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Combining climate, land use change and dispersal to predict the distribution of endangered species with limited vagility

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4 Running title: **Integrating climate, land use change and dispersal**

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ABSTRACT

Aim. To investigate the effects of both climate and land use change on the distribution of endangered beetle species with limited vagility, accounting for and ignoring species-specific dispersal when projecting species distribution.

Location. Europe.

Time period. 2007-2012; 2040-2050.

Taxon. Saproxylic beetles.

Methods. Using current (2007-2012) species occurrences, we predicted the distribution of six endangered saproxylic beetles under a range of future (2040-50) climate and land use change scenarios in Europe by using ecological niche models.

Results. Our results showed that, while all the species considered would increase their distribution, areas both accessible and suitable would range between only 5% and 38% of the total potential available area, depending on the species and the future scenarios considered.

Main conclusion. We strongly encourage researchers and conservationists to combine climate and land use change with dispersal when projecting species distribution under future scenarios. This should avoid misleading predictions and overestimation, as climate and land use change generate differing effects depending on the inclusion or exclusion of species dispersal abilities.

KEYWORDS: ecological niche models, future scenarios, global change, macroecology, *n*-dimensional hypervolume, saproxylic beetles, species traits.

1. INTRODUCTION

Many rare species are dispersal-limited, exhibiting a low probability of colonizing new sites and establishing viable populations (Baur, 2014). The current and future distributions of these species are highly influenced by human-related environmental change, such as climate and

49   land use change, creating insurmountable barriers to their dispersal across space and time

50   (Jaeschke et al., 2013). Although both climate and land use change are considered dominant

51   drivers of biodiversity at a global scale (Barbet-Massin et al., 2012; Pimm et al., 2014), only

52   the former has been widely used as a predictor for modelling future species distributions (e.g.

53   Markovic et al., 2014; Titeux et al., 2016). Indeed, during the last 25 years, more than 85% of

54   published research in this field explored the impact of future climate change alone on

55   biodiversity (Titeux et al., 2016). Moreover, in the few studies that considered the impact of

56   land use change on species distribution (Radinger et al., 2016; Milanesi et al., 2017a), the

57   combined effect with climate change was rarely investigated (Mantyka-Pringle et al., 2014;

58   Radinger et al., 2016). Since species range shift varies depending on site-specific climate-land

59   use combinations, neglecting the effect of land use change could lead to biased predictions of

60   species distributions under future conditions. Especially, this holds true for species with

61   limited dispersal capacities, for which even minimal land use changes can dramatically impact

62   their colonization capacity (Velo-Antón et al., 2013; McCauley et al., 2014).

63   Actually, the Biotic-Abiotic-Mobility framework ('BAM'; Soberón & Peterson, 2005)

64   highlighted also the importance of species-specific dispersal characteristics in determining

65   species distribution (De Marco et al., 2011; Nobis & Normand, 2014; Vasudev et al., 2015).

66   Incorporating dispersal in ecological niche models (ENMs) improves predictions for current

67   and future species occurrence compared to standard ENMs (Engler & Guisan, 2009; Smolik

68   et al., 2010; Vasudev et al., 2015). However, most studies developing ENMs to predict the

69   distribution of species under future scenarios have not incorporated species-specific dispersal

70   abilities, relying on overly simplistic conceptualizations of dispersal (Franklin, 2010; Peterson

71   et al., 2011).

72   Taking into account these limitations, in this study we (i) investigated the effect(s) of

73   climate and land use change on species with short-distance dispersal abilities and (ii) defined

74   areas that should be accessible to them in the future. We used the current (2007-2012)

75 occurrences of six endangered saproxylic beetles, widely considered to be umbrella species

76 for biodiversity conservation (Ranius, 2002; Buse et al., 2007; Russo et al., 2011; Campanaro

77 et al., 2011; Solano et al., 2013; Bełcik et al., 2019), to develop ENMs using current climate

78 and land use conditions. We then projected the distributions of our target species under future

79 scenarios to estimate species potential occurrences in the years 2040-50 (based on four

80 different climate and land use change scenarios). Finally, taking into account the species-

81 specific dispersal abilities of our target species, we limited their distributions in 2040-50 to

82 areas accessible to them across Europe.

83

84 **2. METHODS**

85 2.1 Study area and species data

86 Our study area consisted of all continental European countries (excluding Belarus, Moldova,

87 Russia and Ukraine, because of the lack of data in national biodiversity repository servers and

88 in other official archives; Fig. 1). The study area ranges from 0 to 4,810 m a.s.l., and is

89 characterized by forests (33.3% of the total area), croplands (32.4%), shrub-lands (11.5%)

90 and, to a lesser extent, grasslands (7.8%) and human settlements (4%).

91 We selected six threatened species of saproxylic beetles (out of the 21 saproxylic

92 beetles species listed in the EU habitat directive), namely *Cerambyx cerdo*, *Cucujus*

93 *cinnaberinus, Lucanus cervus*, *Morimus funereus, Osmoderma eremita* and *Rosalia alpina,*

94 for which information on observed dispersal distances were available in literature (Table S1).

