Climate change fosters the decline of epiphytic Lobaria species in Italy

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Climate change fosters the decline of epiphytic *Lobaria* species in Italy

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ABSTRACT

Similarly to other Mediterranean regions, Italy is expected to experience dramatic climatic changes in the coming decades. Do to their poikilohydric nature, lichens are among the most sensitive organisms to climate change and species requiring temperate-humid conditions may rapidly decline in Italy, such in the case of the epiphytic *Lobaria* species that are confined to humid forests. Our study, based on ecological niche modelling of occurrence data of three *Lobaria* species, revealed that in the next decades climate change will impact their distribution range across Italy, predicting a steep gradient of increasing range loss across time slices. *Lobaria* species are therefore facing a high extinction risk associated with reduction of their range. The current patterns indicate that only *L. pulmonaria* still has a continuous distribution across Italy, with potential contact between Apennine and Alpine populations. This situation is consistent with the wider climatic niche of this species, still offering a major opportunity for its successful long-term conservation. Results (a) support the inclusion of the three *Lobaria* species in European conservation policies, such as the Habitat Directive, and (b) warn against an over-estimation of the indicator power of single flagship species to establish conservation priorities for lichens, indicating that even lichens with peculiar and similar climatic envelopes may fail to co-occur within a given forest stand. A multiple indicator approach could provide more useful tools for a community-based conservation strategy for epiphytes.

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1. Introduction

Climate is one of the main drivers of species distribution, determining latitudinal and altitudinal patterns of species diversity at global level (Hawkins et al., 2003; O'Brien, 1993, 2006; Vetaas, 2006). There is increasing evidence indicating that climatic conditions are globally changing, posing one of the greatest threats to biodiversity (Bellard et al., 2014). For this reason, in recent decades the effect of global change is among the main topics in conservation science.

Due to their poikilohydric nature, lichens are among the most sensitive organisms to climatic factors (Nascimbene and Marini, 2015; Giordani et al., 2014). In a poikilohydric organism the water content tends to reach equilibrium with that of the surrounding environment (Proctor and Tuba, 2002). Lichen physiology is therefore closely coupled to ambient temperature and moisture, which influence thallus water saturation and desiccation (Green et al., 2008; Gauslaa et al., 2012; Merinero et al., 2014). Both water and temperature directly control relevant eco-physiological processes influencing growth rates and species distribution (Insarov and Schroeter, 2002; Nascimbene and Marini, 2015). Increasing ambient temperature may influence lichen response due to increased respiratory carbon losses (Schroeter et al., 2000). Moreover, high temperature influences thallus rewetting and water content, inducing frequent and severe desiccation events that hinders photosynthetic activity (Insarov and Schroeter, 2002). These warming-related effects could be, therefore, exacerbated by poor precipitation (Hawkins et al., 2003). As a consequence, changing climatic conditions are expected to impact lichens (Bässler et al., 2015; Nascimbene and Marini, 2015), causing changes to community composition (e.g. Aragón et al., 2012) that are related to the ability of the species to handle increasing drought.

This ability is strongly related to the photobiont type and to the thallus growth form (Bässler et al., 2015; Nascimbene and Marini, 2015) that, for example, determine contrasting responses between crustose trentepohliod and foliose cyanobacterial species, the former being enhanced by warming conditions, the latter being related to temperate-humid conditions. As suggested by van Herk et al. (2002), in a climate warming scenario drought-tolerant and sub-tropical species are likely to replace drought-sensitive species in temperate-Mediterranean regions.

Similarly to other Mediterranean regions, peninsular Italy is expected to experience dramatic climatic changes in the coming decades, with an increase in the frequency and intensity of drought and of extreme temperatures (IPCC, 2013, 2014). This climatic pattern could seriously impact the biota of the Mediterranean basin that is among the most important hotspots of biodiversity at the global level (Médail and Quézel, 1999).

In this framework, many lichens that require temperate-humid conditions may rapidly decline in Mediterranean regions, such in the case of the epiphytic *Lobaria* species that are among the most threatened lichens in Europe (Nascimbene et al., 2013a; Otalora et al., 2015). In Italy, three *Lobaria* s. lat. species (Stenroos et al., 2003; Högnabba et al., 2009) are mainly confined to humid forests with long ecological continuity that buffer sub-optimal macroclimatic conditions (Merinero et al., 2014; Nascimbene et al., 2013a). The Italian populations are critical for the long-term conservation of *Lobaria* species in Europe since in this region genetic differentiation is higher than in other European areas (e.g. for *L. pulmonaria*; Widmer et al., 2012). Under these circumstances, Italy has a strong responsibility at the European level for the conservation of these species.

