

1 **Prioritization of sites for plant species restoration in the Chilean Biodiversity**

2 **Hotspot: A spatial multi-criteria decision analysis approach**

3

4 **Running Head:** Prioritizing sites for plant species restoration

5

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13

14 **Author contributions:** IF and NM conceived and designed the research; NM performed the niche
15 modeling; IF built the spatial layers and performed the GIS analyses; IF and NM wrote and edited the
16 manuscript.

17

18

19 **Abstract**

20

21 Various initiatives to identify global priority areas for conservation have been developed over the last 20
22 years (e.g. Biodiversity Hotspots). However, translating this information to actionable local scales has
23 proven to be a major task, highlighting the necessity of efforts to bridge the global-scale priority areas with
24 local-based conservation actions. Furthermore, as these global priority areas are increasingly threatened
25 by climate change and by the loss and alteration of their natural habitats, developing additional efforts to
26 identify priority areas for restoration activities is becoming an urgent task. In this study we used a Spatial
27 Multi-Criteria Decision Analysis (SMCDA) approach to help optimize the selection of sites for restoration

28 initiatives of two endemic threatened flora species of the “Chilean Winter Rainfall-Valdivian Forest”
29 Hotspot. Our approach takes advantage of freely GIS software, niche modeling tools, and available
30 geospatial databases, in an effort to provide an affordable methodology to bridge global-scale priority
31 areas with local actionable restoration scales. We used a set of weighting scenarios to evaluate the
32 potential effects of short-term vs long-term planning perspective in prioritization results. The generated
33 SMCDA was helpful for evaluating, identifying and prioritizing best suitable areas for restoration of the
34 assessed species. The method proved to be simple, transparent, cost effective and flexible enough to be
35 easily replicable on different ecosystems. This approach could be useful for prioritizing regional-scale
36 areas for species restoration in Chile, as well as in other countries with restricted budgets for
37 conservation efforts.

38

39 **Keywords:** Conservation planning; Restoration planning; Niche modeling; Maxent; Climate change;

40 *Bielschmiedia miersii*; *Pouteria splendens*.

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42

43 **Implications for Practice:**

- 44 • Developing methodological approaches to identify and prioritize areas for restoration activities is a
45 crucial task for restoration planning, especially in regions with limited resources for conservation
46 initiatives.
- 47 • The increasing availability of free GIS software, niche modeling tools, and geospatial databases offer
48 valuable resources that can be integrated into a spatial multi-criteria decision analysis (SMCDA) to help
49 in the selection of best areas for restoration initiatives.
- 50 • The SMCDA provide a flexible, transparent, affordable and replicable framework to prioritize regional-
51 scale areas for restoration of plant species in Chile, as well as in other countries with restricted budgets
52 for conservation efforts.

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56 **Introduction**

57

58 Humans have extensively and profoundly altered Earth's landscapes by transforming natural habitats in
59 productive lands and by appropriating a vast extension of available natural resources (Ellis et al. 2010;
60 Ellis & Ramankutty 2008). The replacement of natural habitats by agricultural lands, artificial forests, and
61 urban areas has generated the loss, fragmentation, and degradation of natural habitats leading to an
62 alarming global increase in species extinction rates (Foley et al. 2005; Brook et al. 2008). While the
63 current biodiversity crisis is far reaching and complex, resources available for planning and developing
64 conservation strategies are still very limited (Wilson et al. 2009; Watson et al. 2011). Therefore, one of
65 the main challenges for conservation biologist has been the development of methodological approaches
66 that helps in the prioritization of limited resources among different conservation options (Redford et al.
67 2003).

68

69 Among these challenges, a frequent task for conservationists has been the selection of areas to be
70 prioritized for conservation actions. At the global scale these initiatives have aimed to identify those
71 ecoregions that are most valuable for conservation around the world (Brooks et al. 2006). Examples of
72 these initiatives are the "Global 200 Ecoregion" (Olson & Dinerstein 2002), the "Crisis Ecoregion"
73 (Hoekstra et al. 2005), and probably the most recognized of all, the world "Biodiversity Hot Spots" (Myers
74 1990; Myers et al. 2000; Mittermeier et al. 2004). Even though these initiatives have been fruitful in
75 signaling priority areas at a global-scale, their real success has been criticized because they have not
76 provided information regarding how to allocate resources within prioritized ecoregions (Wilson et al.
77 2006). For these initiatives to have real impacts in local conservation actions will require the development
78 of complementary regional and local scales prioritization approaches (Redford et al. 2003). This is a
79 critical issue because the large extent of prioritized areas are in developing countries (Brooks et al. 2006)
80 where budgets for conservation initiatives are often much smaller than is required (Waldron et al. 2013).

81

82 At finer scales conservationists have placed a great extent of their efforts to identify and bring under
83 protection the most valuable sites for conservation. These efforts have largely been guided by the use of

84 “systematic conservation planning” (Margules & Pressey 2000), which has provided a useful framework
85 to optimize the selection of sites to be targeted for developing conservation strategies (Sarkar et al. 2006;
86 Wilson et al. 2009). In general conservation planning can be defined as “the process of deciding where,
87 when and how to allocate limited conservation resources to minimize the loss of biodiversity, ecosystem
88 services and other valued aspects of the natural world” (Pressey & Bottrill 2009). It concerns the
89 prioritization of sites based in their biodiversity value, and the participatory planning and collaborative
90 implementation of strategies that secure the long-term viability of biological diversity (Kukkala & Moilanen
91 2013). Whereas systematic conservation planning has largely influenced the way institutions and
92 governments prioritize the efforts to protect valuable ecosystems (Sarkar et al. 2006), this systematic
93 approach seems to not have permeated to other fundamental conservation actions, such as restoration
94 planning (but see Noss et al. 2009)

95
96 Biodiversity restoration activities are among the most expensive conservation strategies worldwide (Holl
97 et al. 2003). However the development of approaches specifically aimed to prioritize sites for restoration
98 or reintroduction of species has been scarcely addressed (Noss et al. 2009). In contrast to the
99 predominant systematic conservation planning approach that focuses primarily in prioritizing areas that
100 currently contain target species, restoration activities often need to prioritize sites that have reduced
101 populations, or even the complete absence of the species to conserve. Furthermore, because systematic
102 conservation planning has focused primarily on current biodiversity patterns, it has had limited
103 applications for conservation strategies in a rapidly changing climate (Pressey et al. 2007). As a result,
104 species may lose protection as their ranges shift out of current reserve boundaries (Schloss et al. 2011).
105 Therefore the development of complementary efforts that helps decision-makers to identify best areas for
106 restoration activities under a climate change perspective should be taken as a major objective.