95 We obtained species occurrence data for the period 2007-2012 from (i) the European

96 Environment Information and Observation NETwork (EIONET, 2013) Central Data

97 Repository server (http://cdr.eionet.europa.eu/), (ii) the Swiss Biological Records Center

98 (http://lepus.unine.ch/carto/) and (iii) the Norwegian Taxonomy Initiative

99 (http://www.biodiversity.no/). All species occurrences were resampled at the same spatial

100 resolution of EIONET data (10 × 10 km grid cell size; Fig. 1), resulting in a total of 4,310

4

101   cells for *C. cerdo*, 3,561 for *C. cinnaberinus*, 11,535 for *L. cervus*, 2,211 for *M. funereus*,

102   5,248 for *O. eremita* and 2,628 for *R. alpina*. We tested for overestimation of saproxylic

103   species occurrences calculating a modified version of the Multivariate Environmental

104   Similarity Surface (mMESS, Milanesi et al., 2017b). We find consistent results (Fig. S1-6)

105   and thus, we included all data collected in the further analysis.

106

107   2.2 Species ecological requirement

108   The species considered in this study (Table S1) are highly susceptible to both climate and

109   land use changes (Gough et al., 2015). In fact, being highly specialized wood-living beetles,

110   their survival is, above all, linked to the availability of suitable forest habitat. As such, their

111   ability to respond to climate change is mainly influenced by habitat degradation (Filz et al.,

112   2013; Ball-Damerow et al., 2014). Moreover, the study species are characterized by low

113   dispersal distances (Schiegg, 2001), and inhabit most of the European deciduous old-growth

114   forests currently threatened by large-scale human disturbance (Wirth et al., 2009; Stokland et

115   al., 2012).

116   *C. cerdo* is widespread in most parts of Europe, but more common in the Mediterranean

117   regions, generally associated with oak forests consisting of mature or partially dead, and sun-

118   exposed trees (Sama, 1988). This species occurs in semi-open forest patches of lowland and

119   hilly forests (Redolfi de Zan et al., 2017).

120   *C. cinnaberinus* is a poorly known species (Horák, 2011) limited to Europe, scattered

121   distributed throughout the continent, probably because of past population decline and local

122   extinctions (Horák & Chobot, 2009; Horák et al., 2010). This species live under the bark of

123   dead tree trunks (Horák et al., 2008) in lowland poplars and willows forests or partially-mixed

124   mountain forests (e.g.; Horák et al., 2010).

125   *L. cervus* is widely spread across Europe and is associated with mature deciduous

126   forests. It can be found especially in lowland and medium-altitude oak woodlands, where the

5

127 saproxylic larvae feed on rotten deadwood at ground level (Campanaro et al., 2011). This

128 species may also be common in urban habitats (e.g. city parks, private gardens; Hawes, 2008;

129 Harvey et al., 2011).

130   *M. funereus* inhabits mature beech, poplar and oak forests (Sama, 2009) within a

131 relatively narrow geographical zone in south-eastern Europe (Jurc et al., 2008; Carpaneto et

132 al., 2015). Even though their preferred habitats are mature forests, populations of this species

133 often occur in coppiced stands, characterised by old stumps and decaying wood on the ground

134 (Hardersen et al., 2017).

135   *O. eremita* is a genus that includes many species. Based on genetic studies (Audisio et

136 al. 2007, 2009), there is now consensus that *Osmoderma eremita* is just one of four species

137 occurring in Europe. However, in our analysis, we considered all these species as belonging to

138 *Osmoderma eremita*. It is generally associated with hollow veteran trees (Ranius & Hedin,

139 2001; Svensson et al., 2011), of the ecotonal areas and clearings of mature forests, agricultural

140 and urban landscapes (Maurizi et al., 2017).

141   *R. alpina* lives mainly in the mountainous regions of central and southern Europe and is

142 associated with beech forests, but also maples and elms (Bosso et al., 2013; Lachat et al.,

143 2013). It prefers open and semi-open woodlands (Russo et al., 2011), reproducing mainly in

144 mature, dead (or declining), and sun-exposed trees (Campanaro et al., 2017a).

145

146 2.3 Predictor variables

147 For the period 2007-2012, we considered a total of 28 predictors of species occurrence,

148 accounting for the assumed habitat characteristics of the target species, and for which

149 continuous spatial data were available for the entire study area (Table S2). We considered two

150 topographic variables (ASTER GDEM; gdem.ersdac.jspacesystems.or.jp), seven land use

151 variables (CORINE Land Cover 2012; https://land.copernicus.eu/pan-european/corine-land-

152 cover/clc-2012) and the Euclidean distances to human settlements (Table S2). Moreover, we

6

153   considered 19 bioclimatic variables (http://www.worldclim.org; Table S2). All predictors

154   were resampled at a 10×10 km grid cell size.

155   For the period 2040-50, we considered four different scenarios of climate and land use

156   change. Specifically, thanks to recent advances in the development of socioeconomic

157   storylines and their potential effect on future land use patterns, we used four land use change

158   scenarios addressing both changes in land cover and land use intensity, reflecting

159   socioeconomic, cultural, political, and technological changes in the EU (Stürck et al., 2015;

160   data provided by the authors). These scenarios, namely Libertarian Europe (A1), Eurosceptic

161   Europe (A2), Social Democracy Europe (B1) and European Localism (B2), represent strong,

162   high, moderate and low economic interventions and growth, respectively (see Table S3 and

163   Stürck et al., 2015 for details on the scenarios).

164   Similar to Ihlow et al. (2016), we considered four climate change scenarios

165   (Representative Concentration Pathways, RCPs) for the year 2050 averaging 11 general

166   circulation models (GCMs: BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, hadGEM2-

167   ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, MIROC-ESM, MIROC5, MRI-CGCM3 and

168   Nor-ESM1-M). These scenarios were obtained from the fifth assessment of the

169   Intergovernmental Panel for Climate Change (IPCC AR5WG1 2014; http://www.ipcc.ch).

170   The selected RCPs represent four possible greenhouse gas emission trajectories, including

171   low (RCP 2.6), moderate (RCP 4.5), high (RCP 6) and strong (RCP 8.5) increases in global

172   radiative forcing (Ihlow et al., 2016). Based on these scenarios, we used the same predictors

173   for the period from 2007-2012, available at a 10×10 km grid cell size (the same resolution as

174   current climatic conditions) from the Worldclim website (http://www.worldclim.org).

