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ORIGINAL PAPER

Will natura 2000 european network of protected areas support conservation of Southwestern Alps endemic flora under future climate?

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Abstract
Networks of protected areas (PAs) are globally recognized as playing a key role for in situ conservation of species. Despite a high potential for biodiversity conservation, PAs may not mitigate the current biodiversity loss because they do not consider climate change impact. In fact, because PAs have static geographical boundaries, they may hardly keep pace with dynamics in species distribution caused by the climate change, which was not considered when they were designed. In this study, we used species distribution modelling of 85 plant taxa endemic or subendemic to Southwestern Alps to evaluate the effectiveness of PAs network in protecting endemics under future climate change scenarios. PAs cover roughly the 30% of the Southwestern Alps. PAs will harbour more expected distribution range of taxa in the future than today, probably because they occur in high altitude areas rich in endemics that have been climatically stable areas in the past and that will likely remain relatively climatically buffered in the future. Moreover, PAs are distributed to poorly cover expected range of endemics at low and middle elevation, which are threatened by urbanization and climate change. We recommend additional protection at low and middle elevation, considering the future climatic suitability of species.

Keywords Biodiversity conservation · Management effectiveness · Protected areas designation · Representation · Species distribution models

Introduction

The networks of protected areas (PAs) are globally recognized as playing a key role for in situ conservation of species (Watson et al. 2016), provided that they have adequate conservation plans and budget to implement their actions (Hochkirch et al. 2013). In recogni-

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tion of the central role of the PAs in biodiversity conservation, species protection policy in Europe is mainly based on the Natura 2000 PAs network. This conservation network is one of the most important and largest in the world and currently it stretches over the 18% of the European Union land areas (European Environment Agency 2021). The Natura 2000 PAs network has been designated to protect habitat types or core areas for several endangered, vulnerable, rare or endemic species. Even if most of the land remains privately owned, the States assure that the sites are managed in a sustainable manner, both ecologically and economically. To date, over 1.000 animal and plant species and 200 habitat types are protected by the Natura 2000 PAs network. Moreover, the United Nations Convention on Biological Diversity and the European Commission proposed to increase conserved terrestrial areas from the current 18–30% by 2030 (European Commission 2020; Convention on Biodiversity 2020).

In general, studies aimed at investigating the effectiveness of the Natura 2000 PAs designation concluded that, with a few exceptions, the PAs cover a high amount of areas important for conservation of species and they harbour a high biodiversity (Maiorano et al. 2015; van der Sluis et al. 2016; Jung et al. 2021; Salmerón-Sánchez et al. 2021; Xu et al. 2022). However, despite this potential for biodiversity conservation, the PAs seem not to mitigate the current biodiversity loss (Rada et al. 2019). The PAs aim at curbing threats such as the infrastructure development, habitat and species loss, and the competition with invasive species. However, worldwide studies aimed at assessing the effectiveness of the PAs detected several limitations, such as: the inadequate managing and funding; the lack of consistent legislation; and the non-consideration of climate change impact (Leverington et al. 2010; Cao et al. 2015; Elsen et al. 2020). The environmental representativeness of the PAs may be biased because they are often disproportionately located in few environments less affected by anthropic activities, reducing the array of environmental conditions covered by them and, in turn, the potential for species to track change in environment (Joppa and Pfaff 2009; Elsen et al. 2020). Moreover, because the PAs have static geographical boundaries, it may be hard to keep pace with the dynamics in species distribution caused by climate change, which was not taken into account when they were designed (Heywood 2019). Species might move out of the PAs due to range shifts caused by climate change, jeopardizing their effectiveness in protecting those species for which they were originally designed (Hole et al. 2009). Nevertheless, newly suitable areas may favour the shift of other species within the PAs (Berteaux et al. 2018). For this reason, even if the PAs are expected to lose some populations and species, they will likely continue to accommodate several species, which will be shifting their distribution (Thomas and Gillingham 2015). As a whole, the networks of the PAs might facilitate range shifts, assuring protection of many species within the network despite a shift in species composition in the single PA (Lehikoinen et al. 2019).