Our study is based on ecological niche modelling of the three Italian epiphytic *Lobaria* species. In particular, we focused on (a) the analysis of the climatic niches of the species under current conditions. This would allow to investigate the climatic envelopes of the three species, assessing the degree of climatic overlapping among them, and the relationship between climatic niche features and the geographic distribution patterns of (co-) occurrence of the species; (b) the prediction of their future distribution patterns under climate change scenarios. This would allow for the estimation of possible range losses and gains and spatial-temporal patterns of population dynamics under the impulse of climate change. This combined approach would provide a tool for supporting the development of proactive strategies to prevent and mitigate climate change impacts (Pereira et al., 2010; Parmesan et al., 2011), enhancing effective local conservation for these epiphytic species. The study is therefore intended to address two main questions: 1) do the climatic niches of the three species differ under current climatic conditions, and does this determine different spatial patterns of habitat suitability? 2) how projected climate change will impact the current habitat suitability of the three *Lobaria* species?

2. Methods

2.1. The study species and occurrence data

Lobaria pulmonaria (L.) Hoffm. is a mainly temperate, holarctic tripartite species with sexual and vegetative dispersal strategies (Scheidegger, 1995), functional differentiation (reproductive and meristematic) of thallus lobes (Scheidegger et al., 1998; Giordani and Brunialti, 2002), large thallus size and thickness that enhances the lichen's water holding capacity (Merinero et al., 2014; Table 1).

Lobaria amplissima (Scop.) Forssell is a mainly European species of mild-temperate climates. It has internal cephalodia and a shrubby cyanobacterial photomorph attached to the foliose green algal photomorph (Stenroos et al., 2003). Both photomorphs may develop independently. The rosette-forming thalli of *L. amplissima* are more substrate-adherent than those of *L. pulmonaria*. *L. amplissima* reproduces only by ascospores (sexual reproduction).

Lobarina scrobiculata (Scop.) Nyl. mainly occurs in temperate regions of Europe and North America with high amounts of annual rainfall. Its thallus is smaller than that of the other two species and it has cyanobacterial photobionts exclusively (Merinero et al., 2014). *L. scrobiculata* mainly reproduces by vegetative propagules, while sexual reproduction rarely occurs.

Species occurrence data were obtained from a national database including all available records of the three selected species in Italy (Nascimbene et al., 2013c). We removed identical occurrence records using ENMTools (Warren et al., 2010; see also Warren and Seifert, 2011).

2.2. Climatic variables

Nineteen bioclimatic variables representative of the period 1950–2000 were downloaded from the WorldClim database website (http://www.worldclim.org) at a 30-s (i.e., about 1 km × 1 km) spatial resolution (Hijmans et al., 2005) for the extent of Italy. Climatic variables related to temperature and precipitation were assumed to be important for limiting the distribution of lichen species. To reduce the multicollinearity between predictors and to minimize model overfitting, we performed a pairwise Pearson correlation between bioclimatic predictors. We retained predictors that showed a high relative contribution to the Species Distribution Models (SDMs) on the basis of jackknife test of variable importance performed with the software Maxent and that were not highly correlated to each other ($r \le |0.70|$; see recommendation of Elith et al., 2006). Six variables were retained for the analyses: BIO3—Isothermality, BIO4—Temperature Seasonality, BIO8—Mean Temperature of Wettest Quarter, BIO9—Mean Temperature of Driest Quarter, BIO 13—Precipitation of Wettest Month and BIO15—Precipitation Seasonality.

2.3. Scenarios of climate change

Two greenhouse gas emission scenarios (GESs: A2 and B1) were selected to assess plausible future conditions based on a range of human activities over the next few decades (IPCC, 2014). Scenario A2 describes a heterogeneous world with regionally oriented economic development. This scenario projects rapid population growth that will reach 15 billion by the year 2100; per capita, economic growth and technological change are slower than in the other previously developed scenarios. Scenario B1 describes a convergent world with the global population peaking mid-century and declining thereafter, but with rapid change in the world's economic structure toward a service and information economy, with reductions in the intensity of material consumption and the introduction of clean and resource-efficient technologies. The emphasis in this scenario is on finding global solutions that allow economic development that are socially and environmentally sustainable, including improved equity, but without additional climate initiatives. We used climatic projections from two internationally recognized

Table 1
Functional traits of the three *Lobaria* s. lat. species occurring in Italy.

	Lobaria pulmonaria	*Lobarina scrobiculata*	*Lobaria amplissima*
Reproductive strategy	Gamic and agamic (by isidia and/or soredia)	Agamic by soredia; gamic (rare)	Gamic
Photobiont type	Chlorococcoid algae (main); cyanobacteria (in internal cephalodes)	Cyanobacteria	Chlorococcoid algae (main); rarely cyanobacteria, (in external cephalodes)
Growth form	Foliose (leaf-like lobes)	Foliose (concave and rounded lobes)	Foliose (rounded lobes)

general circulation models (GCMs): HADCM3 and ECHAM5. To explore future changes in the potential range of the three species analysed here, the six variables retained in the analyses were downloaded from the WorldClim database website (http://www.worldclim.org) at a 30-s (i.e., about 1 km × 1 km) spatial resolution for the years 2020, 2050 and 2080.