107
108 The increasing development of freely available spatial software, and the production and release of
109 geospatial data by governments and international organizations have greatly improved our capacity to
110 address spatial conservation planning challenges (Baldwin et al. 2014). Furthermore, the availability of
111 niche modeling softwares and the development and release of future climate projections have also

112 increased our capability for conservation planning under a climate change scenario (Schwartz 2012).
113 Even though, available planning software, such as Marxan are already capable to handle future
114 environmental variability (e.g. Carvalho et al. 2011; Veloz et al. 2013), they often need large amount of
115 specific data that may not be readily available, or even may not be relevant for regional scale restoration
116 prioritization goals. Moreover, their use may be perceived as complex and challenging by practitioners,
117 which could preclude their application for decision-making (Baldwin et al. 2014).

118
119 To overcome these difficulties, the integration of Multi-Criteria Decision Analysis (MCDA) in a Geographic
120 Information System (GIS) could provide an inexpensive, simple, flexible, transparent and replicable
121 approach to integrate available and generated spatial information to prioritize sites for restoration
122 initiatives at a regional scale. From a rudimentary perspective a GIS-based MCDA or Spatial Multi-Criteria
123 Decision Analysis (SMCDA) can be seen as a decision support process that integrates geospatial data
124 and combining rules to obtain information for decision-making (Malczewski 2006). The SMCDA approach
125 provides a framework that takes explicit account of multiple criteria, helps to structure the management
126 problem, provides a model that can serve as a focus for discussion, and offers a transparent process that
127 leads to rational, justifiable, and explainable decisions (Mendoza & Martins 2006). SMCDA has been
128 increasingly used in environmental sciences and forest management in last decades; however it
129 application for selecting sites for restoration have been scarcely explored (Mendoza & Martins 2006;
130 Huang et al. 2011).

131
132 The objective of this study was to develop and evaluate a complementary approach to systematic
133 conservation planning that could be widely used to identify and prioritize site for species restoration
134 initiatives at the regional scale. As a representative case study, we focused our analysis on the selection
135 of priority areas for restoration for two threatened endemic tree species *Bielschmiedia miersii* and
136 *Pouteria splendens* of the “Chilean Rainfall-Valdivian Forest Biodiversity Hotspot” (Arroyo et al. 2004).
137 These species are dominant trees in their respective ecological communities, are inadequately covered
138 by protected areas, and are increasingly threatened by human driven activities (Hechenleitner et al. 2005;
139 Schulz et al. 2010; Pliscoff & Fuentes-Castillo 2011).

140 **Methodology**

141

142 **Study area**

143

144 The study area covers the “shrub and sclerophyllous forest ecological region” of Central Chile (Gajardo
145 1994), including the coastal and inner territories that make up the current distribution of *B. miersii* and *P.*
146 *splendens* (Fig. 1). Original landscapes within this ecological region were characterized by a dominance
147 of shrubs species in the coastal ranges, and a mix of forest and shrubs in more inland areas (Gajardo
148 1994). This region has been severely transformed by the fragmentation of the original landscape, and the
149 remaining habitats are increasingly threatened by human activities (Pliscoff & Fuentes-Castillo 2011).

150

151 Climate within the study area can be broadly characterized as Mediterranean, with marked colder
152 temperatures and rainy periods during winter months, and warmer and dry period during summer
153 (Luebert & Pliscoff 2006). However, local climate characteristics differ considerably over the geographical
154 range of the study area. Historical data for the northern city of Illapel (31°37'50" S; 71°09'55" W) registers
155 an annual total precipitation of ~240 mL, while data for the southern city of Rancagua (31°54'43" S;
156 71°30'39" W) reports a yearly total precipitation of ~500 mL. Annual average temperatures are similar
157 over the study range (around 12 - 13°C), but thermic oscillation during warmer and colder seasons differs
158 between the coastal and inland territories (Dirección Meteorológica de Chile 2001). For example, the
159 inner city of Santiago (33°27'50" S; 70°38'26" W) has an average maximum temperature of 29.7°C during
160 summer months and a minimum average temperature of 3.9° C during winter, whereas for the same
161 period the maximum and minimum temperatures for the coastal city of Valparaiso (33°02'42" S;
162 71°37'14" W) are 20.8°C and 9.2°C respectively (Cruz & Calderón 2008).

163

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167

168 **Spatial Multi Criteria Decision Analysis (SMCDA)**

169

170 To identify the best suitable areas for restoration with *B. miersii* and *P. splendens* we performed a GIS-
171 based multi criteria decision analysis (Malczewski 2006) consisting in the integration of four spatial raster
172 layers by using a weighted scheme (Eq. 1).

173

$$PRS_i = W_{PHS} \times PHS_i + W_{FHS} \times FHS_i + W_{LUT} \times LUT_i + W_{PSC} \times PSC_i$$

174 (Eq. 1)

175

176 We designed the equation and layers to produce a Priority for Restoration Score (PRS) ranging from 0 to
177 10 for each species (*i*), with higher values indicating better areas for restoration. Weights (W_x) are specific
178 for each variable and their sum must be equal to 1. Spatial layers in Equation 1 are: Present habitat
179 suitability (PHS), used as an indicator of the relative quality of each pixel's current climatic conditions for
180 the occurrence of the assessed species. Future habitat suitability (FHS), used as an indicator of the
181 relative quality of each pixel's future climatic conditions for the occurrence of the assessed species. Land-
182 use type (LUT), which represents the current availability of lands with potential conditions to start a
183 restoration project with the studied species. Priority sites for conservation (PSC), which are areas
184 prioritized by the Chilean government for future conservation initiatives, and used as an indicator of the
185 suitability of each pixel to hold restoration activities in the long-term. The specific methods to generate
186 these four layers are explained below.

