of badlands, prevented the probable formation of some habitat types common in the Northern Apennines, like 5130 or 6220* (cfr. Emilia-Romagna, 2015).

Concerning habitat 9260, we attributed to this type the relevés performed in Monte Carlo and Montecerreto because of the presence – although declining – of mature individuals of *Castanea sativa* and other arboreal species listed by Biondi et al. (2010), such as *Acer campestre*, *A. obtusatum*, *Carpinus betulus*, *Fraxinus ornus, Sorbus torminalis*. The latter, in many cases, are linked to the abandonment phase of the chestnut stands and to their consequent natural recolonisation by species typical of the natural forests which were artificially substituted by these orchards (cfr. Biondi et al., 2010; Pezzi et al., 2020).

A methodological clarification is needed: in the final list we retained only the habitats for which at least three concurrent relevés were

Table 1
List of the habitat types outlined for the Republic of San Marino, with indication of the diagnostic species found for each habitat type and their surface extension.

Code	Title	Diagnostic species found	Surface area
3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.	*Chara vulgaris*	105 m^2
6110*	Rupicolous calcareous or basophilic grasslands of the *Alysso-Sedion albi*	*Catapodium rigidum, Cerastium pumilum, Cerastium semidecandrum, Draba verna, Minuartia hybrida, Orlaya grandiflora, Saxifraga tridactylites, Sedum album, Sedum sexangulare, Trifolium scabrum*	468 m^2
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)	*Allium sphaerocephalon, Anacamptis morio, Anthyllis vulneraria, Bromopsis erecta, Asperula purpurea, Brachypodium rupestre, Centaurea deusta, Centaurea scabiosa, Eryngium amethystinum, Erysimum pseudorhaeticum, Festuca inops, Helianthemum appenninum, Hippocrepis comosa, Orchis purpurea, Phleum hirsutum* subsp. *ambiguum, Salvia pratensis, Sanguisorba minor, Scabiosa columbaria, Trifolium ochroleucum*	0.17 km^2
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	*Epilobium hirsutum, Eupatorium cannabinum, Ranunculus repens, Petasites hybridus, Thalictrum lucidum*	550 m^2
7220*	Petrifying springs with tufa formation (*Cratoneurion*)	*Cratoneuron filicinum*	36 m^2
8310	Caves not open to the public	Habitat attribution based on the presence of caves, rather than on diagnostic species	NA
91AA*	Eastern white oak woods	*Asparagus acutifolius, Carpinus betulus, Cornus sanguinea, Crataegus monogyna, Emerus major, Fraxinus ornus, Hedera helix, Ligustrum vulgare, Ostrya carpinifolia, Quercus pubescens, Rosa sempervirens, Rubia peregrina, Viola alba* subsp. *dehnhardtii*	2.43 km^2
9260	*Castanea sativa* woods	*Acer campestre, Acer obtusatum, Anemone trifolia, Carpinus betulus, Castanea sativa, Corylus avellana, Fraxinus ornus, Quercus cerris, Rubus hirtus, Ruscus aculeatus, Sambucus nigra, Sorbus torminalis, Viola reichenbachiana*	0.068 km^2
9340	*Quercus ilex* and *Quercus rotundifolia* forests	*Cyclamen repandum, Phillyrea latifolia, Quercus ilex, Rubia peregrina*	0.033 km^2
		Total surface	**2.71 km^2**

available. This threshold is obviously low, but justified by the already mentioned high landscape fragmentation typical of San Marino: in various cases, it was not possible to perform many relevés in the polygons chosen, nor was it possible to change the polygons searching for better results. The latter fact was due to both the limited extent of the Republic territory (the polygons analysed were often the only ones available) and the sampling method adopted, which takes into consideration the former habitat classification by Santolini (2009). The method itself can be regarded as a mixed one: reasoned (opportunistic) choice of the areas to be analysed, wherever possible, but random choice of the points where to perform the vegetation relevés. Given the particular characteristics of the San Marino territory (intense urban sprawl, intense human impact, intense land use), a random choice of the polygons would likely lead to an underestimation of the number of habitats, for the increased probability to sample an area whose vegetation is not clearly ascribable to a HD type. Therefore we preferred this mixed sampling method.

On the basis of this survey, we recommend to design one or more protected areas that could be assimilated to N2K sites in EU countries to manage the mentioned habitats, according to the same (or similar) policies adopted in EU countries. In addition, since several habitats have a dynamic development which can be accelerated by land use and climatic change, management plans specifically aiming at maintaining the formerly existing situation could be unrealistic. Therefore an initiative to support habitat connectivity and natural dynamical processes, as it is done in national parks, could be planned to contribute to the strict protection of 10 % of area (Cazzolla Gatti et al., 2023).

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CRediT authorship contribution statement

Francesco Santi: Writing – original draft, Investigation, Data curation, Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Fabrizio Buldrini:** Methodology, Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Luca Di Nuzzo:** Investigation, Writing – review & editing. **Riccardo Santolini:** Writing – review & editing, Resources. **Alessandro Chiarucci:** Writing – review & editing, Methodology, Supervision, Conceptualization.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2025.127060.

Data availability

Data are stored in the AMS-VegBank database (Alessi et al., 2022) and made available upon request. The summary matrix with presence/absence data and site locations can be found in Appendix 1.

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