Consequently, despite some failings, the PAs remain overall the best currently available tool to overcome the threats causing biodiversity loss (Rands et al. 2010) and the worldwide commitments to increase the percentage of protected territory provide opportunities for filling gaps in the current PAs networks. Knowledge about the potential shifts in species' ranges is required to inform conservation management and policymakers and to support appropriate decision-making (Hannah et al. 2007; Rannow et al. 2014). In particular, studies aiming at assessing the effect of future climate by utilizing modelling approaches are needed to enhance the assessment and realization of the conservation potential of Natura 2000 network (Orlikowska et al. 2016).

The Southwestern Alps (hereafter SW Alps) provide an ideal study area to evaluate the effectiveness of PAs in protecting species under projected climate change scenarios. The SW Alps, located at the crossroads of the Mediterranean Basin and the Alps, are the richest centre of endemic plants of the European Alps (Aeschimann et al. 2011a) and one of the main hotspots of biodiversity in the Mediterranean basin because of the high number of species and endemics (Medail and Quezel 1997). They harbour more than 150 endemic and subendemic taxa (i.e., taxa present mainly in the study area but also in neighbouring areas; Aeschimann et al. 2011b). This richness is mainly due to the high local climatic heterogeneities, as a consequence of the close proximity of the Mediterranean and Alpine climates, and the high topographic heterogeneity (Casazza et al. 2005, 2008, 2016; Fauquette et al. 2018), resulting in a complex biogeographical history (Casazza et al. 2005, 2008, 2016), characterized by both vicariance events (Diadema et al. 2005; Minuto et al. 2006) and in situ persistence during the glaciations (Patsiou et al. 2014; Casazza et al. 2016). In general, endemic mountain plants are expected to contract their distributional range due to climate change (Dirnböck et al. 2011; Dullinger et al. 2012) because they usually have a narrow ecological niche (Essl et al. 2009). Similarly, in the SW Alps climate change is supposed to induce range shift and contraction in several species (Engler et al. 2011), even if the overall number of endemics expected to be extinct is relatively low probably due to the rough topography and environmental heterogeneity (Dagnino et al. 2020). Currently, in the SW Alps there are roughly 200 PAs belonging to the Natura 2000 network that ensure the conservation of a wide range of rare, threatened or endemic animal and plant species.

In this study, we used species distribution modelling (SDM) of 85 plant taxa endemic or subendemic to the SW Alps (hereafter referred as endemics *sensu lato* (*s.l.*)) to evaluate the effectiveness of PAs network in protecting these taxa under future climate change scenarios. More specifically, we are asking the following questions: (i) To what extent are the current estimated distributional ranges of taxa covered by the Natura 2000 PAs network and to what extent will they be in the future? (ii) Do the expected distributional range covered by PAs under current and future climates change between protected and unprotected taxa or between taxa belonging to different vegetation belts? (iii) Will the number of taxa present in each PA change under future climates?

Materials and methods

Study area and taxa

The study area is the SW Alps (Marazzi 2005), which cover roughly 35,000 km^2 (7,875 km^2 and 27,125 km^2 representing the 22.5% and 77.5% in Italy and France, respectively). We selected only the taxa in which at least 70% of distributional range (calculated as the minimum convex polygons) occurs in the SW Alps, for a total of 85 taxa (i.e., roughly 50% of species endemic and subendemic to the study area, labelled as endemics *s.l.*). Seven taxa are listed in Annexes II and IV of Habitat Directive, 37 are protected by French legislation (national or regional), 41 are protected by Italian legislation (national or regional), 19 are protected by legislation of both countries and 26 are not protected. Occurrence's data (for a detailed description of the selection procedure, see Online Resource 1) were obtained from field surveys, herbarium specimens, the Conservatoire Botanique National SILENE data base (http://www.silene.eu/index.php?cont=accueil) and LiBiOss (Regione Liguria; http://www.cartografiarl.regione.liguria.it/Biodiv/Biodiv.aspx). To mitigate pseudo-replication of occurrences, we retained for each taxon only one occurrence per 1 × 1 km grid cell. The final data set consisted of 30,612 occurrences, ranging from 28 to 1,815 occurrences per taxon.