187

188 *Present Habitat Suitability (PHS)*

189

190 We used Maxent software version 3.3.3k (Phillips et al. 2006; Phillips & Dudík 2008;
191 <http://www.cs.princeton.edu/~schapire/maxent>) to model present and future potential habitat suitability of
192 *B. miersii* and *P. splendens*. We input georeferenced data of recorded individuals of both species as
193 presence points and climatic geospatial data gathered from the WorldClim database
194 (<http://www.worldclim.org>). Worldclim database consists in 19 bioclimatic layers generated from the

195 interpolation of climatic data compiled around the world with a resolution of $\sim 1 \text{ Km}^2$ (Hijmans et al. 2005).
196 Species-presence data was obtained from herbarium specimens, literature records, previous species
197 surveys, and data collected in several field campaigns during the year 2011. We aggregated species
198 presence points to match climatic data resolution avoiding pseudo replication. A total of 75 presence
199 points for *B. miersii* and 22 for *P. splendens* were included in the modeling procedure.

200
201 To ensure the quality of the final habitat suitability models and to reduce potential over-parameterization (
202 Williams et al. 2003; Merow et al. 2013) we performed a Pearson correlation analysis of the 19 bioclimatic
203 variables using for that the software ENMTools version 1.4.4 (Warren et al. 2010). As suggested by
204 previous studies (Kumar & Stohlgren 2009), all variables with correlations larger than 0.8 were evaluated
205 to retain only those more relevant for the species ecology. After the correlation analysis, only 8 out the 19
206 bioclimatic variables were included in the modeling of *B. miersii* and *P. splendens* suitable habitats (See
207 supplementary data).

208
209 To select the model parameters we generated and compared several different models by utilizing the
210 corrected Akaike information criterion (AICc) available in the software ENMTOOLS version 1.4.4 (Warren
211 et al. 2010). We took this approach, instead of using Maxent default parameters, as recent studies have
212 shown that could provide better results than Maxent standard configuration (e.g. Merow et al. 2013; Syfert
213 et al. 2013), especially when modeling with a small number of samples ($< 20 - 25$) (Shcheglovitova &
214 Anderson 2013). The results suggested that the best combination of parameters were HQPT with a
215 regularization multiplier of 2 for *B. miersii* and LQ with a regularization multiplier of 1 for *P. splendens*
216 (See supplementary data).

217
218 To generate the final model for *B. miersii* we used a random sample of 75% of the presence points, while
219 the 25% remaining points were used to validate the model. The model efficiency was analyzed by the
220 reported AUC (area under the curve). The generated distribution model for *B. miersii* showed an AUC of
221 0.974, which is classified as an excellent predicting performance (Elith 2000).

222

223 In the case of *P. splendens* we followed the “Jackknife” model testing procedure proposed by Pearson et
224 al. (2007), which is especially helpful for bioclimatic modeling with small presence point data. The
225 procedure consists in removing one presence point from the original dataset (n=22) to subsequently run
226 the model with the remainder (n – 1, 21 points) presence points. This process was repeated for all
227 presence points generating 22 different models. We then analyzed *P. splendens* modeling performance
228 by using the software “pValuecompute v.1.0” (Pearson et al. 2007). Performance test for the modeled
229 distribution showed good predicting capability, with a success of 86% (p < 0.001).

230
231 Finally we built the PHS raster layers by standardizing the data produced by the Maxent modeling phase
232 into values ranging from 0 to 10. We did this by dividing the probability values of each pixel by the
233 maximum probability value obtained in the entire grid, and then multiplying the resulting value by 10.
234 Generated layer was then resampled to 100 m/pixel through the bilinear interpolation method.

235

236 *Future Habitat Suitability (FHS)*

237

238 To generate the future habitat suitability layer under a hypothetical climate change scenario, we re-
239 projected the models generated in the PHS section by using projected climatic data for the period 2041-
240 2060. We used the climatic projection model known as HadGEM2-ES (Jones et al. 2011) because of its
241 good overall performance in predicting the seasonal variability of precipitation and temperature in South
242 America (Cavalcanti & Shimizu 2012). We chose the RCP 2.6 scenario as a conservative representation
243 of concentrations pathways (RCP) of greenhouse gases (Moss et al. 2010). The RCP 2.6 scenario
244 assumes that the global greenhouse emissions will have their maximum concentration between the years
245 (2010 - 2020), declining after this period. The new climatic layers were downscaled and calibrated using
246 WorldClim 1.4 as the baseline “present” climate (Hijmans et al. 2005). The same bioclimatic variables
247 selected to build the distribution model under the current climatic conditions for each species were used
248 to perform the modeling of future potential habitat suitability. The final FSH raster layer was standardized
249 in values ranging between 0 and 10 and resampled to 100 m/pixel by using the same process used to
250 generate the PSH layer.

251 *Land-use type (LUT)*

252

253 We used the Chilean national forest inventory spatial dataset (available at <http://sit.conaf.cl/>) to categorize
254 land-use within the study area. This polygon-based data set was recently updated and is one of the main
255 tools used by the government to develop policies regarding to forest conservation and management
256 (CONAF-Corporación Nacional Forestal 2011). We reclassified the more than 50 land-use type
257 categories present in the inventory in three main classes (*i.e.* urban, productive, natural) based on the
258 urban-rural-natural spatial pattern present in central Chile (Schulz et al. 2010). Urban lands encompassed
259 all areas classified as urban or industrial by the forest inventory, and were considered not suitable for
260 restoration and therefore given a value of 0. We based this decision on the large difficulties involved in
261 recovering urban and industrial land into areas suitable for restoration initiatives (Pavao-Zuckerman
262 2008). Productive lands included all areas used for agriculture and silvicultural activities and were given a
263 value of 5. This intermediate score represented areas that could be suitable for restoration, but where
264 restoration projects will face several difficulties due to private land-use conflicts and soil restoration
265 challenges (Rey Benayas & Bullock 2012). Natural lands grouped all areas covered by natural vegetation
266 communities, and were given a value of 10. The resulting reclassified vector layer was then converted to
267 a raster layer with a 100 m/pixel resolution.

