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

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1 **Climate change fosters the decline of epiphytic *Lobaria* species at the southern border of their**  
2 **European range**

3  
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21

22 **Running title:** Impact of climate change on forest epiphytes

23

24 **Abstract**

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

41

42 **Keywords:** climatic niche, epiphytic lichens, global change, habitat suitability, niche modelling, range loss

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44

45

## 46 1. Introduction

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

52 Do to their poikilohydric nature, lichens are among the most sensitive organisms to climate change  
53 (Nascimbene & Marini, 2015; Giordani et al. 2014). In particular, changing climatic conditions are expected  
54 to impact forest epiphytic lichens (Bassler et al., 2015; Nascimbene & Marini, 2015), contributing to the local  
55 extinction of several species and causing changes to community composition (e.g. Aragón et al., 2012). In a  
56 poikilohydric organism the water content tends to reach equilibrium with that of the surrounding  
57 environment (Proctor & Tuba 2002). Lichen physiology is closely coupled to ambient temperature and  
58 moisture, which influence thallus water saturation and desiccation (Green et al., 2008; Gauslaa et al., 2012;  
59 Merinero et al., 2014). Both water and temperature directly control relevant eco-physiological processes  
60 influencing growth rates and species distribution (Insarov & Schroeter, 2002; Nascimbene & Marini, 2015).  
61 Increasing ambient temperature may impact lichens due to increased respiratory carbon losses (Schroeter et  
62 al., 2000). Moreover, high temperature influences thallus rewetting and water content, inducing frequent and  
63 severe desiccation events that hinders the photosynthetic activity (Insarov & Schroeter, 2002). These  
64 warming-related effects could be therefore exacerbated by poor precipitations (Hawkins et al., 2003).  
65 Similarly to other Mediterranean regions, peninsular Italy is expected to experience dramatic climatic  
66 changes in the coming decades, with increasing frequency and decreasing intensity of warm and cold days,  
67 along with an increase in the frequency and intensity of drought (IPCC, 2013, 2014). This climatic pattern  
68 could seriously impact the biota of the Mediterranean basin that is among the most important hotspots of  
69 biodiversity at the global level (Médail & Quézel, 1999).

70 In this framework, many lichens that require temperate-humid conditions may rapidly decline in  
71 Mediterranean regions, such in the case of the epiphytic *Lobaria* species that are among the most threatened  
72 lichens in Europe (Nascimbene et al., 2013a; Otalora et al., 2015). In Italy, three *Lobaria* s. lat. species  
73 (Stenroos et al., 2003. Högnabba et al., 2009) reach the southern border of their distributional range  
74 (Yoshimura, 1971; Widmer et al., 2012; Zalewska & Bohdan, 2012) and are mainly bounded to humid,  
75 undisturbed, forests that buffer sub-optimal macroclimatic conditions (Merinero et al. 2014; Nascimbene et  
76 al., 2013a). The Italian populations are critical for the long-term conservation of *Lobaria* species in Europe  
77 since this region hosts the most important post glacial refugia and the main centres of genetic differentiation  
78 (e.g. for *L. pulmonaria*; Widmer, et al., 2012). Under these circumstances, Italy has a strong responsibility at  
79 the European level for the conservation of the species.

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

## 93 2. Methods

### 94 2.1 The study species and occurrence data

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

99 *Lobaria amplissima* (Scop.) Forssell is a mainly European species of mild-temperate climates. It has  
100 internal cephalodia and a shrubby cyanobacterial photomorph attached to the foliose green algal photomorph  
101

102 (Stenroos et al., 2003). Both photomorphs may develop independently. The rosette-forming thalli of *L.*  
103 *amplissima* are more substrate-adherent than those of *L. pulmonaria*. *L. amplissima* reproduces only by  
104 ascospores (sexual reproduction).

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

109 Species occurrence data were obtained from a national database including all available records of the  
110 three selected species in Italy. We removed identical occurrence records using ENMTools (Warren et al.,  
111 2010; see also Warren & Seifert, 2011).