Data processing and species distribution modelling

We downloaded 19 bioclimatic variables for both current (i.e., 1979–2013) and future (i.e., 2061–2080) time slices at about 1 × 1 km spatial resolution from CHELSA v.1.2 dataset (Karger et al. 2017). For the future climate, we chose two representative concentration pathways (RCPs) representing possible future emission trajectories and coded according to a possible range of radiative forcing values in the year 2100 relative to preindustrial values (+2.6 and +8.5 W/m2, hereafter RCP2.6 and RCP8.5, respectively). For each RCP we used projections from five general circulation models (GCMs), that are not interdependent according to Sanderson et al. (2015): CESm1-CAM5, FIO-ESM, IPSLCM5A-MR, MIROC5 and MPI-ESM-MR. To assure the ability of models to make predictions in novel future environments (i.e., temporal transferability), we used the first two axes of a principal component analysis (PCA) as environmental variables for species distribution modelling, as suggested by Petitpierre et al. (2017). The PCA was calculated on all bioclimatic rasters of the study area pooled together, then the values of the first two axes of the PCA of each climate were separated (i.e., all the combinations of RCPs and GCMs). To account for model-based uncertainties in the modelling process (Araújo and New 2007), we used five species distribution modelling techniques implemented in the R package BIOMOD2 v 3.3.7 (Thuiller et al. 2009) belonging to three different model classes: two machine learning methods (i.e., generalised boosted models—GBM, and random forest—RF), two regression methods (i.e., generalized linear models—GLM and multivariate adaptive regression splines—MARS) and one classification method (i.e., classification tree analysis—CTA). We generated ten replicate sets of pseudo-absences for each taxon. For each pseudo-absence set, we repeated 10 times a split-sample cross-validation, using a random subset (30%) of the initial data set. We used two different measures implemented in BIOMOD2 to evaluate model performance: the area under the curve of a ROC plot (Hanley and McNeil 1982) and the true skill statistic (Allouche et al. 2006) (for detailed results, see Online Resource 3). We averaged projections from different model techniques and GCMs to implement an ensemble forecasting approach and converted the continuous suitability maps into binary projections of taxon presence and absence using three different thresholds implemented in the R package "PresenceAbsence" (Freeman and Moisen 2008). Because the choice of threshold may affect projection bias, we used three different thresholds, which perform equally or better than others (Liu et al. 2005; Cao et al. 2013). For each taxon, we obtained 15 binary projections for the current, 75 for the RCP2.6 and 75 for the RCP8.5 scenarios, respectively. To assess uncertainty in the predictions and produce a single binary map for each time slice, we combined all SDM techniques in an ensemble projection, considering the taxon occurring in a cell if at least 50% of models projected its occurrence there (i.e., a majority consensus rule).