175

176   2.4 Data analysis

177   To avoid multi-collinearity among predictors, we estimated the variance inflation factor (VIF)

178   for each predictor. Thus, in the further analysis we retained 13 (ecologically relevant;

179   Thomaes et al., 2008; Bosso et al., 2013; Campanaro et al., 2017b) out of 28 predictors due to

180   VIF values lower than three (i.e. poorly correlated with other predictors; Zuur et al., 2010;

181   Table S2).

182   Thus, we applied a recently developed ENMs, namely "*n*-dimensional hypervolume" (R

183   package HYPERVOLUME v. 2.0.11; Blonder et al., 2014; 2017a), considering current

184   species occurrences, climate and land use conditions but projecting on different future (2040-

185   50) climate and land use change scenarios (see Table S4 for details on model parameters). *N*-

186   dimensional hypervolume has several benefits compared to other extant ENMs as it (i)

187   considers all the dimensions (predictors) to measure the volume of a high-dimensional shape

188   (including holes or other complex geometrical features; Blonder et al., 2014; 2017a), (ii)

189   allows delineation of the entire hypervolume without generating unbounded volumes

190   (Blonder et al., 2014; Peterson et al., 2011) and (iii) while relying on presence-only data,

191   correctly classified false absences through robust bandwidth estimation methods (e.g.

192   Silverman estimator; Blonder et al., 2017b).

193   Similar to Jaeschke et al. (2013), we identified suitable areas accessible to our target

194   species in the future multiplying the yearly dispersal distance of each species (Table S1) for

195   the total number of years (n=33, from 2013 to 2045, average of 2040-50). The resulting

196   distances were divided by the number of years larvae would take to develop in the adult stage

197   (Table S1) plus one and then used to define accessible areas around current occurrences.

198

199   **3. RESULTS**

200   Without taking into account species-specific dispersal abilities, we found that suitable areas

201   for the saproxylic beetles for the period 2040-50 would vary between 3,345,200 km^2 and

202   4,661,300 km^2, corresponding to the scenario A2 – RCP 2.6 for *M. funereus* and scenario B2

203   – RCP 6 for *L. cervus*, respectively (Table 1). Specifically, suitable conditions for *C. cerdo*

204   would occur all over Europe, mainly in the central-eastern part of the continent, while those

205 for *C. cinnaberinus* would occur in many areas of central-eastern Europe (excluding

206 Switzerland). For *L. cervus* suitable areas would be mainly located from eastern to western

207 Europe (excluding the southern part of the European continent), while those of *O. eremita*

208 would be in central-eastern Europe, including Sweden and Finland. Finally, suitable areas for

209 *M. funereus* would be widely located across central-eastern Europe, while *R. alpina* would be

210 distributed throughout Europe, though most concentrated in France, Lithuania and Latvia.

211   When examining the suitable areas available for the six modelled species (generated

212 without accounting for dispersal abilities) we found a higher impact of climate change relative

213 to land use change on the distribution of *C. cerdo, C. cinnaberinus, M. funereus* and *R.*

214 *alpina*. For these species we found a direct relationship between climate change increase and

215 the availability of suitable areas (Fig. 2). Conversely, the suitable area of *L. cervus* and *O.*

216 *eremita* is more susceptible to land use change than climate change, reaching the maximum

217 extent in land use change scenarios B2 and A1, respectively (Fig. 2)

218   When we combined climate and land use change with species-specific dispersal

219 abilities, we found that from 2040-50 accessible suitable areas for the six saproxylic beetles

220 would range between only 5.05% and 38.98% of the total available suitable areas calculated

221 previously (Table 2; Table S5). When considering dispersal abilities, *C. cerdo* would reach

222 24% of its suitable area available from 2040-50 (Fig. S7), while *C. cinnaberinus* would reach

223 only 13% (Fig. S8), mainly located in Eastern Europe, Fennoscandian and Baltic countries. *L.*

224 *cervus* would reach the largest percentage of its suitable area available from 2040-50 in

225 relation to the other species considered, corresponding to 36 – 38% (Fig. S9), while *M.*

226 *funereus* would reach only 5% of its suitable area for this timeframe (Fig. S10), mainly

227 located in Slovenia, Hungary, Bulgaria, Southern Romania and Northern Greece. Finally, *O.*

228 *eremita* would reach 26% of its suitable areas available in 2040-50 (Fig. S11), mainly located

229 in central Europe, while *R. alpina* would reach 14% of its suitable area available during this

230   timeframe (Fig. S12), mainly located in the mountainous and hilly areas of Southern Europe

231   (excluding Bosnia, Montenegro, Albania and Kosovo).