## 112 113 2.2 Climatic variables

114 Nineteen bioclimatic variables were downloaded from the WorldClim database website  
115 (<http://www.worldclim.org>) at a 30-s (i.e., about 1×1 km) spatial resolution (Hijmans et al., 2005) for the  
116 extent of Italy. Climatic variables related to temperature and precipitation was assumed to be important for  
117 limiting the distribution of lichen species. To reduce the multicollinearity between predictors and to  
118 minimize model overfitting, we performed a pairwise Pearson correlation between bioclimatic predictors and  
119 we retained predictors that showed a high relative contribution to the Ecological Niche Models (ENMs) and  
120 were not highly correlated to each other ( $r \leq |0.70|$ ; see recommendation of Elith et al., 2006). Six variables  
121 were retained for the analyses: BIO2—Mean Diurnal Range, BIO4—Temperature Seasonality, BIO8—Mean  
122 Temperature of Wettest Quarter, BIO9—Mean Temperature of Driest Quarter, BIO 13—Precipitation of  
123 Wettest Month and BIO15—Precipitation Seasonality.

## 124 125 2.3 Scenarios of climate change

126 Two greenhouse gas emission scenarios (GESs: A2 and B1) were selected to assess plausible future  
127 conditions based on a range of human activities over the next few decades. Scenario A2 describes a  
128 heterogeneous world with regionally oriented economic development. This scenario projects rapid  
129 population growth that will reach 15 billion by the year 2100; per capita, economic growth and technological  
130 change are slower than in the other previously developed scenarios. Scenario B1 describes a convergent  
131 world with the global population peaking mid-century and declining thereafter, but with rapid change in the  
132 world's economic structure toward a service and information economy, with reductions in the intensity of  
133 material consumption and the introduction of clean and resource-efficient technologies. The emphasis in this  
134 scenario is on finding global solutions that allow economic development that are socially and  
135 environmentally sustainable, including improved equity, but without additional climate initiatives. We used  
136 climatic projections from two internationally recognized general circulation models (GCMs): HADCM3 and  
137 ECHAM5. To explore future changes in the potential range of the three species analysed here, we extracted  
138 the climate predictors for the years 2020, 2050 and 2080.

## 139 140 2.4 Ecological niches of the species

141 Niche divergence between species could be the result of an effective niche differentiation in the E-space that  
142 translates into the occupation of different habitats in the G-space. Niche divergence could also reflect  
143 differences in the relationships between the climatic variables across different regions of geographical space  
144 (Broennimann et al., 2012; Theodoridis et al., 2013). Values of environmental variables were extracted for  
145 all the occurrences of each species and inter-species divergence was examined. For this, we used a non-  
146 parametric Kruskal-Wallis test to assess differences among species along each climatic variable  
147 independently. Kernel density plots were used to visualize the distribution of each variable.

148 Species occurrence data and the six bioclimatic variables were used for the construction of ENMs for  
149 each species with Maxent 3.3.3e (Phillips et al., 2006). We used 70% of the occurrence records for each  
150 species to calibrate the model and 30% to test it, a common practice in ecological studies (Phillips et al.,  
151 2006). All other parameters were set to a default value. The performance of the models was assessed using  
152 the area under the receiver operating characteristic curve (AUC; Hanley & McNeil, 1982).

153 Niche breadth in G-space was estimated by applying Levins inverse concentration metric (1968) as  
154 implemented in ENMTools to the resulting sets of suitability scores; these were standardized so that the  
155 minimum possible niche breadth within this space was 0 (indicating that only one grid cell in the  
156 geographical space has a nonzero suitability) and the maximum niche breadth was 1 (where all grid cells are  
157 equally suitable). Selection of an appropriate background area is critical to the analysis of niche similarity

158 (Warren et al., 2010), and consequently we created different background areas to account for the effects of  
159 different backgrounds on the modelling process. We followed two different approaches. The first approach  
160 uses the output of the ENM of each species' dataset to create a baseline threshold that maximizes the sum of  
161 sensitivity and specificity of the test data (Liu et al., 2005), and these in combination (common background).

162 The second approach uses a 10-, 20- and 30-km buffer zone around the occurrence points of each  
163 species. All analyses were performed in R statistical software (R Development Core Team, 2005) using the  
164 set of functions provided in Broennimann et al. (2012).