2.4. Species distribution model

Species occurrence data and the six bioclimatic variables were used for the construction of SDMs for each species with the software Maxent 3.3.3e (Phillips et al., 2006). We used 70% of the occurrence records for each species to calibrate the model and 30% to test it, a common practice in ecological studies (Phillips et al., 2006). All other parameters were set to a default value. The performance of the models was assessed using the area under the receiver operating characteristic (ROC) curve (AUC; Hanley and McNeil, 1982). The AUC is a measurement of the discriminatory capacity of classification models that takes into account sensitivity (Se), the proportion of instances of presence correctly predicted as presence, and specificity (Sp), the proportion of instances of absence correctly predicted as absence. The ROC curve plots Se versus (1 - Sp) (i.e. the proportion of instances of absence wrongly predicted as presence) across all possible thresholds between 0 and 1. The threshold selection method to convert the continuous predictions of Maxent to species presence or absence was based on maximizing training sensitivity and specificity.

2.5. Niche shift

Niche divergence could be the result of an actual difference in habitat selection between taxa, or because of a different habitat availability in the regions occupied by taxa (Warren et al., 2008; Broennimann et al., 2012). In order to discriminate between these hypotheses, we tested differences in environmental space and performed the niche similarity test. Values of environmental variables were extracted for all the occurrences of each species and inter-species divergence was examined. For this, we used a non-parametric Kruskal-Wallis test to assess differences among species along each climatic variable independently. Kernel density plots were used to visualize the distribution of each variable. The similarity test compares the observed overlap between the niche of two species to a distribution of 100 simulated overlap values generated by comparing the SDM of one species to a SDM created from random points drawn from the geographical background area of the other species (Warren et al., 2008, 2010). Niche overlap was measured by Schoener's D index, which ranges from 0 (no overlap) to 1 (full overlap; Schoener, 1970). Significant results can suggest that the ecological niches of species are either more different or more similar than expected, so this is treated as a two-tailed test. The background area should ideally include suitable habitats for the species and therefore the selection of an appropriate background area is critical to the analysis of niche similarity (Warren et al., 2010). Consequently, we created different background areas to account for the effects of different backgrounds on the modelling process following two different approaches. The first approach uses the combination of the output of the SDM of each pair of species (common background) converted into a binary variable (presence/absence) by applying a threshold that maximizes the sum of sensitivity and specificity of the test data (Liu et al., 2005). The second approach uses a 10-km buffer zone around the occurrence points of each species.

Niche breadth was estimated by applying Levins inverse concentration metric (1968) as implemented in ENMTools to the resulting sets of suitability scores; these were standardized so that the minimum possible niche breadth within this space was 0 (indicating that only one grid cell in the geographical space has a nonzero suitability) and the maximum niche breadth was 1 (where all grid cells are equally suitable).

2.6. Spatial indices for distribution under different time periods

The percentage of overall predicted range change (C), in relation to the present-day predicted distribution, was estimated using the formula $C = 100 \times (RG - RL) / PR$, where RG (range gain) is the number of grid cells projected to be not suitable under present climate but suitable under future climate, RL (range loss) is the number of grid cells projected to be suitable under present climate but not suitable under future climate and PR (present range) is the number of grid cells projected suitable under current climatic scenario. A negative C value indicates a loss in overall range, whereas a positive value indicates an increase in overall range size. The range turnover (T) per cell of the climate envelope range was estimated using $T = 100 \times (RL + RG) / (PR + RG)$. A T value of 0 indicates no shift in range, whereas a value of 100 indicates a complete range shift when compared with the predicted range under current conditions. The full-dispersal scenario assumes that a species could reach all geographical areas that are predicted to be suitable in future climate projections (i.e., $RG \geq 0$). On the contrary, the no-dispersal scenario assumes no dispersion from current to future suitable sites (i.e., $RG = 0$) implying that future sites that might become suitable for a species remain unoccupied. The no-dispersal scenario was calculated as the percentage of range lost (percentage of RL), while the full-dispersal scenario was calculated as percentage of range changed (C), as the result of the difference between RG and RL related to the present range (PR). The full-dispersal scenarios is likely to be unrealistic because it assumes that a species can colonize all locations without physiological, environmental or geographical limitations, while the no-dispersal scenario is likely to be more appropriate for poor dispersers as *Lobaria* species frequently are.

2.7. Limitations and caveats

Results of SDMs should be considered with particular attention to the main limitations of the approach. Shifts associated with recent climate change are likely to have been brought through both direct and indirect (biotic interactions) effects of climate (Thomas, 2010). Unfortunately, detailed knowledge of variation in demography and biotic drivers of species distribution over large spatial scales are currently not available for a majority of lichen species. Coarse scale models might underestimate the presence of locally suitable habitats that could allow species persistence (Franklin et al., 2013). We produced our models at roughly 1 km² of resolution to avoid the problem of hidden local refugia, as suggested by Maiorano et al. (2011) and Franklin et al. (2013).