232   When including species-specific dispersal abilities we generally found a higher impact

233   of land use change on the distribution of all six saproxylic beetles compared to when dispersal

234   abilities were excluded (Fig. 3). Specifically, the highest percentage of accessible suitable

235   areas for *C. cerdo* and *M. funereus* would be reached in the context of land use change

236   scenario B1 while for *C. cinnaberinus* and *R. alpina*, it would be land use change scenario B2

237   (Fig. 3). Finally, for *L. cervus* and *O. eremita*, the highest percentage of available suitable area

238   reached corresponds to the A1 land use change scenario (Fig 3). Generally, an increase in

239   greenhouse gas emissions corresponds to an increase in the available suitable areas for *C.*

240   *cerdo, C. cinnaberinus, L. cervus* and *R. alpina,* while in a decrease *O. eremita* (Fig 3).

241   However, climate change would have a weak effect on the available suitable areas reached for

242   *M. funereus* (Fig. 3).

243

244   **4. DISCUSSION**

245   Our results highlighted differences in the predicted distributions of saproxylic beetles given

246   the differing effects that climate and land use can generate when accounting for or ignoring

247   species dispersal abilities. Land use change was found to be the main constraint to species

248   distributions when accounting for dispersal, while climate change when ignoring dispersal.

249

250   4.1 Distribution of saproxylic species considering future climate and land use changes

251   Our modelled species' ranges will grow in the future due to the combined effects of changing

252   temperatures and precipitations (due to greenhouse gas emissions increase) and an expansion

253   of forested areas (occurring in all the land use scenarios considered). However, while climate

254   change has a similar effect on most of the investigated species, the effect of land use change is

255   more species-specific. This is mainly due to the different landscape variables considered: the

10

256 expansion of grasslands, the abandonment of grasslands resulting in forest expansion, the

257 expansion of human settlements, the intensification of forest management, and the resulting

258 habitat diversity and the intensity of their exploitation (Stürck et al., 2015).

259

260 4.2 Accessible vs. available suitable areas under future climate and land use change scenarios

261 We found that none of the saproxylic beetles considered in this study will reach all of the

262 suitable areas available in 2040-50, due to the limited dispersal abilities characterizing these

263 species. Flightless species with narrow geographic distributions would be able to occupy

264 sometimes as little as 5% of the suitable area available to them in 2040-50, as is the case with

265 *M. funereus*. Conversely, widespread species might be able to cover as much as 38% of the

266 suitable area available to them in 2040-50, as is the case with *L. cervus*. Thus, species-specific

267 dispersal abilities greatly limit the ability to colonize new suitable areas.

268 Without accounting for species-specific dispersal abilities, we generally found a strong

269 effect of climate change when predicting future species distributions (except for *L. cervus* and

270 *O. eremita*). Indeed, for most of our species, suitable areas would increase with increasing

271 greenhouse gas emissions, indicating better climatic conditions for their occurrence in the

272 future, supporting a general expansion of many species of saproxylic beetles to higher

273 elevations and latitudes in Europe. However, suitable areas of *L. cervus* and *O. eremta* would

274 be mainly affected by land use change: the future scenarios "European localism" (B2 – low

275 economic interventions and growth) and "Libertarian" (A1 – strong economic interventions

276 and growth) predicted the maximum distribution expansion of these species, respectively.

277 When accounting for species-specific dispersal abilities, we found a weak effect of

278 climate change and a rather strong effect of land use change. Indeed, we found a clear, inverse

279 relationship between the amount of suitable accessible areas and the degree of land use

280 change for *C. cinnaberinus* and *R. alpina*, for which the scenario "European localism" (B2 –

281 low economic interventions and growth) predicted the highest expansion of suitable

282   accessible areas. This land use change scenario, followed by "Social Democracy Europe" (B1

283   – moderate economic interventions and growth), predicted the maximum expansion for *C.*

284   *cerdo* and *M. funereus.* The main differences among these two scenarios concern the extent of

285   grasslands, croplands (not included in the ENMs due to multi-collinearity, but see below),

286   forests and the intensity of their exploitation (Table S3; Stürck et al., 2015). However, while

287   the intensification of forest management, predicted for both the B1 and B2 scenarios, would

288   present a threat for saproxylic beetles (Jonsson et al*.,* 2005; 2006), the increase in forest cover

289   (more than 170,000 km^2 of current croplands would be abandoned and return naturally to

290   forests or grasslands; Stürck et al., 2015) would increase the extent of suitable habitat for our

291   target species. Moreover, the de-intensification of grasslands predicted for both the B1 (in

292   combination with human settlement contraction) and B2 scenarios (i.e. reduction of livestock

293   density to sustainable grazing) represent a positive change for saproxylic beetles (Russo et al.,

294   2011).

295   Although, at a broad scale, climate change is expected to be the main constraint for

296   many species distributions, here we found that this is only true for *C. cinnaberinus, R. alpina*

297   and *C. cerdo* in the unrealistic scenario of unlimited dispersal. Conversely, we found that land

298   use change affects all our modelled species. In particular, *L. cervus* and *O. eremita*

299   distributions are affected by land use change in both the cases of limited and unlimited

300   dispersal, while those of *C. cerdo, C. cinnaberinus, M. funereus* and *R. alpina* are affected by

301   land use change only upon taking their dispersal abilities into account. The strong effect of

302   land use change on these saproxylic beetles could be explained by the high dependence of

303   these species on the amount, availability and distribution of deadwood, which, in turn, is

304   closely linked to forest use (Bradford et al., 2014; Mazziotta et al., 2016).