165

### 166 3. Results

#### 167 3.1 Species occurrence and co-occurrence in Italy

168 We collected 548, 270 and 156 occurrence records for *L. pulmonaria*, *L. amplissima* and *Lobarina*  
169 *scrobiculata*, respectively, from 660 1×1 km cells in Italy (Table 2). In most cases (572 cells) only one of the  
170 three species was reported, whereas a partial overlap of two species was observed in 71 cells. The co-  
171 occurrence of the three species was only observed in 17 cells, corresponding to a very low percentage with  
172 respect to the overall distribution of the species in Italy. *L. amplissima* co-occurred with one and/or both  
173 other species in 48% of its geographic range, in contrast with what observed for *L. pulmonaria*, which co-  
174 occurred with the other taxa in only 15% of the cells. Data for *L. scrobiculata* are intermediate between the  
175 other species, co-occurring with them in 39% of its range.

176

#### 177 3.2 Niche differentiation under current conditions

178 The climatic requirements of the three species were quite similar (Fig. 1). The Schoener's D values were  
179 always >0.7, corresponding to a high degree of niche overlap (Rödder & Engler 2011). Nonetheless,  
180 measures of three out of the six climatic variables (BIO4, BIO8 and BIO15) differed significantly ( $P < 0.05$ )  
181 for *L. pulmonaria* vs. *L. amplissima*, while measures for only one bioclimatic variable (BIO13) of *L.*  
182 *scrobiculata* differed significantly from those of the other two species.

183 Models inferred from occurrence records predicted the distribution of the three species. Cross-  
184 validated AUC values for all models were high (>0.9) and low test omission rates indicated an excellent  
185 model performance. For all three species, core areas with the highest predicted occurrences were represented  
186 by the Northern Apennine and by montane areas of Southern Italy (Fig. 2). *L. pulmonaria* showed a  
187 considerably wider potential distribution across Italy compared with the other two species. Its occurrence  
188 was predicted in the lowest montane areas of the Alps, along the Apennines and in the mountains of Sicily  
189 and Sardinia. The predicted distribution of *L. amplissima* and *L. scrobiculata* indicated severe fragmentation  
190 of their distribution in central Italy and the Alps. However, the climatic suitability value of these species  
191 seemed to be higher than that of *L. pulmonaria* in montane areas of Sardinia and Sicily.

192 Tests for niche similarity in the geographical space supported high niche similarity (> 0.75), and  
193 generally statistically significant overlaps were observed in all pairwise comparisons between the three  
194 species (Table 3). As far as the niche breadth was concerned, *L. amplissima* showed the lowest niche breadth  
195 (0.23), whereas the niche breadths of *L. pulmonaria* and *L. scrobiculata* were quite similar (0.34 and 0.35,  
196 respectively).

197

#### 198 3.3 Predicted effects of climate change

199 Both A2 and B1 scenarios predicted a similar drastic decrease of the range of the three species from current  
200 conditions to 2080 (Fig. 2), with slight differences depending on the scenario involved. Therefore, climate  
201 change is expected to impact the distributional range of the three species (Fig. 3) that showed strong  
202 temporal trends for all descriptors. The average percentage of range loss (RL) for *L. amplissima* was 44.9%,  
203 58.1% and 79.0% for 2020, 2050 and 2080, respectively (Fig. 3a). The trend for *L. scrobiculata* was quite  
204 similar with a predicted RL = 74.0% in 2080 when compared with current conditions. The estimated average  
205 RL for *L. pulmonaria* at the three time slices was even higher, increasing from 48.5% to 85.6% from 2020 to  
206 2080. On the contrary, the three species are expected to gain a moderate percentage of areas with suitable  
207 climate in 2020, with the range gain (RG) ranging from 12.8% for *L. amplissima* to 19.3% for *L.*  
208 *scrobiculata* (Fig. 3b). The RG for all species tended to decrease in 2080 with *L. amplissima* gaining the  
209 smallest area (5.3% compared to current conditions). As a consequence, the range change (RC) is expected  
210 to be strongly negative for all species in 2020 and beyond (Fig. 3c), with the RC being the largest (-24.1%)  
211 for *L. scrobiculata* and the least (-34.7%) for *L. pulmonaria*. In 2050, the three species are expected to have  
212 a negative RC involving as much as half of their current predicted range, with the highest RC for *L.*  
213 *pulmonaria* (-55.6%). In 2080, the three species would have lost almost 3/4 of their current predicted range

214 on average, but relevant differences would occur with the smallest RC (−78.7) for *L. pulmonaria* and the  
215 largest (−65.7%) for *L. scrobiculata*. All three species showed a predicted range turnover (RT) >50% for  
216 2020 (Fig. 2d), with the average expected to exceed 80% in 2080, and the greatest RT (86.7%) for *L.*  
217 *pulmonaria*.