3. Results

3.1. Species occurrence and co-occurrence in Italy

We collected 548, 270 and 156 occurrence records for *L. pulmonaria*, *L. amplissima* and *Lobarina scrobiculata*, respectively, from 660 1 km × 1 km cells in Italy (Table 2; Fig. 1). In most cases (572 cells) only one of the three species was reported, whereas a partial overlap of two species was observed in 71 cells. The co-occurrence of the three species was only observed in 17 cells, corresponding to a very

Table 2
Number of grid cells in which the three *Lobaria* s. lat. species occur and co-occur in Italy.

Species in a grid cell	Species combination	Number of cells (total)	
3 species	*L. pulmonaria + L. scrobiculata + L. amplissima*	17	(17)
2 species	*L. pulmonaria + L. scrobiculata*	29	(71)
	L. pulmonaria + L. amplissima	27	
	L. scrobiculata + L. amplissima	15	
1 species	*L. pulmonaria*	411	(572)
	L. scrobiculata	97	
	L. amplissima	64	

Fig. 1. Current distributions of the three species of *Lobaria* in Italy: A) *Lobaria pulmonaria*; B) *Lobarina scrobiculata*; C) *Lobaria amplissima*.

low percentage with respect to the overall distribution of the species in Italy. *L. amplissima* co-occurred with one and/or both other species in 48% of its geographic range, in contrast with what observed for *L. pulmonaria*, which co-occurred with the other taxa in only 15% of the cells. Data for *L. scrobiculata* are intermediate between the other species, co-occurring with them in 39% of its range.

3.2. Niche differentiation under current conditions

The climatic requirements of the three species were quite similar (Fig. 2). The Schoener's D values were always >0.7, corresponding with a high degree of niche overlap (Rödder and Engler, 2011). Nonetheless, measures of three out of the six climatic variables (BIO4, BIO8 and BIO15) differed significantly ($P < 0.05$) for *L. pulmonaria* vs. *L. amplissima*, while measures for only one bioclimatic variable (BIO13) of *L. scrobiculata* differed significantly from those of the other two species.

Models inferred from occurrence records predicted the distribution of the three species. Cross-validated AUC values for all models were high (>0.9) and low test omission rates indicated an excellent model performance. For all three species, core areas with the highest predicted occurrences were represented by the Northern Apennine and by montane areas of Southern Italy (Fig. 3). *L. pulmonaria* showed a considerably wider potential distribution across Italy compared with the other two species. Its occurrence was predicted in the lowest montane areas of the Alps, along the Apennines and in the mountains of Sicily and Sardinia. The predicted distribution of *L. amplissima* and *L. scrobiculata* indicated severe reduction of their distribution in central Italy and the Alps. However, the climatic suitability value of these species seemed to be higher than that of *L. pulmonaria* in montane areas of Sardinia and Sicily.

Tests for niche similarity in the geographical space supported high niche similarity (>0.75), and generally statistically significant overlaps were observed in all pairwise comparisons between the three species (Table 3). As far as the niche breadth (Levins inverse concentration metric) was concerned, *L. amplissima* showed the lowest niche breadth (0.23), whereas the niche breadths of *L. pulmonaria* and *L. scrobiculata* were quite similar (0.34 and 0.35, respectively).

3.3. Predicted effects of climate change

Both A2 and B1scenarios predicted a similar drastic decrease of the range of the three species from current conditions to 2080 (Fig. 3), with slight differences depending on the scenario involved. Therefore, climate change is expected to impact the distributional range of the three species (Fig. 4) that showed strong temporal trends for all descriptors. The average percentage of range loss (RL) for *L. amplissima* was 44.9%, 58.1% and 79.0% for 2020, 2050 and 2080, respectively (Fig. 4a). The trend for *L. scrobiculata* was quite similar with a predicted RL = 74.0% in 2080 when compared with current conditions. The estimated average RL for *L. pulmonaria* at the three time slices was even higher,

increasing from 48.5% to 85.6% from 2020 to 2080. In contrast, the three species are expected to gain a moderate percentage of areas with suitable climate in 2020, with the range gain (RG) ranging from 12.8% for *L. amplissima* to 19.3% for *L. scrobiculata* (Fig. 4b). The RG for all species tended to decrease in 2080 with *L. amplissima* gaining the smallest area (5.3% compared to current conditions). As a consequence, the range change (RC) is expected to be strongly negative for all species in 2020 and beyond (Fig. 4c), with the RC being the largest (−24.1%) for *L. scrobiculata* and the least (−34.7%) for *L. pulmonaria*. In 2050, the three species are expected to have a negative RC involving as much as half of their current predicted range, with the highest RC for *L. pulmonaria* (−55.6%). In 2080, the three species would have lost almost 3/4 of their current predicted range on average, but relevant differences would occur with the smallest RC (−78.7) for *L. pulmonaria* and the largest (−65.7%) for *L. scrobiculata*. All three species showed a predicted range turnover (RT) >50% for 2020 (Fig. 4d), with the average expected to exceed 80% in 2080, and the greatest RT (86.7%) for *L. pulmonaria*.