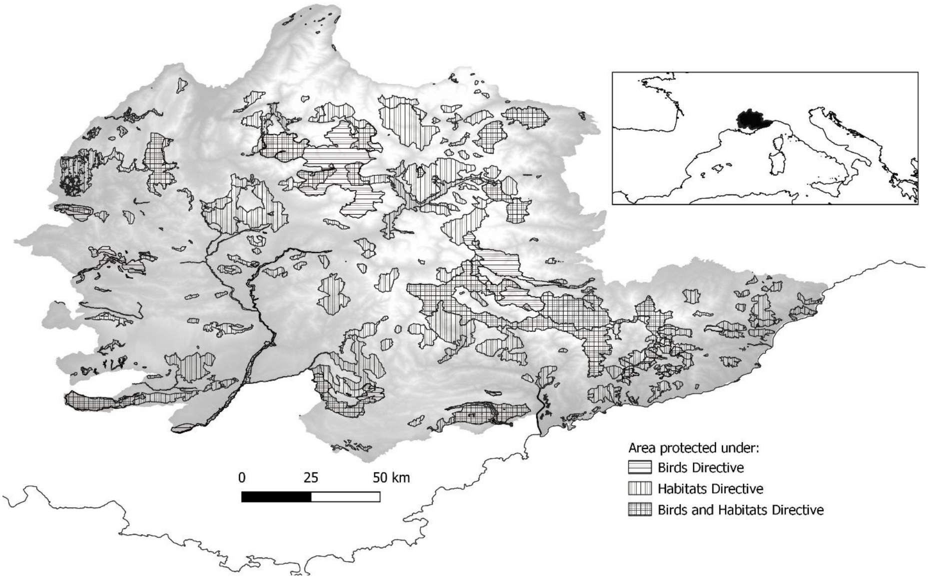

Fig. 1 Distribution of protected areas in the SW Alps

Natura 2000 network and species data

We obtained location data for the PAs in the Natura 2000 network from the European Environmental Agency (https://www.eea.europa.eu). In the SW Alps there are 197 PAs (ranging from ~900 km^2 to less than 1 km^2) belonging to the Natura 2000 network (Fig. 1). Among them, 24 are Special Protection Areas (SPAs) designated under the Birds Directive, 166 are Special Areas of Conservation (SACs) designated under the Habitats Directive and seven are sites designated under both directives. In particular, the SPAs cover 1,196 km^2, SACs cover 4,938 km^2 and areas designated under both directives cover 2,810 km^2.

For the 85 endemics *s.l.*, we calculated the percentage of potential distributional range covered by PAs under current and future climates. We also assessed whether PAs maintained the current level of endemics *s.l.* richness calculating the percentage of endemics *s.l.* lost or gained in PAs. Eventually, we assessed the number of PAs in which each taxon occurs under present and future climates. To analyse whether the protection of the PAs network changes among vegetation belts, we divided the study area into three main vegetation belts (i.e., colline, montane and subalpine), according to altitude and mean annual temperatures thresholds (for a detailed description see Online Resource 2), following the approach of Engler et al. (2011). Each taxon was assigned to the vegetation belt with the highest frequency of occurrences. We used the Nemenyi non-parametric multiple comparisons test to test for difference among climate scenarios and vegetation belts. All the analyses were performed in R (R Core Team 2019).

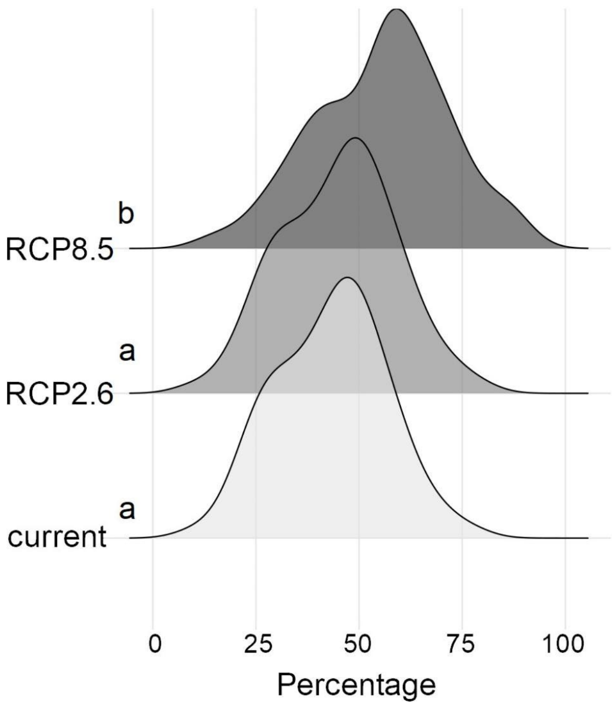

Fig. 2 Percentage of the expected range inside PAs. Light grey indicates current climate, grey indicates future RCP2.6 and dark grey indicates future RCP8.5. Results of post-hoc tests for statistical differences are reported: different letters indicate significant differences ($p<0.05$)