305

306   4.3 Caveats

307 We followed the approach of Jaeschke et al. (2013) for estimating yearly dispersal distance of

308 saproxylic beetles. While we estimated yearly dispersal distance by dividing the maximum

309 dispersal distance of each species by the number of years larvae would take to develop in the

310 adult stage plus one, this likely resulted in overestimation of the distance these species are

311 able to cover. Because of the lack of information on species-traits for our target species, we

312 assumed that the probability of colonization was 1 rather than 0. In doing so, we estimated the

313 maximum dispersal probability without including any species-traits in the model. Measuring

314 the real dispersive capacity of a species is very complex (Trakhtenbrot et al., 2005). In a

315 variety of actively dispersing invertebrates, precise estimations of long-distance dispersal

316 ability are based on morphological characteristics, such as body size or wingspan (Merckx &

317 VanDyck, 2002; Cizek, et al., 2006), or on life-history traits (Sutherland et al., 2000).

318 However, in many cases, such qualitative proxies do not prove informative about dispersal

319 ability, due to the uncertainty involved in the identification of the dispersal distance

320 mechanism (Trakhtenbrot et al., 2005). As such, often quantitative models are preferred

321 (Trakhtenbrot et al., 2005). Some used data on variables affecting dispersal to predict the

322 magnitude and frequency of long-distance dispersal, including changes in parameter values

323 caused by human impacts threatening biodiversity (Trakhtenbrot et al., 2005).However,

324 because of the high variability in behavioural and environmental factors (Higgins et al.,

325 2003), these models tend to be case-specific (e.g. South & Kenward, 2001; Macdonald &

326 Rushton, 2003) and often are applied on passive dispersers (Nathan et al., 2002) rather than

327 active animals, such as our target species. For many active dispersers, including insects,

328 phenomenological models are often used (Trakhtenbrot et al., 2005). These approaches can be

329 applied if previous population demographic studies are available, for example, capture-mark-

330 recapture studies that can provide presence/absence or dispersal distance data for the species

331 studied (Kuras et al., 2003). The quality and quantity of the necessary data needs to be

332 thoroughly assessed to make accurate predictions for specific species in a landscape context

333   (Whitmee & Orme, 2012). For most studies on species distribution these data are not

334   available (Nathan, 2002).

335   Despite its limitations, we felt that the approach of Jaeschke et al. (2013) can be

336   reasonably applied to our target species for two main reasons. First, the dispersal distances

337   reported in this study are most likely underestimated. Most field studies on saproxylic

338   dispersal distance focus on one or few populations (Chiari et al., 2013; Torres-Vila et al.,

339   2017), and are spatially limited (Rossi De Gasperis et al., 2016; Drag et al., 2011) leading to

340   an underestimation of the real distances an individual might be able to cover. This

341   underestimation could be partially compensated by overestimation in our model. Second,

342   although we may overestimate dispersal in our target species, our resulting spatial predictions

343   are still very useful. In fact, they are more accurate than the unconstrained or no-dispersal

344   scenarios often incorrectly assumed in most of the ENMs predicting the impact of climate

345   change on species distributions (Araújo & Rahbek, 2006; Broennimann et al., 2006; Botkin et

346   al., 2007).

347   While deadwood is the main resource affecting saproxylic beetle occurrence (Stokland

348   & Siitonen, 2012; Milberg et al., 2016) and can influence microclimatic parameters (e.g.

349   hollow trees, Ranius, 2002; Pilskog et al., 2016), we couldn't include deadwood-related

350   variables in our analyses as deadwood amount and forest management intensity data is

351   lacking at a continental scale (as well as a global scale). Actually, deadwood availability

352   depends on forest management, which alter its distribution and abundance in a quite

353   unpredictable way (i.e. much more than climate and land use; Della Rocca et al., 2018). Thus,

354   simulated future scenarios of deadwood amount/forest management intensity would be

355   random and not based on accurate data and validations. Hence, assuming that climate and

356   land use change are the main driving forces available to model species distribution (Walther

357   et al., 2002; Hitch & Leberg 2007; Guo et al., 2018), we can identify those areas where

358   saproxylic species would exist should the deadwood required for their survival be present.

359   Finally, while the monitoring our target species is mandatory for EU Member States and

360   regularly carried out in Switzerland and Norway, there are currently no standardized

361   monitoring protocols at a continental scale (Campanaro et al., 2016). However, the methods

362   used to sample our target species (e.g. attractive pheromones, baited traps, direct observations

363   along transects) are the same within our study area (Campanaro et al., 2016; Maurizi et al.,

364   2017) and thus comparable among different countries. Indeed, conservation actions at the

365   continental scale within the EU are based on these data, collected from 28 countries.

366

367   **5. CONCLUSIONS**

368   We developed this study with the observation that most of the published papers aiming to

369   predict species distribution under global change often lack the inclusion of species-specific

370   dispersal abilities. Surprisingly, this holds true also when dealing with species with low

371   vagility for which the dispersal is obviously the main factor limiting their distribution

372   (McCauley et al., 2014). Thus, in this study we showed the importance of dispersal ability in

373   species distribution modeling and how the effect of climate and land use change differed if

374   dispersal abilities are taken into account or not. Moreover, we showed that combining climate

375   and land use change scenarios with species-specific dispersal distances, resulted in more

376   accurate and realistic projections of species distributions. Our findings are very important

377   especially because poor dispersers suffer of high risk of extinction (Beissinger, 2000) due to

378   their limited ability to move away from unsuitable habitat or climatic conditions.