When focusing on the sites where the species currently occur, a future reduction of the climatic suitability for all the species was estimated (Fig. 5). For both scenarios of global change (A2 and B1), the mean predicted occurrence of the species at those sites will be always <0.5 after 2020. The A2 scenario predicted a drastic decrease, independent of the species, in 2080 with the probability of occurrence being ca. 0.1 for all species. The B1 scenario produced similar results, even though the reductions from 2050 to 2080 would be less pronounced when compared with those predicted basing on the A2 scenario; by 2080, the climatic suitability would be slightly higher for all three species.

4. Discussion

Our study revealed that, despite they rarely co-occur, the three epiphytic *Lobaria* species have partially overlapping but not equivalent climatic niches (the significant differences between the niches are discussed below), and that predicted climate changes in the Mediterranean basin are fostering their decline at the southern border of their European range. However, a wider climatic niche, which is likely related to specific functional traits, may have allowed *L. pulmonaria* to reach and maintain a more widespread and less fragmented distribution across Italy as compared with the other two species. This would give more chances for long-term conservation if protection policies are rapidly adopted. Details on these general findings are discussed in the following sections arranged according to the two main questions addressed in this study.

4.1. Do the climatic niches of the three species differ under current climatic conditions, and does this determine different spatial patterns of habitat suitability?

Despite belonging to the same epiphytic community composed of species related to sub-oceanic conditions (Barkman, 1958), the three
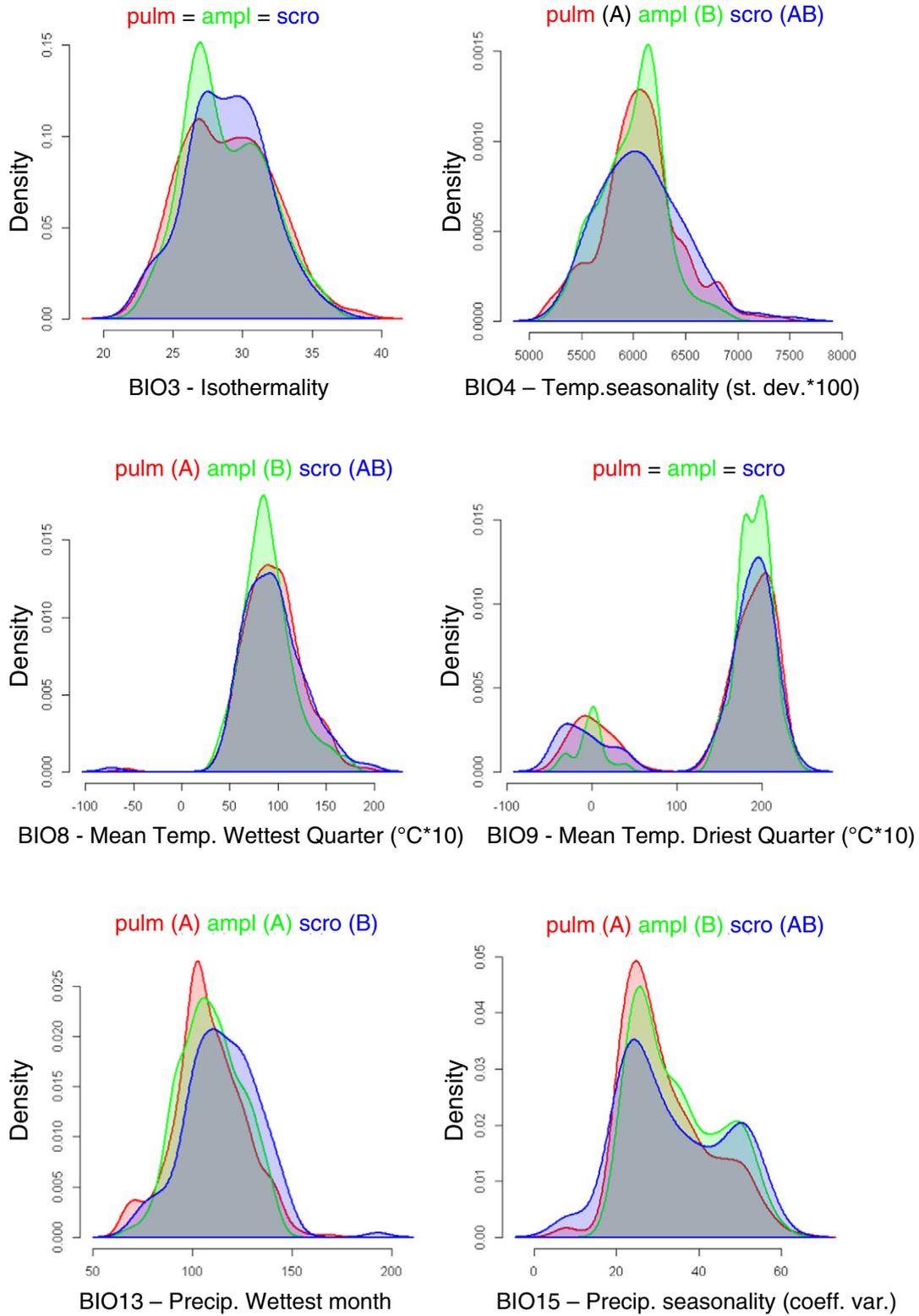
Fig. 2. Kernel density plots of the six climatic variables for the three species of *Lobaria* s. lat. in Italy. Differentiation among species and the results of Kruskal–Wallis tests are indicated in each plot. A lack of significant difference (at the $P = 0.05$ level) is indicated by an equal sign and same letter, while significant differences are indicated by either higher or lower signs and different letters. Pulm = *Lobaria pulmonaria*; ampl = *Lobaria amplissima*; scro = *Lobarina scrobiculata*.