Results

The Natura 2000 PAs network covers the 25.47% (8,945 km^2; Fig. 1) of the study area. In particular, the network covers the 26% (~6,900 km^2) of French territory and the 25% (~2,050 km^2) of Italian territory. Endemics *s.l.* occur in 97.0% of PAs (i.e., 161 out of 166), which overall cover less than half of the potential distribution range of taxa. Specifically, the percentage of range predicted to fall within PAs between current and RCP2.6 was similar, ranging from 14.09 to 80.19% (average 44.67%) and from 13.90 to 81.63% (average 46.35%), respectively (Fig. 2 and Online Resource 4). Under current conditions, the PAs cover more than 50% of estimated range for 28 taxa and more than 70% of their estimated range for only three taxa (Online Resource 4). Under the RCP2.6, the PAs cover more than 50% of estimated range for 35 taxa and more than 70% of estimated range for four taxa (Fig. 2 and Online Resource 4). Conversely, under the RCP8.5 the percentage of range predicted to fall within PAs is expected to increase (Fig. 2), ranging from 18.94 to 90.11% (average 55.69%). In particular, the number of endemics *s.l.* for which at least 50% of estimated range falls within PAs is expected to increase up to 39 and 16 taxa will have more than 70% of their estimated range protected by PAs (Fig. 2 and Online Resource 4). The percentage of expected distributional range covered by PAs is similar between protected (at European, national, and regional levels) and unprotected taxa under current and both future climates (Fig. 3). Under all climates, a higher percentage of expected distributional range is covered by PAs in subalpine taxa than in colline and mountain ones (Fig. 4). Moreover, the number of endemics *s.l.* occurring in PAs is expected to remain steady under the RCP2.6 and to decrease under the RCP8.5 (Fig. 5). Similarly, in the future, the percentage of the PAs

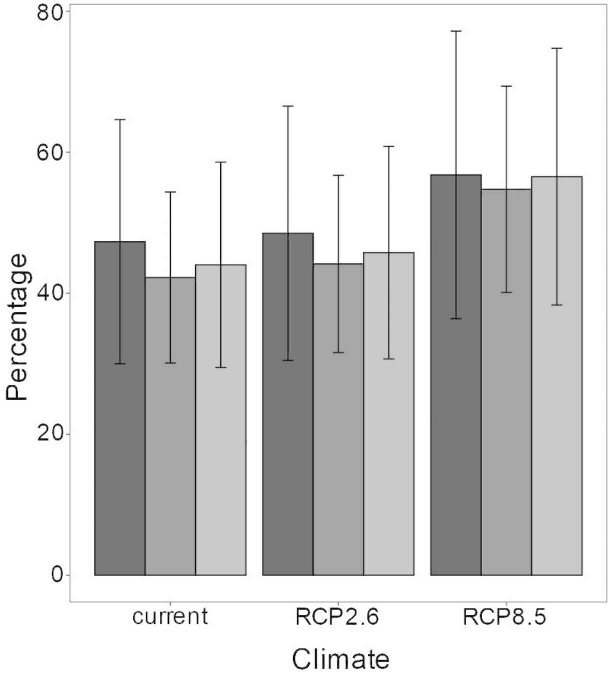

Fig. 3 Difference between expected distributional range covered by PAs in protected and unprotected taxa under current and future climates. Dark grey indicates taxa protected by European directives, grey indicates taxa protected by national or regional laws and light grey indicates unprotected taxa