218 When focusing on the sites where the species currently occur, a future reduction of the climatic  
219 suitability for all the species was estimated (Fig. 4). For both scenarios of global change (A2 and B1), the  
220 mean predicted occurrence of the species at those sites will be always <0.5 after 2020. The A2 scenario  
221 predicted a drastic decrease, independent of the species, in 2080 with the probability of occurrence being ca.  
222 0.1 for all species. The B1 scenario produced similar results, even though the reductions from 2050 to 2080  
223 would be less pronounced when compared with those predicted basing on the A2 scenario; by 2080, the  
224 climatic suitability would be slightly higher for all three species.

#### 225 226 **4. Discussion**

227 Our study revealed that, despite they rarely co-occur, the three epiphytic *Lobaria* species have similar  
228 climatic envelopes and that predicted climate changes in the Mediterranean basin are fostering their decline  
229 at the southern border of their European range. However, a wider climatic niche, which is likely related to  
230 specific functional traits, may have allowed *L. pulmonaria* to reach and maintain a more widespread and less  
231 fragmented distribution across Italy as compared with the other two species. This would give more chances  
232 for long-term conservation if protection policies are rapidly adopted. Details on these general findings are  
233 discussed in the following sections arranged according to the two main questions addressed in this study.

##### 234 235 *4.1 Do the climatic niches of the three species differ under current climatic conditions, and does this 236 determine different spatial patterns of habitat suitability?*

237 Despite belonging to the same epiphytic community composed of species related to sub-oceanic conditions  
238 (Barkman, 1958), the three *Lobaria* species rarely co-occurred at the same sites in Italy. To explore this  
239 phenomenon, we tested whether the climatic niches of these species differ under current climatic conditions  
240 and if the dissimilarity could explain divergent spatial patterns of their habitat suitability. The species  
241 showed large overlaps for most of the considered climatic variables, except for some variables for which  
242 differences between species were observed both for the amplitude of the range and for optimal values along  
243 given climatic gradients. For example, *L. amplissima* and *L. pulmonaria* significantly differed in three  
244 analysed climatic variables, the former preferring conditions with a stronger oceanic influence. However, our  
245 results did not support the hypothesis that differences in the climatic niche of the three species could have  
246 determined distinct distributional patterns in Italy. In fact, similarity test indicated that the observed niche  
247 overlap is not due to habitat similarity in the regions occupied by the species, but more probably to a similar  
248 habitat selection (Warren, al., 2008; Broennimann, al., 2012). This outcome is in accordance with a possible  
249 competitive exclusion mechanism (Armstrong & McGehee 1980) which may have determined the current  
250 divergent distribution of the three species in Italy. Among them, *Lobaria pulmonaria* seems to have a higher  
251 competitiveness, as indicated by its wider distribution pattern across Italy, with potential contact between  
252 Apennine and Alpine populations. This situation is consistent with the wide climatic niche of this species  
253 that is likely fostered by peculiar functional traits. *L. pulmonaria* has both green-algal and cyanobacterial  
254 photobionts, as well as sexual and vegetative dispersal strategies (Scheidegger, 1995), functional  
255 differentiation (reproductive and meristematic) of thallus lobes (Scheidegger et al., 1998; Giordani &  
256 Brunialti, 2002), and large thallus size and thickness that enhance its water holding capacity (Merinero et al.,  
257 2014). These traits might have supported a higher ecological adaptability of *L. pulmonaria* compared to *L.*  
258 *amplissima* and *L. scrobiculata* that is reflected by a more widespread distribution across Italy.

##### 259 260 *4.2 How projected climate change will impact the current habitat suitability of the three Lobaria species?*

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

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

273 This situation suggests that the current distribution pattern of *L. pulmonaria* in Italy may mask an  
274 extinction debt (Tilman et al., 1994) that will be rapidly paid in the coming decades. Conversely, the less  
275 pronounced pattern of decrease of the other two *Lobaria* species and their more fragmented and restricted  
276 distribution may indicate that they have already paid a large part of their extinction debt. This contrasting  
277 situation could be associated with the higher sensitivity to climate change of *L. amplissima* and *L.*  
278 *scrobiculata* as corroborated by our results indicating a higher sensitivity of these species to specific  
279 climatic factors such as temperature and precipitation seasonality.  
280

## 281 5. Conclusions

282 Our findings stake a claim for a rapid inclusion of the three *Lobaria* species in conservation policies  
283 designed to protect threatened organisms, such in the case of the Habitat Directive (European Commission,  
284 1992). The patterns of current distribution and predicted temporal dynamics of these species across Italy  
285 suggest that they are susceptible to a steep decline driven by climate change that would drastically reduce  
286 their ability to survive at the southern border of their European range that, at least for *L. pulmonaria*,  
287 corresponds to the main centre of genetic differentiation (Widmer et al., 2012).