379   Saproxylic beetles are emblematic from this point of view. Through our approach we were

380   able to accurately identify areas with fundamental species-specific resources, such as ancient

381   woods, forest remnants, hedgerows and old deciduous tree and to provide tolls for

382   establishing protected areas and/or extending already existing ones. Concluding, we

383   encourage researchers and conservationists to follow our approach when species dispersal

384 information is available to avoid misleading and overestimated predictions, providing support

385 for conservation actions on these species and their habitats.

386

387 **DATA AVAILABILITY STATEMENT**

388 Species occurrence data used in this study is freely available at the following links:

389 http://cdr.eionet.europa.eu/, http://lepus.unine.ch/carto/ and http://www.biodiversity.no/.

390 GIS layers related to bioclimatic predictors for both current and future scenarios used in this

391 study are available at http://www.worldclim.org. Current land use GIS layers are available at

392 https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012, while future land use

393 scenarios are freely available at http://labs.kh.hercules-landscapes.eu/labs/themeLD.html.

394

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649

650   **BIOSKETCH**

651   **Francesca Della Rocca** is an Adjunct Professor at the Department of Biology and

652   Biotechnology, University of Pavia, and is broadly interested in the biogeography of

653   endangered saproxylic beetles. **Pietro Milanesi** is a postdoc at the Swiss Ornithological

654   Institute in spatial statistical modelling and is mainly interested in macroecology. Author

655   contributions: FDR and PM conceived and designed this study, analyzed the data and wrote

656   the firsts drafts of this manuscript, and alternately commented and revised the manuscript.
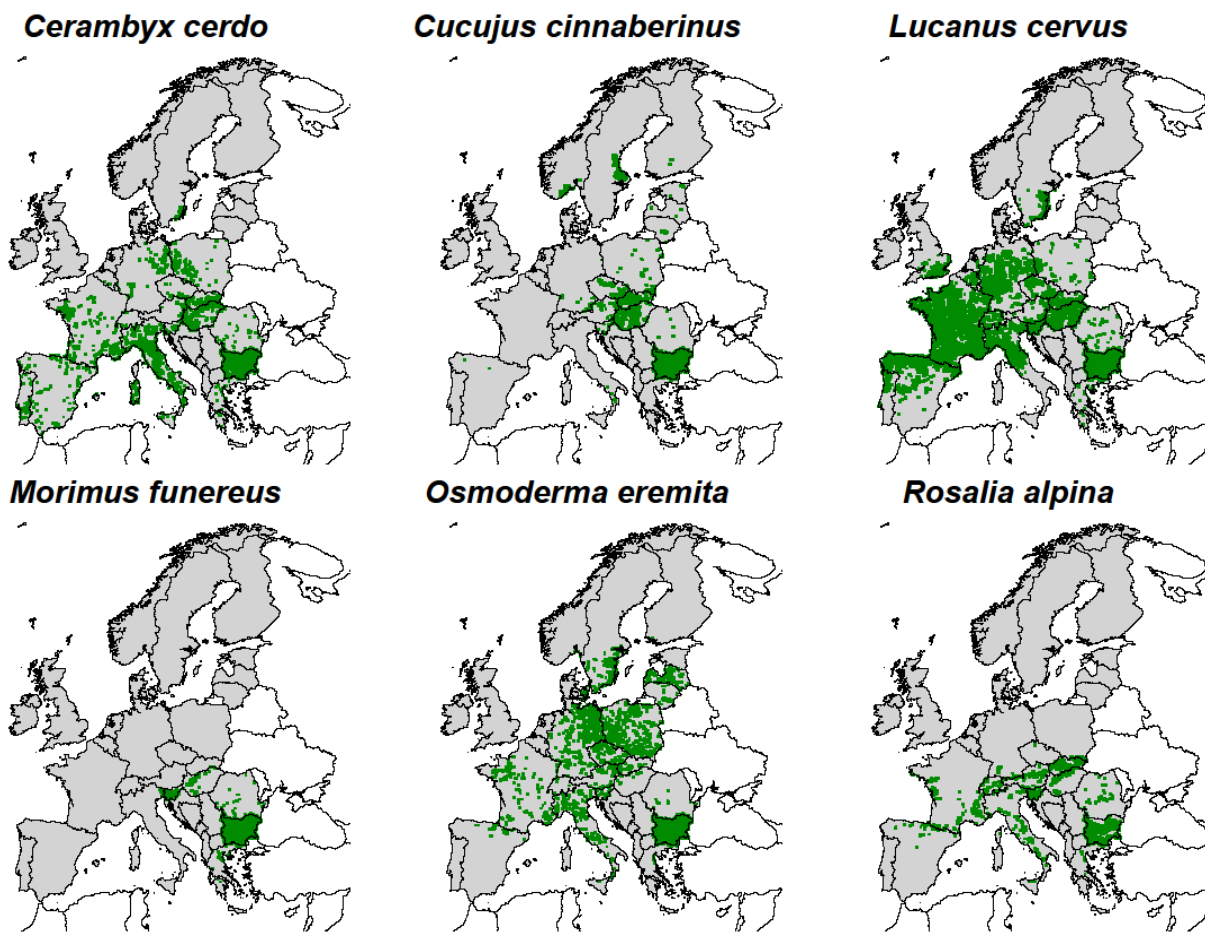
657   Table 1. Suitable areas (km^2) for saproxylic beetles in Europe without considering species-