268

269 *Priority Sites for Conservation (PSC)*

270

271 Priority Sites for Conservation are specific areas identified by the Chilean government as the most
272 important zones to develop private or public conservation efforts. There are a total of 68 Priority Sites for
273 Conservation in Chile, and they represent a proactive mechanism specified in the Chilean Biodiversity
274 National Strategy to promote initiatives focused on conservation and protection of biodiversity in the long-
275 term (Conama 2003; Pliscoff & Fuentes-Castillo 2011)We used the latest version of the PSC vector layer
276 available from the Chilean Environmental Ministry map service (<http://ide.mma.gob.cl/>). From this layer we
277 selected only the PSCs that were within our study area. We assigned a value of 10 to all the areas within
278 defined priority sites for conservation, and a decreasing values of one unit (*i.e.* 9,8,7...0) for every one

279 kilometer of distance to the priority area. Therefore, all the areas that are farther than 9 km from a PSC
280 have a value of 0. Our scoring scheme for the PSC layer (*i.e.* distance based) follows the
281 recommendation of the Convention on Biological Diversity (Article 8) to develop complementary
282 sustainable development efforts near protected and other areas of conservation importance (United
283 Nations 1992). The resulting vector layer was then converted to a raster layer with a 100 m/pixel
284 resolution.

285

286 ***SMCDA Weighting and Analysis***

287

288 We developed five weighting scenarios to evaluate the effect of different approaches on habitat
289 prioritization results. The weighting scenarios covered a gradient from an extreme short-term to an
290 extreme long-term approach (Table 1). The extreme short-term scenario (EST) allocates all the weight to
291 the layers related with the current feasibility to start restoration projects (*i.e.* PHS, LUT), disregarding the
292 contribution of the layers implicated with the long-term viability of restoration projects. At the other hand,
293 the extreme long-term scenario (ELT) allocates all the weight to the layers associated with long-term
294 viability of restoration activities (*i.e.* FHS, PSC), but disregards factors that may be important for the
295 current implementation of the project. Between these extreme scenarios we built three intermediate
296 weighting scenarios, including a short-term (ST), a non-weighted (NW), and a long-term (LT) scenario
297 (Table 1).

298

299 All GIS processing was performed using the free GIS platform Quantum GIS 2.6 Brighton (www.qgis.org).
300 Output layers generated from the SMCDA were “masked” to fit only the areas potentially suitable for the
301 assessed species. We did this by creating a masking layer composed by the aggregated area of present
302 and future niche modeling distribution. We used the “minimum presence threshold” value to set the
303 distribution boundary for each species. All final raster layers were translated to prioritization maps for
304 qualitative evaluation, and areas corresponding to the highest suitability scores (*i.e.* 9 and 10) where
305 computed for quantitative analysis.

306

307 **Results**

308

309 ***Input layer results***

310

311 The six raster layers we generated to be used as inputs for the SMCDA are shown in Fig. 2. Even though
312 the main objective of this work was to develop a simple method for prioritizing site for restoration under
313 different scenarios, we consider it relevant to briefly describe the resulting layers that were used as the
314 input variables for our method. This is not only important for placing results in context, but also to provide
315 information that helps to evaluate the SMCDA results.

316

317 Modeled distribution under current climate of *B. miersii* shows a concentration of highest values in the
318 mountainous range covering the northwestern part of the species current distribution. This is coincident
319 with the area that concentrates the large extent of recorded populations. However, the model also
320 assigned intermediate and lower values to several areas where currently populations occur, as those in the
321 central and southern part of current distribution (Fig. 2a). The projected distribution with climate change
322 does not show major differences with the projection under current climatic conditions, except for a slight
323 increase in the range of highest values toward the south and east (Fig. 2b).

324

325 In the case of *P. splendens*, the modeled distribution under current climate is almost entirely restricted to
326 the coastal plains, ravines, and valleys that are directly influenced by the ocean climate. Highest values
327 for *P. splendens* tend to be localized in three main areas located in the northern, central and southern
328 range of predicted distribution. Whereas the southern and central areas coincide with historic presence
329 records for the species, there are no historic records for the northern area (Fig. 2c). In contrast with *B.*
330 *miersii*, the modeled distribution for *P. splendens* under climate change shows important changes when
331 compared to the current climate conditions, experiencing a general increase of highest values towards
332 the east, which are mostly concentrated in the central part of the species current distribution range (Fig.
333 2d).

334 Land-use types presenting the highest values tend to be concentrated in the northern part of the study
335 area. These high value areas present a gradual reduction of prevalence towards southern zones where
336 seems to be confined mostly to the upper part of valleys (Fig. 2e). Areas presenting land-use types with
337 intermediate values are mostly represented by valleys and flat areas which are majorly concentrated in
338 the southern part of the study area. Areas presenting the lowest values are concentrated in the eastern
339 part of the area of study. This is coincident with the presence of the Andes Mountain Range, which due to
340 their altitude, topography and severe climatic conditions generate different land covers (e.g. volcanic
341 debris, glaciers, bare rock) that are not viable for restoration with the assessed species (Fig. 2e).

342
343 Areas defined as priority sites for conservation (PSC) by the Chilean government are not evenly
344 distributed in the study area, which is clearly seen as the concentration of highest values in the central
345 and southern parts of the study area, and a complete absence of these sites in northern area (Fig. 2f).
346 Furthermore, PSC are mostly concentrated in the coastal mountainous range (between the Andes
347 mountain and the coast), whereas the coastal plains and zones adjacent to the ocean present only small
348 and highly isolated PSC (Fig. 2f).

349

350 **SMCDA results**

351

352 The generated Priority for Restoration Scores (PRS) maps for the five weighting schemes for *B. miersii*
353 and *P. splendens* are shown in Figure 3. These maps show the distribution of PRS, which represent the
354 ranked suitability of different areas for developing restoration activities under the five different weighting
355 scenarios.

356

357 There are important differences in the spatial patterns of PRS between the different weighting scenarios.
358 In general, both for *B. miersii* and *P. splendens*, there is a decreasing average pixel PRS and increasing
359 spatial clustering when moving from the EST to the ELT scenario (Table 2). The fragmented patterns of
360 highest suitable areas shown in short-term scenarios are associated with the projected spatial distribution

361 of current population (Figure 2a,c), whereas the clustered pattern of long-term scenarios are highly
362 associated with the presence of priority sites for conservation (Figure 2,f).

363

364 While the PRS under the five scenarios show general spatial patterns common to both species, the
365 amount of areas prioritized in the two highest suitability scores does not follow the same patterns (Fig 4).
366 In the case of *B. miersii* the scenario prioritizing the larger amount of areas with the two highest suitability
367 scores (*i.e.* 9 and 10) is the EST, whereas for *P. splendens* is the ELT, which is the opposite scenario. At
368 the other hand, the scenario prioritizing the smaller amount of areas for *B. miersii* is the LT, whereas for
369 *P. splendens* is the ST.