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

296 For *L. amplissima* and *L. scrobiculata*, the situation might already be destined to move toward  
297 extinction in their Italian range that is caused by extensive range loss and habitat fragmentation, which are  
298 usually connected with the loss of genetic variability (Widmer et al., 2012). This precarious situation  
299 emphasizes the vulnerability of these species to local stochastic changes related to both natural and  
300 anthropogenic impacts. *L. pulmonaria* may experience a predicted decline in the coming decades that is even  
301 more abrupt and severe. However, its current relative commonness across Italy still provides a major  
302 opportunity for its successful long-term conservation, given that local protection measures would be soon  
303 adopted. In this perspective, the strict protection of well-established populations and the improvement of  
304 local habitat quality and connectivity by near-to-nature silviculture should be adopted, at least in Natura  
305 2000 sites that are prioritized for nature conservation (European Commission, 1992).

306 It has been demonstrated that, at the local scale, stands with large populations of *L. pulmonaria* are  
307 core areas for many lichens of conservation concern, suggesting that their protection could also enhance the  
308 conservation of these species (e.g. Nascimbene et al., 2010). However, our results warn against an over-  
309 estimation of the indicator power of a single flagship species, indicating that even lichens with peculiar and  
310 similar climatic envelopes may fail to co-occur within a given forest stand, hampering effective large scale  
311 conservation. This definitely suggests that conservation policies targeting single species may be inadequate  
312 for lichens, while a multiple indicator and multiple scale approach (e.g. Giordani, 2012) could provide more  
313 useful tools for a community-based conservation strategy for epiphytes.  
314

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449 **Table 1.** Functional traits of the three *Lobaria* s. lat. species occurring in Italy.  
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|                       | <i>Lobaria pulmonaria</i>  | <i>Lobarina scrobiculata</i>        | <i>Lobaria amplissima</i>  |
|-----------------------|--|-------------------------------------|--|
| 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)  |

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454 **Table 2.** Occurrence and co-occurrence of the three selected *Lobaria* s. lat. species from a 30 arcsec cell grid  
 455 in Italy.  
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| Species occurrence in a grid cell | No. cells | Species Pair /Species  | No. cells                 |
|-----------------------------------|-----------|--|---------------------------|
| 3 species                         | 17        | <i>L. pulmonaria</i> + <i>L. scrobiculata</i> + <i>L. amplissima</i> | 17 (3.5% - 10.8% - 13.8%) |
| 2 species                         | 71        | <i>L. pulmonaria</i> + <i>L. scrobiculata</i>                        | 29 (6.0% - 18.3%)         |
|                                   |           | <i>L. pulmonaria</i> + <i>L. amplissima</i>                          | 27 (5.6% - 22.0%)         |
|                                   |           | <i>L. scrobiculata</i> + <i>L. amplissima</i>                        | 15 (9.5% - 12.2%)         |
| 1 species                         | 572       | <i>L. pulmonaria</i>   | 411 (84.9%)               |
|                                   |           | <i>L. scrobiculata</i>   | 97 (61.4%)                |
|                                   |           | <i>L. amplissima</i>   | 64 (52.0%)                |