658   specific dispersal distances under future (2040-50) scenarios. Four land use change scenarios:

659   Libertarian Europe (A1), Eurosceptic Europe (A2), Social Democracy Europe (B1) and

660   European Localism (B2), representing strong (A1), high (A2), moderate (B1) and low (B2)

661   economic interventions and growth (Stürck *et al.*, 2015), and four Representative

662   Concentration Pathways (RCP) derived by 11 general circulation models (GCMs), were

663   combined to project species distribution in 2040-50. RCPs represent four possible greenhouse

664   gas emission trajectories: low (RCP 2.6), moderate (RCP 4.5), high (RCP 6) and strong (RCP

665   8.5) increases in global radiative forcing (Ihlow et al., 2016). Source RCPs:

666   Intergovernmental Panel on Climate Change 5th assessment - Coupled Model Intercomparison

667   Project Phase 5.

Species	RCP	A1	A2	B1	B2
Cerambix cerdo	2.6	4,350,600	4,364,800	4,340,000	4,347,600
	4.5	4,393,000	4,408,100	4,385,600	4,383,300
	6	4,414,500	4,428,000	4,411,600	4,412,100
	8.5	4,423,000	4,421,700	4,415,600	4,406,800
Cucujus cinnaberinus	2.6	4,357,500	4,359,000	4,352,500	4,351,600
	4.5	4,370,100	4,383,700	4,378,900	4,377,700
	6	4,355,800	4,370,100	4,363,500	4,360,300
	8.5	4,437,500	4,445,500	4,441,900	4,440,900
Lucanus cervus	2.6	4,545,800	4,616,000	4,585,600	4,646,100
	4.5	4,532,300	4,608,900	4,558,300	4,624,800
	6	4,567,800	4,636,200	4,604,100	4,661,300
	8.5	4,508,300	4,577,100	4,539,600	4,601,900
Morimus funereus	2.6	3,392,800	3,345,200	3,409,900	3,366,800
	4.5	3,499,200	3,451,400	3,507,600	3,479,300
	6	3,476,700	3,429,100	3,487,700	3,446,400
	8.5	3,531,600	3,486,700	3,543,500	3,507,700
Osmoderma eremita	2.6	3,906,500	3,839,500	3,897,500	3,853,400
	4.5	3,879,700	3,817,500	3,864,200	3,814,800
	6	3,852,700	3,786,500	3,832,600	3,784,900
	8.5	3,880,500	3,817,500	3,862,700	3,822,000
Rosalia alpina	2.6	3,858,000	3,903,100	3,891,900	3,923,500
	4.5	3,867,900	3,921,000	3,906,400	3,945,200
	6	3,916,400	3,974,200	3,974,500	3,996,100
	8.5	3,923,200	3,975,100	3,966,900	3,996,900

Table 2. Suitable areas (km^2) for saproxylic beetles in Europe accounting for species-specific dispersal distances under future (2040-50) scenarios. Four land use change scenarios: Libertarian Europe (A1), Eurosceptic Europe (A2), Social Democracy Europe (B1) and European Localism (B2), representing strong (A1), high (A2), moderate (B1) and low (B2) economic interventions and growth (Stürck *et al.*, 2015), and four Representative Concentration Pathways (RCP) derived by 11 general circulation models (GCMs), were combined to project species distribution in 2040-50. RCPs represent four possible greenhouse gas emission trajectories: low (RCP 2.6), moderate (RCP 4.5), high (RCP 6) and strong (RCP 8.5) increases in global radiative forcing (Ihlow et al., 2016). Source RCPs: Intergovernmental Panel on Climate Change 5th assessment - Coupled Model Intercomparison Project Phase 5.

Species	RCP	A1	A2	B1	B2
Cerambix cerdo	2.6	1,079,600	1,072,100	1,081,300	1,074,500
	4.5	1,083,500	1,083,000	1,087,200	1,076,100
	6	1,078,800	1,081,600	1,086,100	1,073,700
	8.5	1,090,000	1,089,700	1,091,500	1,086,500
Cucujus cinnaberinus	2.6	573,900	571,500	571,100	574,300
	4.5	578,300	577,700	578,100	583,200
	6	578,600	576,400	578,000	580,200
	8.5	583,600	582,200	584,200	585,600
Lucanus cervus	2.6	1,728,200	1,704,100	1,728,200	1,713,300
	4.5	1,747,700	1,723,700	1,747,500	1,729,900
	6	1,738,300	1,708,100	1,735,000	1,719,400
	8.5	1,757,500	1,727,100	1,749,500	1,737,900
Morimus funereus	2.6	179,000	179,300	182,800	173,900
	4.5	177,600	180,000	181,400	175,600
	6	179,300	181,500	183,000	176,900
	8.5	178,700	181,100	183,200	177,400
Osmoderma eremita	2.6	1,041,000	1,029,800	1,032,300	1,030,900
	4.5	1,021,300	1,015,000	1,022,900	1,018,500
	6	1,032,400	1,016,600	1,020,300	1,017,300
	8.5	1,018,200	1,005,700	1,009,900	1,009,700
Rosalia alpina	2.6	566,000	564,200	561,700	570,000
	4.5	574,800	570,900	569,600	579,300
	6	572,400	565,800	567,600	571,900
	8.5	579,100	571,400	570,900	581,300

679   Figure 1. Study area (in grey) and current species ranges, according to European Environment Information and Observation Network (EIONET)

680   Central Data Repository server, Swiss Biological Records Center and Norwegian Taxonomy Initiative, of the six saproxylic species considered (in

681   green).