370

371

372 **Discussion**

373

374 Results from our work highlight the usefulness of using a SMCDA approach to identify, evaluate and
375 prioritize sites for restoration at a regional scale. By using this approach we were able to identify and
376 quantify the best suitable areas for restoration initiatives of two threatened endemic species of the
377 Chilean Biodiversity Hotspot. The SMCDA provided a simple and transparent methodological framework
378 to integrate available spatial information, generating insightful knowledge readily usable by local decision-
379 makers. Although we could have use additional spatial information as input layers for our approach, we
380 attempted to focus our analysis to spatial layers that can be gathered or easily generated elsewhere. In
381 view of that the aim of this work was not to present the proposed method as a definitive approach –and
382 neither our maps as definitive results, but rather to put in perspective the usefulness of the SMCDA as a
383 tool for spatial prioritization of sites for biodiversity restoration.

384

385 One of the key steps in the developing of a multi-criteria spatial analysis for conservation planning should
386 be the selection of the input layers and the specific weighing applied to each of them (Phua & Minowa
387 2005; Huang et al. 2011). These decisions do not only have to be focused on combining relevant
388 available information, but also must produce legitimate results for decision makers (Munda 2005).

389 Therefore, the relevancy, accuracy and reliability of the information contained in the input layers are key
390 factors for the quality and credibility of our results

391

392 ***Input layers***

393

394 While we could theoretically include a large number of input variables in our SMCDA, the limited
395 availability of spatial information with adequate resolution importantly reduced the number of potential
396 input layers we could use. Furthermore, because the scope of our work was to develop a methodological
397 framework that can be used elsewhere, selection of input layers not only had to be based in the available
398 spatial information in our study area, but also in other regions with similar conservation challenges.

399

400 In this regard, we are aware that several regions may not have updated and accurate available land-use
401 layers as we had, or if they have, the accessibility to the information could be restricted to governmental
402 agencies. However this limitation could be solved by using freely available land-classification software
403 and satellite images, which is a methodology that can accurately classify land cover in the three
404 categories we used in our approach (e.g. Nolè et al. 2015). Even though the of land-use in only three
405 categories (i.e. urban, rural, natural) can be considered too broad for local-scale conservation planning, it
406 could provide useful information about regional-scale availability of natural lands that can be currently
407 targeted for restoration activities with focal species.

408

409 The inclusion in the SMCDA of official recognized “priority sites for conservation (PSC)” is one of the
410 major novelties of our approach. In contrast with traditional protected areas, PSC are mostly areas not
411 currently protected, but officially recognized as primary importance to be protected in the short to mid-
412 term (Conama 2003; Tognelli et al. 2008). PSC inclusion provide an objective indicator on the specific
413 areas that governments would support for future conservation initiatives, which is a fundamental
414 information for planning restoration initiatives under future climate change scenarios. Because the
415 designation of PSC is based in the Convention on Biological Diversity (United Nations 1992; article 8
416 letters a and b), PSC’s represent information that should be available in several of the 194 countries

417 signatories of this convention, and therefore supports its inclusion in the SMCDA as a commonly
418 available spatial information.

419

420 The use of niche modeling software is a key part of our approach because provides fundamental
421 ecological information regarding the areas that have current and future environmental conditions to
422 potentially support restoration projects with the focal species. Additionally, results from the niche
423 modeling phase, such as the most relevant environmental variables related to each species, may also
424 contribute to understand what are key environmental conditions related with the occurrence of species,
425 which can provide useful ecological information for the development of local scale restoration
426 management strategies (Schwartz 2012). However, while niche modelling software are powerful tools,
427 the accuracy of predicted distribution results will depend on the quality of presence data, environmental
428 layers, and parameter settings (Loiselle et al. 2008; Costa et al. 2010; Soria-Auza et al. 2010) In this
429 regard, researchers and practitioners need to be particularly cautious of potential data flaws if they are to
430 use niche modelling to generate the species distribution layers to be used in the SMCDA.

431

432 ***Scenarios weighting scheme***

433

434 The main characteristic of our weighting scheme was to explicitly relate the weighting scenarios with the
435 underlying characteristics of the used spatial layers in terms of their relevance for short-term and long-
436 term decision-making. Each of the five built scenarios has an implicit narrative behind that helps to
437 explain decision-makers the specific weight assigned to each variable. Our assumption was that if
438 restoration strategies are based in short-term planning, current environmental conditions and available
439 natural lands will prevail in decisions. However, if strategies are developed to embrace long-term
440 perspectives, future environmental conditions and projected protected lands need to be increasingly
441 taken into account.

442

443 Even though this weighting scheme was designed to be easily communicated to decision-makers, we did
444 not include a participatory phase to integrate potential decision-makers diversity of opinions. This

445 participatory phase is often considered a fundamental step to legitimate the results in building
446 conservation policies (Munda 2005; Ananda & Herath 2008). However, as we have stated before, our
447 work was not focused on generating a definitive outcome, but rather on evaluating the potential
448 application of the SMCDA approach as a tool for restoration prioritization initiatives. Although our
449 weighting scheme has not passed through a legitimatization phase by decision-makers, we still consider
450 that our results could be helpful because the gradient weighting scheme provide decision-makers with a
451 range of outcomes that can be used as exploratory boundaries to evaluate potential results. Indeed
452 participatory phases often derive in a range of weights, and thus in more than one set of results that are
453 finally used to make a decision (Chen et al. 2010). The use of a gradient weighting scheme when using a
454 small number of variables could also be used to evaluate the sensibility of the SMCDA to changes in
455 weighting values, and therefore to understand what specific values play larger roles in generated results.

456

457 **SMCDA results**

458

459 Outcomes generated through the SMCDA reveals the specific effects of weighting scenarios and the
460 spatial interaction of spatial layers in the distribution and extent of areas identified with high priorities for
461 developing restorations initiatives with the two species used in our study. These results not only provide
462 useful information for local decision-makers, but also help to understand the role of the different input
463 layers in final outcomes.