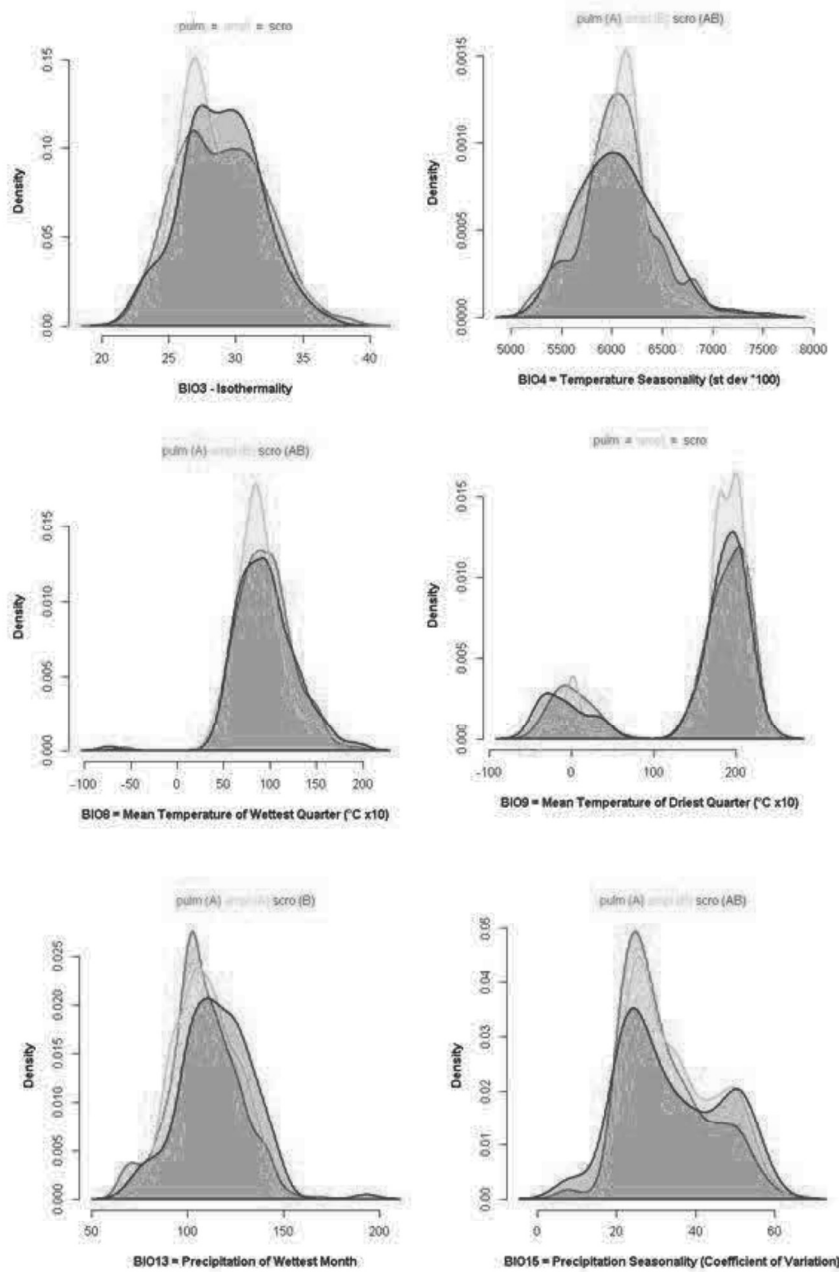
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460 **Table 3.** Results of niche similarity tests in geographical space among species at two resolutions.  
 461 Backgrounds are defined by each taxon' ecological niche model set to a baseline threshold that maximizes  
 462 the sum of sensitivity and specificity of the test data (ENM), by the combination of ENM of each taxon  
 463 (ENM CB), and by applying 10-km buffer zones around the occurrence points of each species. Significant  
 464 results are indicated by 'less' for significant decreasing niche overlap or 'more' for significant similarity  
 465 between the two species. \* $P < 0.05$ ; \*\*  $P < 0.01$ .  
 466

|   | Schoener's D | Common background | 10 km buffer      |
|---|--------------|-------------------|-------------------|
| <i>L. pulmonaria</i> - <i>L. amplissima</i>   | 0.757        | more**;<br>more** | ns;<br>more**     |
| <i>L. pulmonaria</i> - <i>L. scrobiculata</i> | 0.833        | more**;<br>more** | more**;<br>more** |
| <i>L. amplissima</i> - <i>L. scrobiculata</i> | 0.750        | more**;<br>more** | more**;<br>ns     |