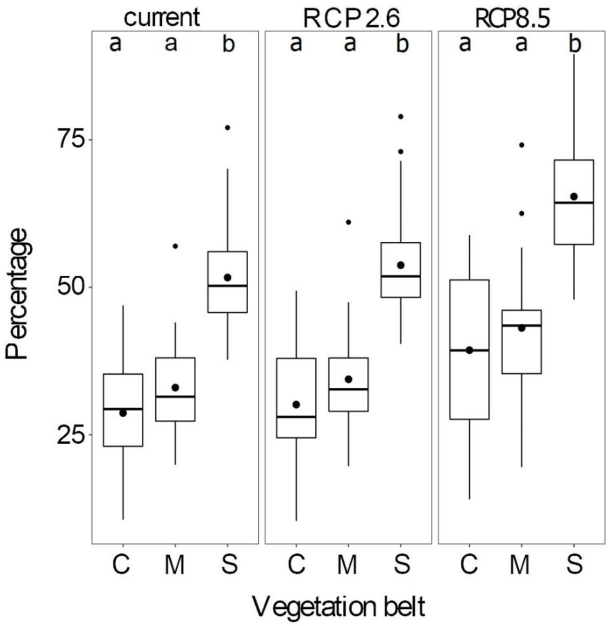

Fig. 4 Percentage of expected distributional range of SW Alps taxa covered by PAs according to their vegetation belt under current and future climate (RCP2.6 and RCP8.5). C, colline; M, mountain and S, subalpine. Results of post-hoc tests for statistical differences are reported: different letters indicate significant differences ($p < 0.05$)

harbouring endemics *s.l.* is expected to be slightly lower than it is today in the RCP2.6 (i.e., 94.6.0% corresponding to 157 PAs out of 166) and it is expected to drop by 15% under the RCP8.5 (i.e., 80.7% corresponding to 134 PAs out of 166).

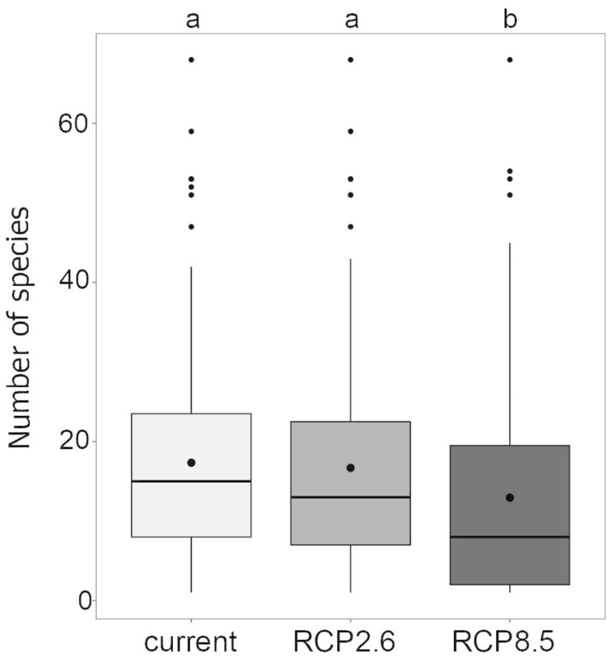

Fig. 5 Number of taxa occurring in each PA under current and future climate (RCP2.6 and RCP8.5). Results of post-hoc tests for statistical differences are reported: different letters indicate significant differences ($p < 0.05$)

Discussion

Protection under current climate

In our study, we present an analysis of the effectiveness of PAs in conserving species endemic to the SW Alps in face of climate change. Assessing the overlap between species ranges and PAs is a necessary first step in evaluating species protection, despite it may clearly fall short of assuring actual species protection because of weak management (Leverington et al. 2010). Furthermore, our results should be considered with particular attention for the main choices we adopted in our study. First, we employed a climatically-based species distribution modelling approach. Despite this approach is widely used, it has some well-known limitations (Araújo et al. 2019) and other factors than climate (e.g., land use) might account for realized distribution (Swab et al. 2012; Casazza et al. 2021b). In the SW Alps, land use change may be a treat mainly for taxa occurring in anthropized coastal environments, which are threatened by increased human activities (e.g., infrastructure development and tourism), and those occurring in subalpine meadows below the tree line, which are threatened by abandonment of human activities (e.g., herding and cultivation). However, the majority of studied taxa occur on rocky habitats in mountainous areas, that are weakly threatened by land use change. In coastal environments and subalpine meadows, climate change may interact with land use change to threat species (Willis et al. 2015), resulting in an underestimation of the range loss. Second, the spatial resolution of climate data may affect the results of SDMs, failing to detect microclimatic refugia, areas where the species might persist, particularly in rugged terrain (Randin et al. 2009). Nevertheless, we produced our models at roughly 1 km^2 of resolution, the resolution suggested by Maiorano et al. (2011) and Franklin et al. (2013) to detect hidden local refugia. However, species interactions, topography and soil ecological conditions mostly act on a finer scale, influencing species distribution and abundance over short distances (≤ 100 m; Chauvier et al. 2022). For this reason, it would be desirable to carry out analyses at a very fine resolution, although this can be computationally challenging for large areas and numerous species.