464

465 Results of the SMCDA for *B. miersii* show a significant larger amount of prioritized area for restoration
466 when compared with the suitable areas for *P. splendens* independently of the assessed scenario, which
467 was an expected result based in the much larger distribution of the former species compared to the later.
468 However, an interesting result from our work was that the total suitability areas for restoration of each
469 species changed in opposite direction when moving from the short-term to the long-term weighting
470 scenarios. Whereas weighting emphasizing long-term scenarios tended to reduce the availability of
471 suitable habitats for *B. miersii* restoration, these same scenarios increase the extent of suitable areas for
472 *P. splendens* restoration projects. As two of out of the four layers (*i.e.* PSC, LUT) were shared for both

473 species in the SMCDA, the divergences of these results are mainly related with the change on the
474 species distribution due to the climate change scenario. In fact, while *B. miersii* is predicted to see
475 reductions in its potential distribution under the future climate, *P. splendens* is expected to have an
476 opposite response, presenting a large increase in projected distribution. This species specific response to
477 climate change highlights the importance to take into account the future climate variability for planning
478 plant species restoration initiatives (Gelviz-Gelvez et al. 2015). Because these two species are dominant
479 trees in their respective ecological community, they can be used as proxy for selecting priority sites for
480 restoration efforts focused in the entire vegetation community.

481

482

483 **Conclusion**

484

485 In this work we demonstrate the usefulness of integrating available spatial layers and niche modeling into
486 a SMCDA approach to develop an affordable, flexible, transparent, and replicable method to prioritize
487 areas for restoration initiatives of plant species taking into account the future climatic variability. It is
488 affordable because it can be performed by using free software (*i.e.* Maxent, QGIS) and freely available
489 spatial information. It is flexible because input layers, layer scoring, and weighting schemes can be
490 modified to fit specific decision-making contexts. It is transparent because each of the steps is clearly
491 identified and justified. And it is replicable because it uses information that can be gathered or generated
492 elsewhere. Finally, our approach does not aim to be used in replacement of other local-scale software-
493 based planning approach, such as Zonation and Marxan, but rather as a complementary method that
494 bridge the global-scale priority areas, with local-scale restoration planning efforts. This SMCDA approach
495 could be used as a management tool to prioritize regional-scale areas for restoration of plant species in
496 Chile, as well as in other countries with restricted budgets for conservation efforts.

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502

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506 CONAF 025/2010: “Distribución, hábitat potencial y diversidad genética de poblaciones de Belloto del
507 Norte (*Beilschmiedia miersii*) y Lúcumo chileno (*Pouteria splendens*)”,

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649 **Tables**

650

651

652 **Table 1.** Scenario weighting scheme used for both species. Scenarios are: EST; extreme short-term, ST;
 653 short-term, NW; non-weighted, LT; long-term, ELT; extreme long-term.

Layers	Scenario Weighting				
	EST	ST	NW	LT	ELT
Present Habitat Suitability	0.50	0.40	0.25	0.20	0.00
Future Habitat Suitability	0.00	0.20	0.25	0.40	0.50
Land-Use Type	0.50	0.30	0.25	0.10	0.00
Priority Sites for Conservation	0.00	0.10	0.25	0.30	0.50

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655

656 **Table 2.** Main statistical summary of PRS for the five evaluated scenarios for each of the assessed
 657 species. Mean, coefficient of variation, and Moran's I coefficient of autocorrelation are shown. Scenarios
 658 are: EST; extreme short-term, ST; short-term, NW; non-weighted, LT; long-term, ELT; extreme long-term.

	<i>B. miersii</i>					<i>P. splendens</i>				
	EST	ST	NW	LT	ELT	EST	ST	NW	LT	ELT
Mean	6.19	5.35	5.15	4.50	4.09	4.73	4.42	4.31	4.07	3.88
CV	0.29	0.31	0.33	0.41	0.58	0.37	0.35	0.35	0.41	0.51
Moran's I	0.93	0.96	0.97	0.98	0.99	0.88	0.94	0.95	0.98	0.98

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669 **Figure Captions**

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672 **Figure 1.** Study Area. The shaded area corresponds to the “shrub and sclerophyllous forest” ecological
673 region, which was used as the boundaries for the niche modeling process. Rectangular area includes the
674 range of distribution of both species, and corresponds to the extent used for creating the maps showed in
675 following sections. Cities mentioned in the text are shown.

676

677 **Figure 2.** Visualization of the spatial layers built and used as input for the SMCDA. Letters a) and b)
678 represent the modeled present (PHS) and future (FHS) habitat suitability for *B. miersii*. Letters c) and d)
679 represent the present and future (PHS and FHS) modeled habitat suitability for *P. splendens*. In a) and c)
680 black dots correspond to the record presence points of these species that were used for the niche
681 modeling process. Letter e) corresponds to the land-use type (LUT) layer, and letter f) to the priority sites
682 for conservation (PSC) layer.

683

684 **Figure 3.** Suitability of areas for restoration with *B. miersii* (top) and *P. splendens* (bottom) under the five
685 assessed scenarios generated through the SMCDA. Values represent Priority for Restoration Score
686 (PRS). Scenarios are: EST; extreme short-term, ST; short-term, NW; non-weighted, LT; long-term, ELT;
687 extreme long-term.

688

689 **Figure 4.** Quantification of total area categorized in the two highest PRS scores (9 and 10) under the five
690 scenarios for each of the two assessed species, a) *B. miersii*, b) *P. splendens*.