Lobaria species rarely co-occurred at the same sites in Italy. To explore this phenomenon, we tested whether the climatic niches of these species differ under current climatic conditions and if the dissimilarity could explain divergent spatial patterns of their habitat suitability. The species showed large overlaps for most of the considered climatic variables, except for some variables for which differences between species were observed both for the amplitude of the range and for optimal values along given climatic gradients. For example, *L. amplissima* and *L. pulmonaria* significantly differed in three analysed climatic variables, the former preferring conditions with a stronger oceanic influence.
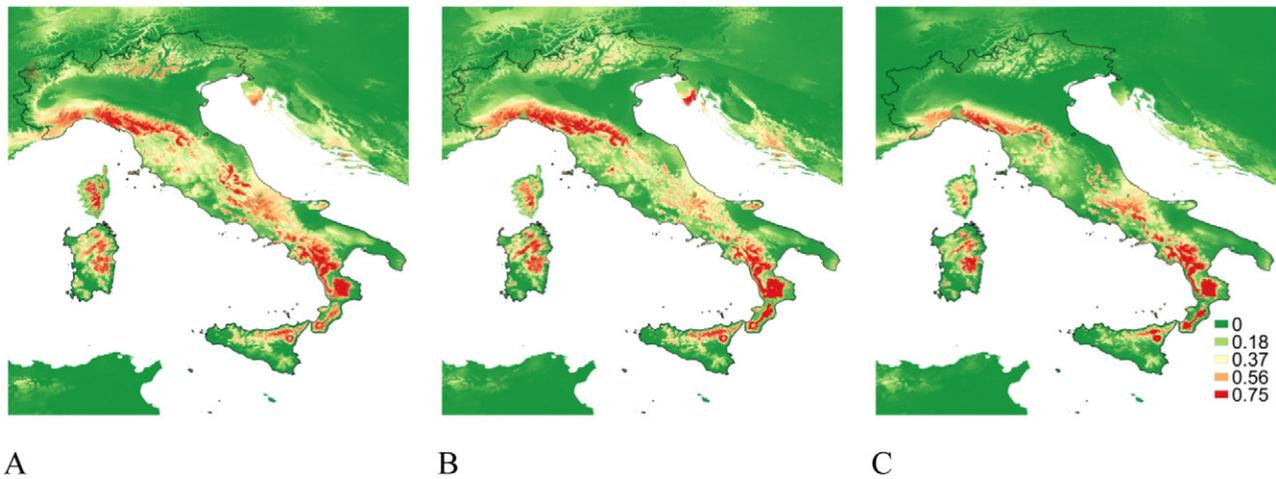
Fig. 3. Predicted habitat suitability in Italy for the three epiphytic *Lobaria* species, according to the Maxent models under current climatic conditions: A) *Lobaria pulmonaria*; B) *Lobarina scrobiculata*; C) *Lobaria amplissima*.

However, our results did not support the hypothesis that differences in the climatic niche of the three species could have determined distinct distributional patterns in Italy. This outcome could reflect the effect of additional environmental drivers, not considered in this study, that act at the local scale, such in the case of land-use intensity, forest structure, topography, and vegetation type (Nascimbene et al., 2012, 2013a). This hypothesis is consistent with recent findings (Nascimbene et al., 2013b), stressing that forest structure and local habitat conditions are the main drivers of species turnover in *Lobaria pulmonaria* communities. In this perspective, the co-occurrence of our three *Lobaria* species in climatically suitable areas would reflect the interplay among different environmental filters acting at different spatial scales.