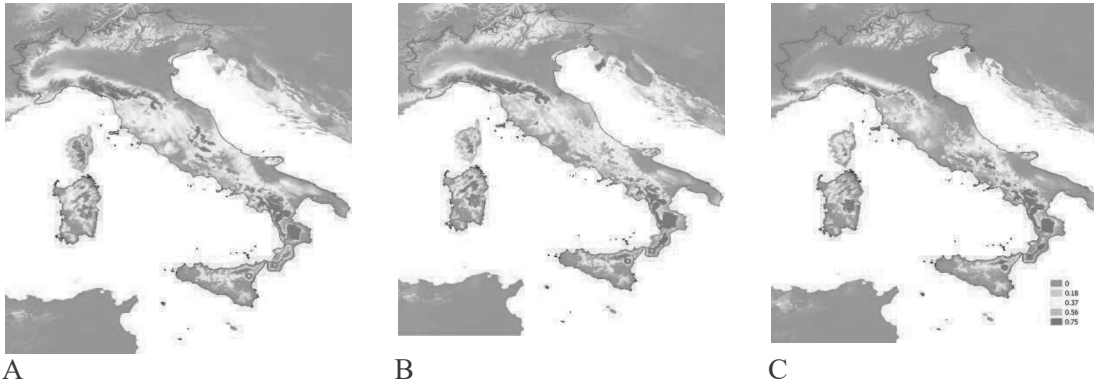
467 \*\* $P \leq 0.01$ ; \* $P \leq 0.05$ ; ns,  $P \geq 0.05$ .  
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470 **Figure 1**-Kernel density plots of the six climatic variables for the three species of *Lobaria* s. lat. in Italy .  
 471 Differentiation among species and the results of Kruskal- Wallis tests are indicated in each plot. A lack of  
 472 significant difference (at the P = 0.05 level) is indicated by an equal sign and same letter, while significant  
 473 differences are indicated by either higher or lower signs and different letters. Pulm = *Lobaria pulmonaria*;  
 474 ampl = *Lobaria amplissima*; scro = *Lobarina scrobiculata*.