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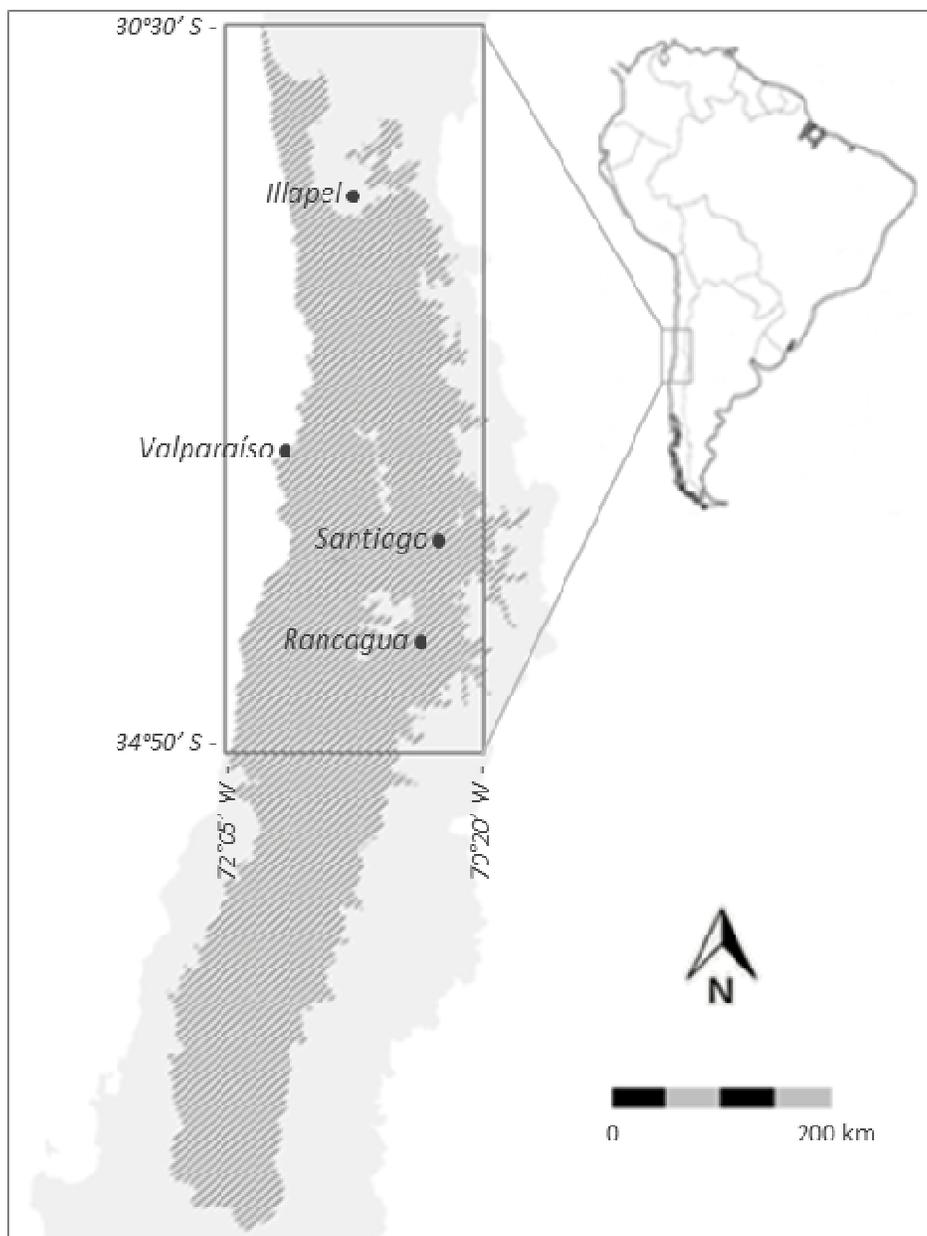
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697 **Figures**

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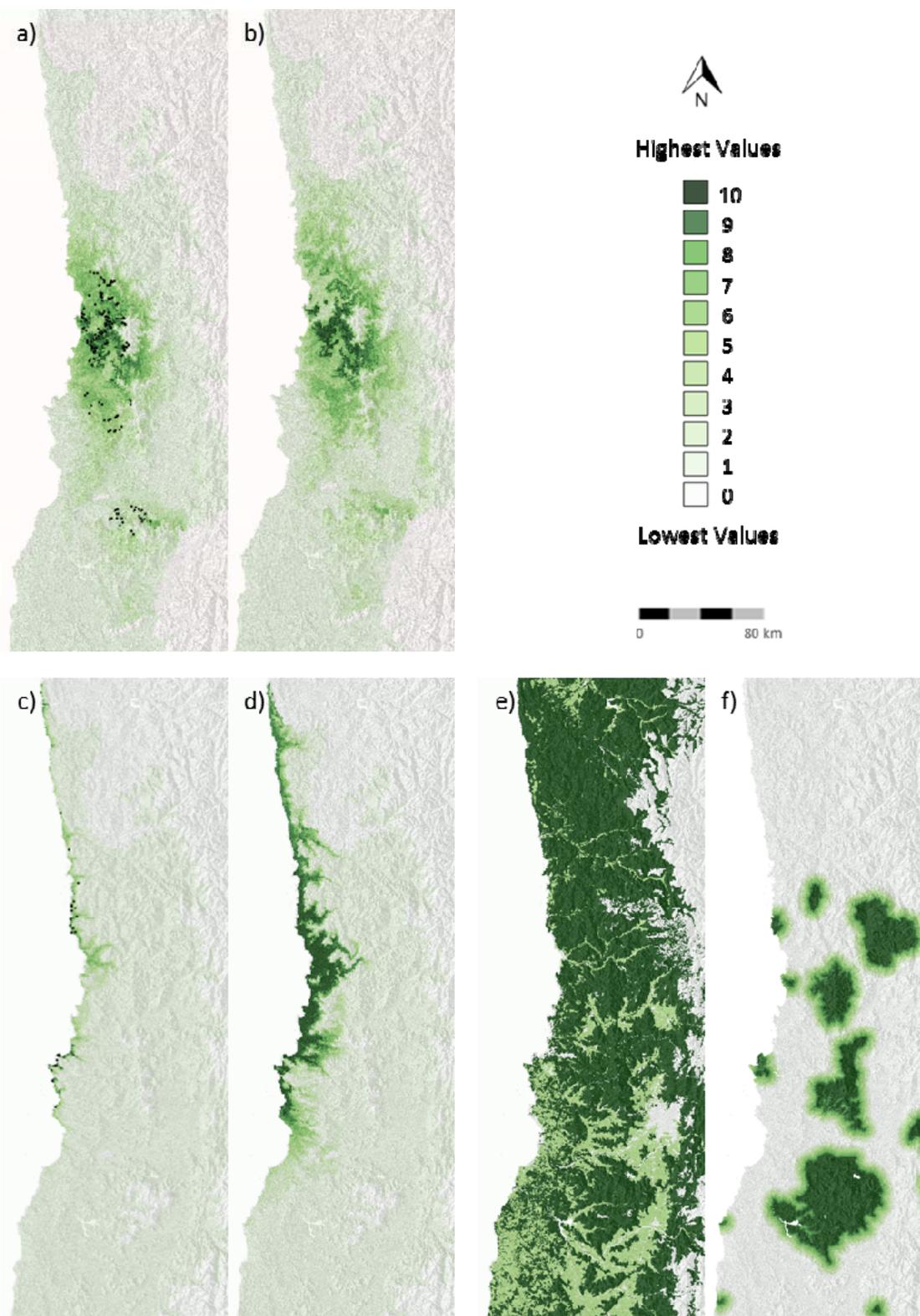


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Figure 1.