4.2. How projected climate change will impact the current habitat suitability for the three Lobaria species?

All the indicators considered in this study (range loss, gain, change, and turnover) suggest that in the next decades climate change will significantly impact the distribution range of the three *Lobaria* species across Italy. Models under climate change scenarios predict a steep gradient of increasing range loss and range turnover across time slices for these species, indicating that they are rapidly facing a high extinction risk associated with a reduction of their range of predicted occurrence. Concurrently, range gain will decrease to nearly zero, causing a highly negative change in their range. This pattern is corroborated by the

dramatic loss of predicted occurrences in the sites in which the species were actually recorded.

The forecasted impact of climate change is even more severe for *L. pulmonaria* than for the other two species, predicting that by 2080 its climatic suitability in the geographical space will be reduced down to 15% of the current size. Under the effects of climate change, the decline of *L. pulmonaria* seems to accelerate in the near future and this could override the species buffering capability related to its ecological adaptability.

This situation suggests that the current distribution pattern of *L. pulmonaria* in Italy may mask an extinction debt (Tilman et al., 1994) that will be rapidly paid in the coming decades. Conversely, the less pronounced pattern of decrease of the other two *Lobaria* species and their more fragmented and restricted distribution may indicate that they have already paid a large part of their extinction debt. This contrasting situation could be associated with the higher sensitivity to climate change of *L. amplissima* and *L. scrobiculata* as corroborated by our results, indicating a higher sensitivity of these species to specific climatic factors such as temperature and precipitation seasonality.

5. Conclusions

Our findings stake a claim for a rapid inclusion of the three *Lobaria* species in conservation policies designed to protect threatened organisms, such in the case of the Habitat Directive (European Commission, 1992). The patterns of current distribution and predicted temporal dynamics of these species across Italy suggest that they are susceptible to a steep decline driven by climate change that would drastically reduce their ability to survive at the southern border of their European range that, at least for *L. pulmonaria*, corresponds to the main centre of genetic differentiation (Widmer et al., 2012).

We are aware that predictions on how species will respond to climate change are based on coarse-grained climate surfaces or idealized scenarios of uniform warming (Ashcroft et al., 2009) that may lead to incorrectly estimate the risk of extinction because they neglect to consider spatially heterogeneous warming at the landscape scale, or fail to identify refugia where species can persist despite unfavourable regional climatic conditions. However, climate change may interact with local factors exacerbating the impact of stand level forest management (Nascimbene et al., 2013b). This may result in even steeper declining patterns than those predicted in our study and would urgently deserve the adoption of conservation activities according to the approach of the Habitat Directive (European Commission, 1992).

Table 3

Results of niche similarity tests in geographical space among species at two resolutions. Backgrounds are defined by each taxon ecological niche model set to a baseline threshold that maximizes the sum of sensitivity and specificity of the test data (SDM), by the combination of SDM of each taxon (common background), and by applying 10-km buffer zones around the occurrence points of each species (10 km buffer). Significant results are indicated by 'less' for significant decreasing niche overlap or 'more' for significant similarity between the two species.

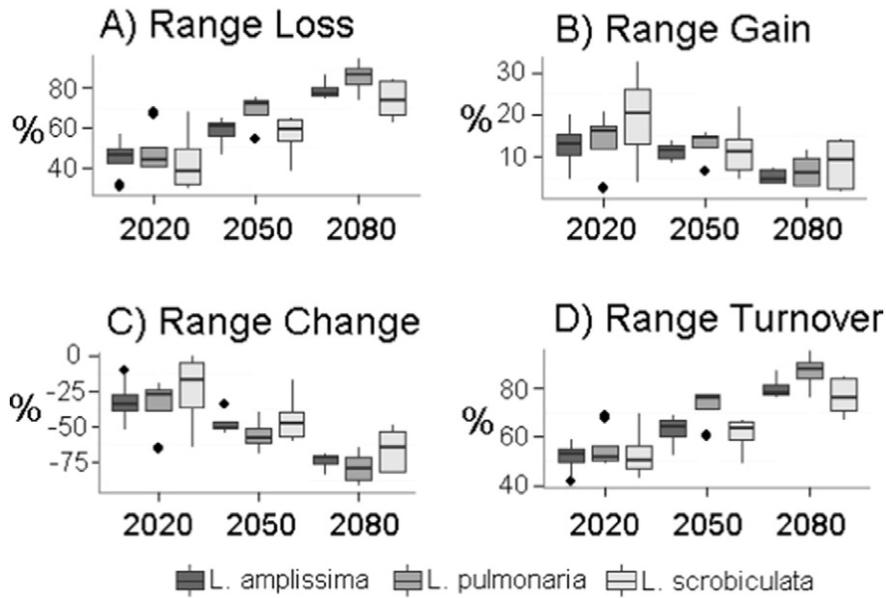| Test	Comparison	Schoener's D	Common background	10 km buffer
L. pulmonaria	*L. amplissima*	0.757	More**	ns
L. amplissima	*L. pulmonaria*		More**	More**
L. pulmonaria	*L. scrobiculata*	0.833	More**	More**
L. scrobiculata	*L. pulmonaria*		More**	More**
L. amplissima	*L. scrobiculata*	0.750	More**	More**
L. scrobiculata	*L. amplissima*		More**	ns

$**P \leq 0.01$; $*P \leq 0.05$; ns, $P \geq 0.05$.