The Natura 2000 PAs network in the SW Alps exceeds the Convention of Biodiversity Aichi Target 11 by the 17% of terrestrial lands protection, covering roughly the 30% of the areas (Fig. 1) and already reaching the target for the 2030. Our analysis suggests that in the SW Alps two-thirds of endemics *s.l.* meet a weak conservation target having less than half of their range covered by the PAs (Fig. 2). Moreover, we did not detect any difference between endemics *s.l.* protected by legislation and the others (Fig. 3). These results are because of national and regional protection laws were not considered when the PAs were designed. Anyway, although endemics *s.l.* are of high concern for conservation, they are often not taken into account in protection laws (Le Berre et al. 2018). For this reason, even though the distributional range of endemics *s.l.* is within the PAs, their long-term survival may not be guaranteed because management measures in the PAs are primarily aimed at conserving habitats and/or species for which they have been designed. It is worth to note that only seven out of 85 taxa considered in this study are listed in the Annexes of Habitats Directive. Five of these taxa have less than half of their estimated range covered by PAs network (i.e., 29.4% in *Asplenium jahandiezii* (Litard.) Rouy, 29.7% in *Lilium pomponium* L., 38.0% in *Campanula sabatia* De Not., 47.0% in *Acis nicaeensis* Lledó, (A) P. Davis & M. (B) Crespo, 48.9% in *Potentilla delphinensis* Gren. & Godr. in Table S1). This result is in contrast with the expectation that PAs networks better cover threatened and directive species than non-directive species (Kukkala et al. 2016a), instead it confirms previous findings that the PAs establishment frequently does not correlate with identified conservation priorities (Chape et al. 2005).

Our data show that the expected distributional range of taxa occurring in the subalpine belt is more covered by PAs than that of montane and colline taxa (Fig. 4) on which human pressures is higher. This result may be explained by the fact that PAs location is usually biased towards areas where they can least prevent change in land use due to human disturbance (Joppa and Pfaff 2009) and, consequently, where conflict with human activities was, and it is, low. In particular, in the study area, the PAs are less present near the coast (Fig. 1) where the urban development and/or mass tourism are more intense (Jacob 2018). Because the PAs regulate access to and use of natural resources, their development and management are politically and socially contentious (Blaustein 2007). Worried by a possible decrease in tourism and stricter control over recreational activities, some local authorities and many stakeholders from coastal communities historically opposed the designation of PAs and lobbied decision-makers (Salmona and Verardi 2001). Moreover, for the studied taxa occurring in subalpine meadows an additional threat is represented by the successional stages of stands, such as the shrubs encroachment because of pastures abandonment (Dullinger et al. 2003). Vegetation dynamics have been already identified as the main cause of the apparent upslope movement of species in the mountain relief of Southeast France and these dynamics need to be considered among the causes of range shift (Bodin et al. 2013).