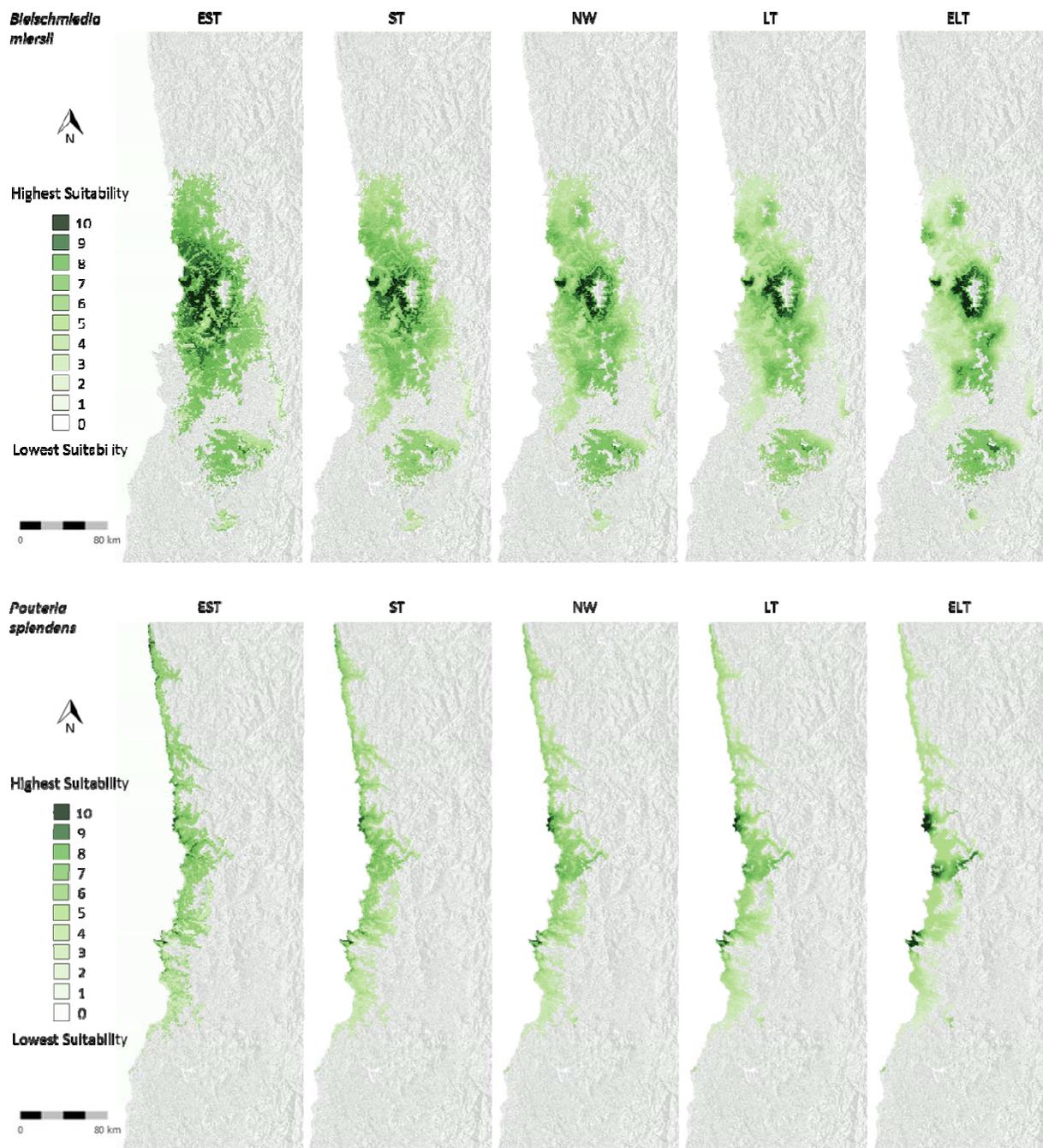


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Figure 2



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Figure 3

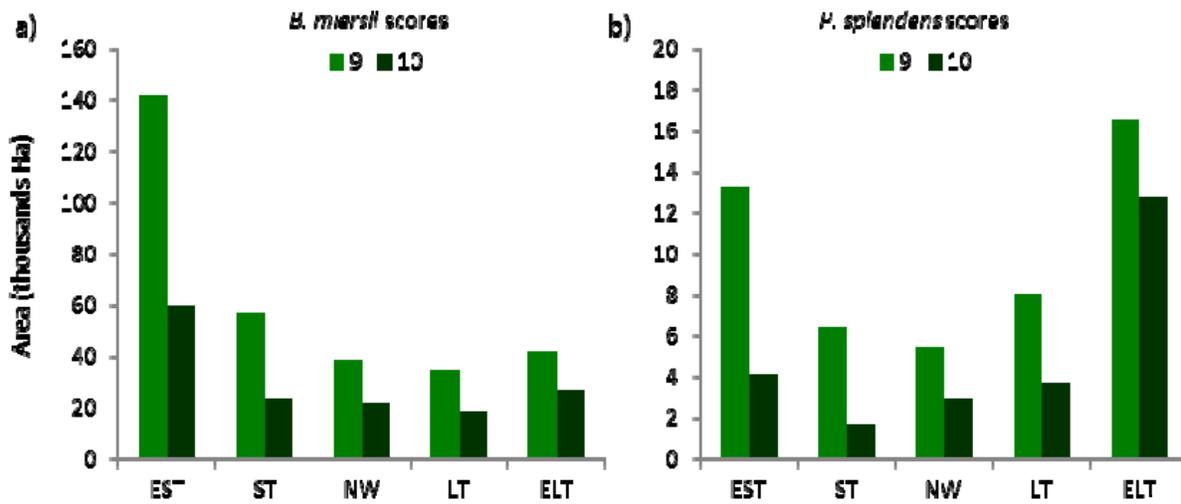


Figure 4

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