Fig. 4. Projected impacts of climate change on the distribution of the three species of *Lobaria* s. lat. in Italy as predicted using two climate change scenarios (A2 and B1), for three time periods (2020, 2050 and 2080). (A) Percentage of range loss (RL); (B) percentage of range change (C); (C) percentage of range gain (RG) and (D) percentage of range turnover (T). The black line represents the median, black circle represents the mean, edge box corresponds to the first and third quartiles (the 25th and 75th percentiles), whiskers are 1.5 ∗ IQR (where IQR is the inter-quartile range).

For *L. amplissima* and *L. scrobiculata*, the situation might already be destined to move toward extinction in their Italian range that is caused by extensive range loss, which may be connected with the loss of genetic variability (Widmer et al., 2012). This precarious situation emphasizes the vulnerability of these species to local stochastic changes related to both natural and anthropogenic impacts. *L. pulmonaria* may experience a predicted decline in the coming decades that is even more abrupt and severe. However, its current relative commonness across Italy still provides a major opportunity for its successful long-term conservation, given that local protection measures would be soon adopted. In this perspective, the strict protection of well-established populations and the improvement of local habitat quality by near-to-nature silviculture should be adopted, at least in Natura 2000 sites that are prioritized for nature conservation (European Commission, 1992).

It has been demonstrated that, at the local scale, stands with large populations of *L. pulmonaria* are core areas for many lichens of conservation concern, suggesting that their protection could also enhance the conservation of these species (e.g. Nascimbene et al., 2010). However, our results warn against an over-estimation of the indicator power of a single flagship species, indicating that even lichens with peculiar and similar climatic envelopes may fail to co-occur within a given forest area, reflecting the interplay of environmental variables acting at different spatial scales. This suggests that conservation policies targeting single species may be insufficient for lichens, while a multiple indicator and multiple scale approach (e.g. Giordani, 2012) could provide more useful tools for a community-based conservation strategy for epiphytes.
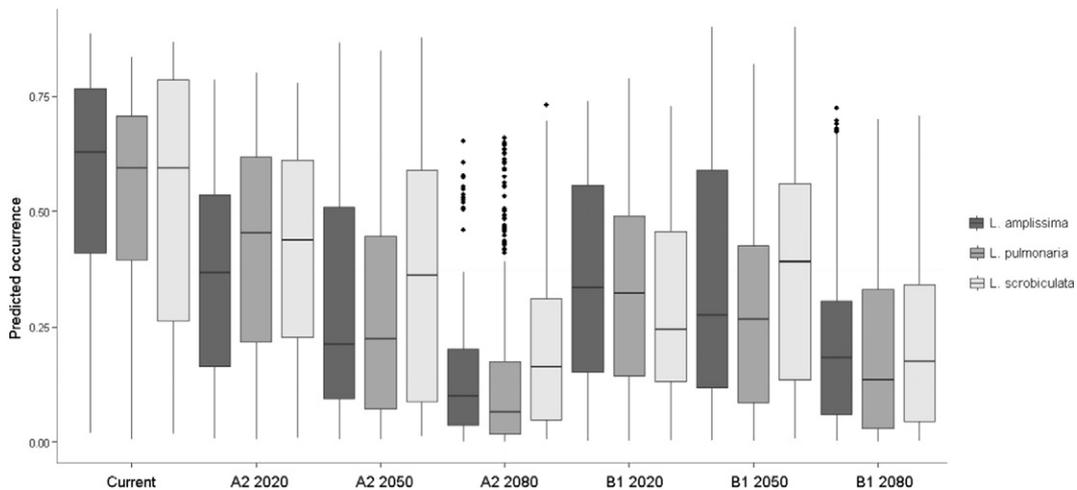
Acknowledgments

Fig. 5. Predicted occurrence of the three *Lobaria* s. lat. species in the 30 arc sec grid cells where the *taxa* have been actually observed in the current conditions. Predictions were carried out using two climate change scenarios (A2 and B1), for three time periods (2020, 2050 and 2080). The black line represents the median, black circle represents the mean, edge box corresponds to the first and third quartiles (the 25th and 75th percentiles), whiskers are 1.5 ∗ IQR (where IQR is the inter-quartile range).

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