Protection under future climate

In the future, the percentage of estimated range covered by Natura 2000 PAs network is expected to increase (Fig. 2), although the number of taxa in each PA is expected to decrease (Fig. 5). The magnitude of these changes was projected to be different according to the future climatic scenario. Differences with current are projected to be weak under the RCP2.6, while they will be dramatic under the RCP8.5. This difference between the two future climatic scenarios is likely because under the RCP2.6 the climate is projected to remain within the limits already experienced by species during the Holocene (Guiot and Cramer 2016). This result underlines that the efficiency of the current PAs network strongly depends on the global efforts to halt emissions to levels planned by global targets. In a previous study on the effect of climate change on endemics and subendemic taxa of the SW Alps Dagnino et al. (2020) found that these taxa are expected to contract their distributional range under future climate. So, the increase in range covered by the PAs suggests that the loss will mainly occurs outside the PAs network. This result may be explained by the concordance between most PAs located in the subalpine areas and areas rich in endemics *s.l.*. In fact, the areas richest of endemics occur at high elevation in the southern part of Alpine chain (Casazza et al. 2008), where late Quaternary climatic fluctuations have been mild and where mountainous topography or favourable sea currents contributed to creating climatically stable areas (Sandel et al. 2011). These areas will likely remain relatively climatically buffered in the future (Harrison and Noss 2017), maintaining the richness of species within the PAs. Indeed, it was showed that in the Alpine hotspots of biodiversity, the species richness may be affected by the within-region environmental heterogeneity rather than macroclimatic conditions (Testolin et al. 2021). Moreover, species turnover due to climate-induced range shift may change species composition in the PAs, while the number of species occurring in the PAs may increase where newly suitable areas will occur (Berteaux et al. 2018), that is, toward northernmost latitudes or at high altitudes. For this reason, even if the PAs are predominantly expected to lose many populations and species, they will likely continue to accommodate several species, which will be shifting their distribution (Thomas and Gillingham 2015).

The low percentage of expected range within PAs in colline endemics *s.l.* suggests that a large part of populations of these taxa are currently and will be in the future not protected (Fig. 4), despite they are particularly threatened by climate change and urbanization (Noble and Diadema 2011). Thus, the existing PAs are likely poor-sited to continue to protect these taxa. On the contrary, SW Alps endemics *s.l.* belonging to montane vegetation belt are less threatened by climate change (Dagnino et al. 2020), although peripheral populations at the southern/low elevation are likely more threatened by climate change and poor protected due to the small extent of the PAs network at low elevation. Nevertheless, these low elevation populations may be genetically and morphologically differentiated from the other populations (Macrì et al. 2021; Casazza et al. 2021a) and then they are worthy of protection (Macdonald et al. 2017; Thompson 2020).

The loss at low elevation and the gain at high elevation of suitable climatic conditions may result in extinction of populations occurring inside the PAs at low elevation and in increase of suitable areas inside the PAs at high elevation where some populations still occur. However, the low decrease in the number of taxa occurring in the PAs (Fig. 5) suggests that Natura 2000 network of PAs will play a central role in assuring endemics *s.l.*

survival in the SW Alps under future climate. For this reason, in a changing world, continuous evaluation and improvement of the PAs networks is of primary importance to achieve biodiversity protection in the future.

Conclusion

In conclusion, in the SW Alps the Natura 2000 network of PAs is extensive both in number and in coverage area. Our study highlighted that the PAs are distributed to poorly cover expected range of endemics *s.l.* at low and middle elevation, threatened by urbanization and climate change. For this reason, we recommend additional protection in these areas, also taking into account the future climatic suitability of species. Besides, the PAs will harbour more expected distribution range of species in the future than today, playing a key role in endemics protection. However, ensuring adequate species representation within a PAs network (like the European Natura 2000 one) is only a first step toward effectiveness. Without effective enforcement and management of protected sites the representativeness is pointless.

Authors' contributions GC and MG equally contributed to this paper as first authors. Conceptualisation: GC and LM; Formal analysis and investigation: DD, GC and MG; Writing: GC and MG; Review and editing: DD, GC, LM and MG; Funding acquisition and supervision: LM.

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Data availability Bioclimatic and Natura 2000 PA network data are available at public repositories cited herein. Spatially explicit data associated with species distribution contain proprietary information and are not for public distribution. For scientific purpose, the data may be requested to the public authority owner.

Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant of the content of this.

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