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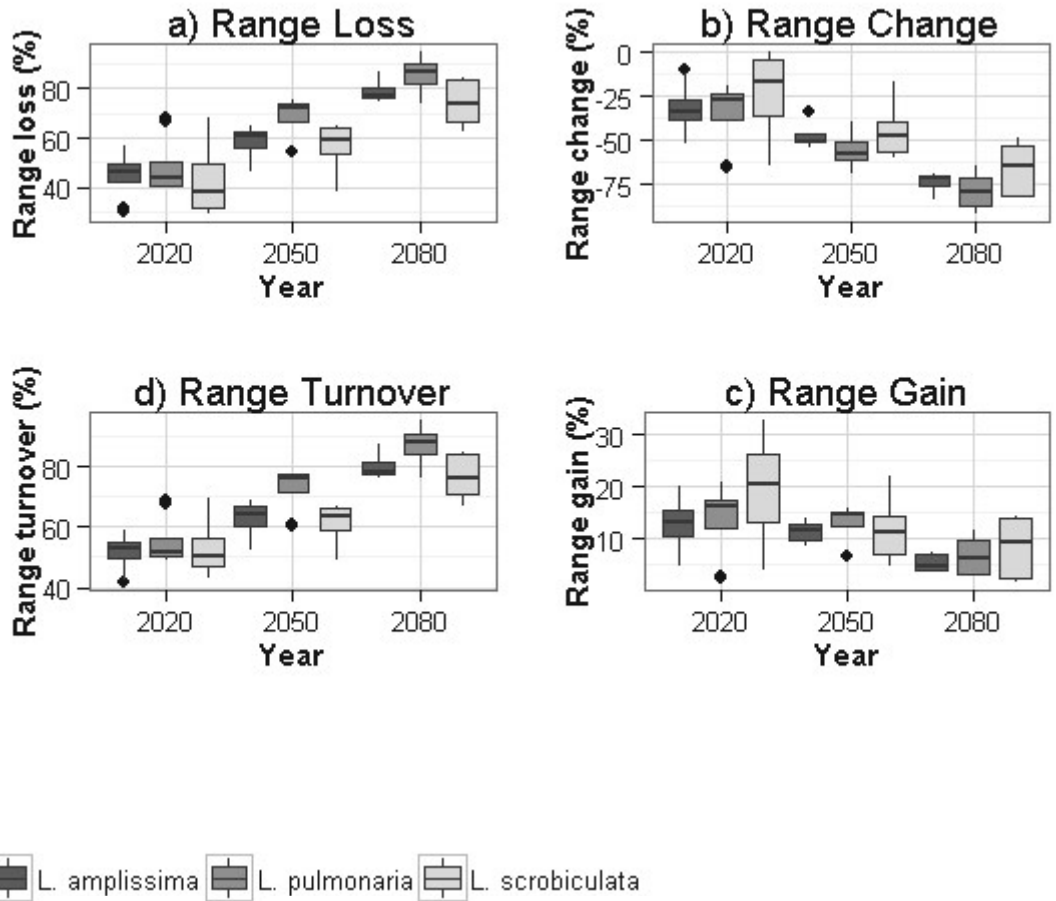
476 **Figure 2-** Predicted habitat suitability in Italy for the three epiphytic *Lobaria* species, according to the  
477 Maxent models under current climatic conditions: A) *Lobaria pulmonaria*; B) *Lobarina scrobiculata*; C)  
478 *Lobaria amplissima*.  
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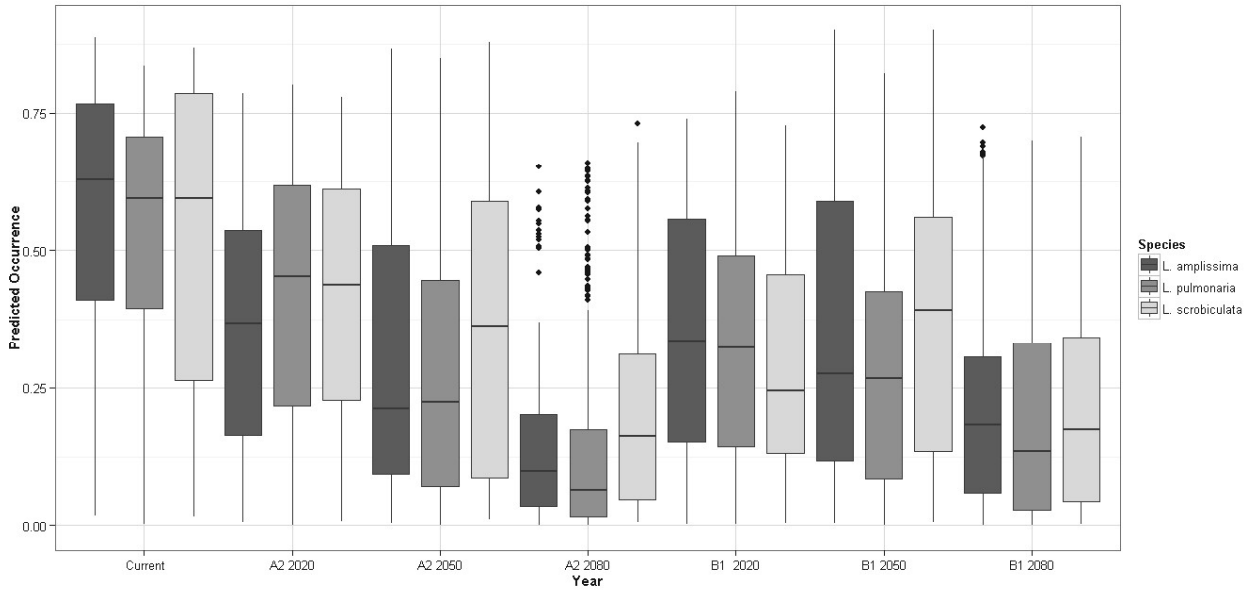
483 **Figure 3** - Projected impacts of climate change on the distribution of the three species of *Lobaria* s. lat. in  
 484 Italy as predicted using two climate change scenarios (A2 and B1), for three time periods (2020, 2050 and  
 485 2080). (A) Percentage of range loss (RL); (B) percentage of range change (C) ; (C) percentage of range gain  
 486 (RG) and (D) percentage of range turnover (T). The black line represents the median, black circle represents  
 487 the mean, edge box correspond s to the first and third quartiles (the 25th and 75th percentiles), whiskers are  
 488 1.5 \* IQR (where IQR is the inter-quartile range).  
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492 **Figure 4** -Predicted occurrence of the three *Lobaria* s. lat. species in the 30 arcsec grid cells where the *taxa*  
 493 have been actually observed in the current conditions. Predictions were carried out using two climate change  
 494 scenarios (A2 and B1), for three time periods (2020, 2050 and 2080).The black line represents the median,  
 495 black circle represents the mean, edge box correspond s to the first and third quartiles (the 25th and 75th  
 496 percentiles), whiskers are  $1.5 * IQR$  (where IQR is the inter-quartile range).  
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