682

683 Figure 2. Response curves of suitable areas (km²), generated without accounting for saproxylic beetles dispersal distances, in relation to four land

684 use change scenarios (Stürck *et al.*, 2015) and four Representative Concentration Pathways (RCP) derived by 11 general circulation models (GCMs)

685 for the period 2040-50 in Europe. Filled red for A1, dashed orange for A2, filled light green for B1 and dashed dark green for B2. Source RCPs:

686 Intergovernmental Panel on Climate Change 5th assessment - Coupled Model Intercomparison Project Phase 5.

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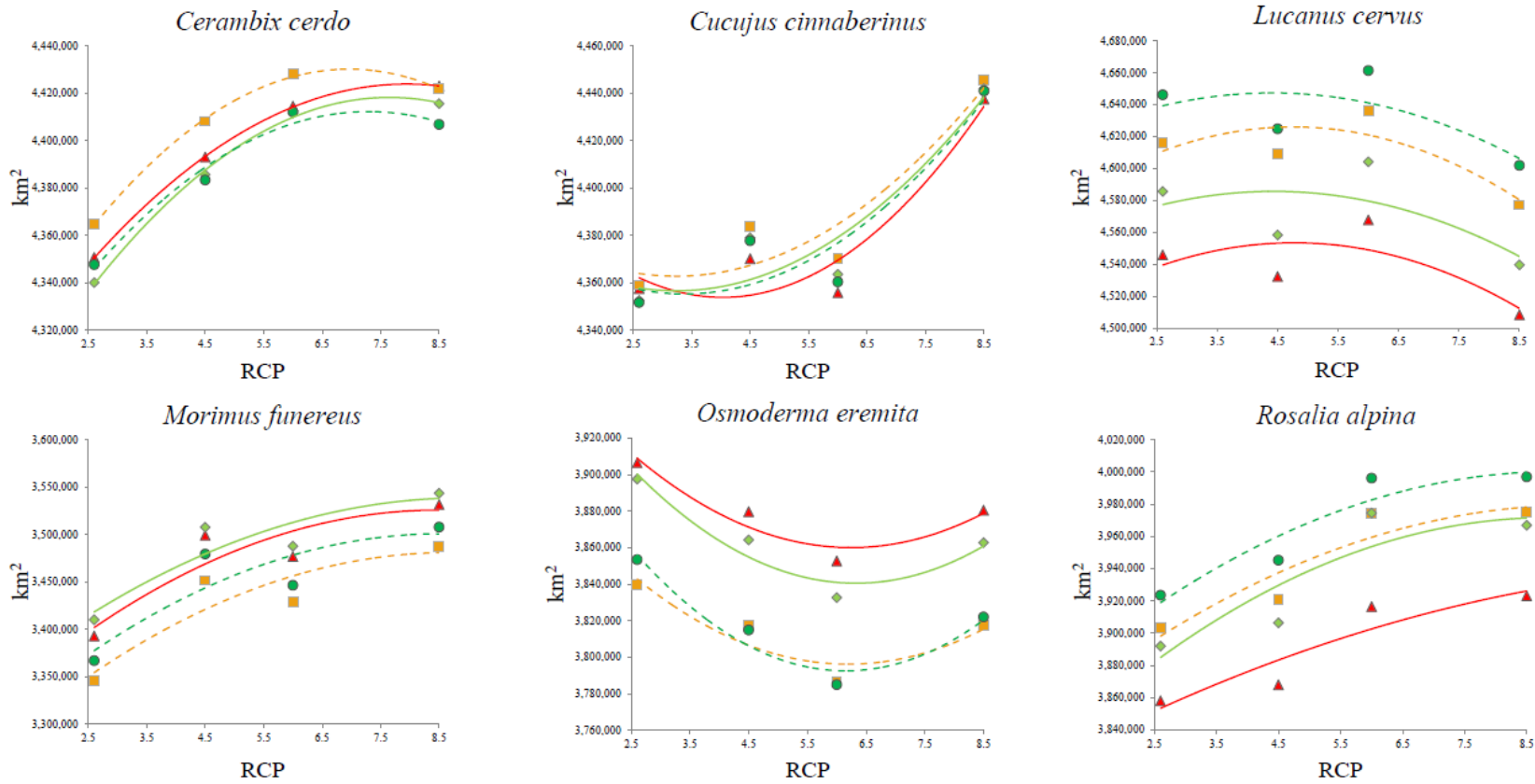
Figure 3. Response curves of suitable areas (km^2), accounting for saproxylic beetles dispersal distances, in relation to four land use change scenarios

(Stürck *et al.*, 2015) and four Representative Concentration Pathways (RCP) derived by 11 general circulation models (GCMs) for the period 2040-

50 in Europe. Filled red for A1, dashed orange for A2, filled light green for B1 and dashed dark green for B2. Source RCPs: Intergovernmental

Panel on Climate Change 5th assessment - Coupled Model Intercomparison Project Phase 5.

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SUPPORTING INFORMATION

693
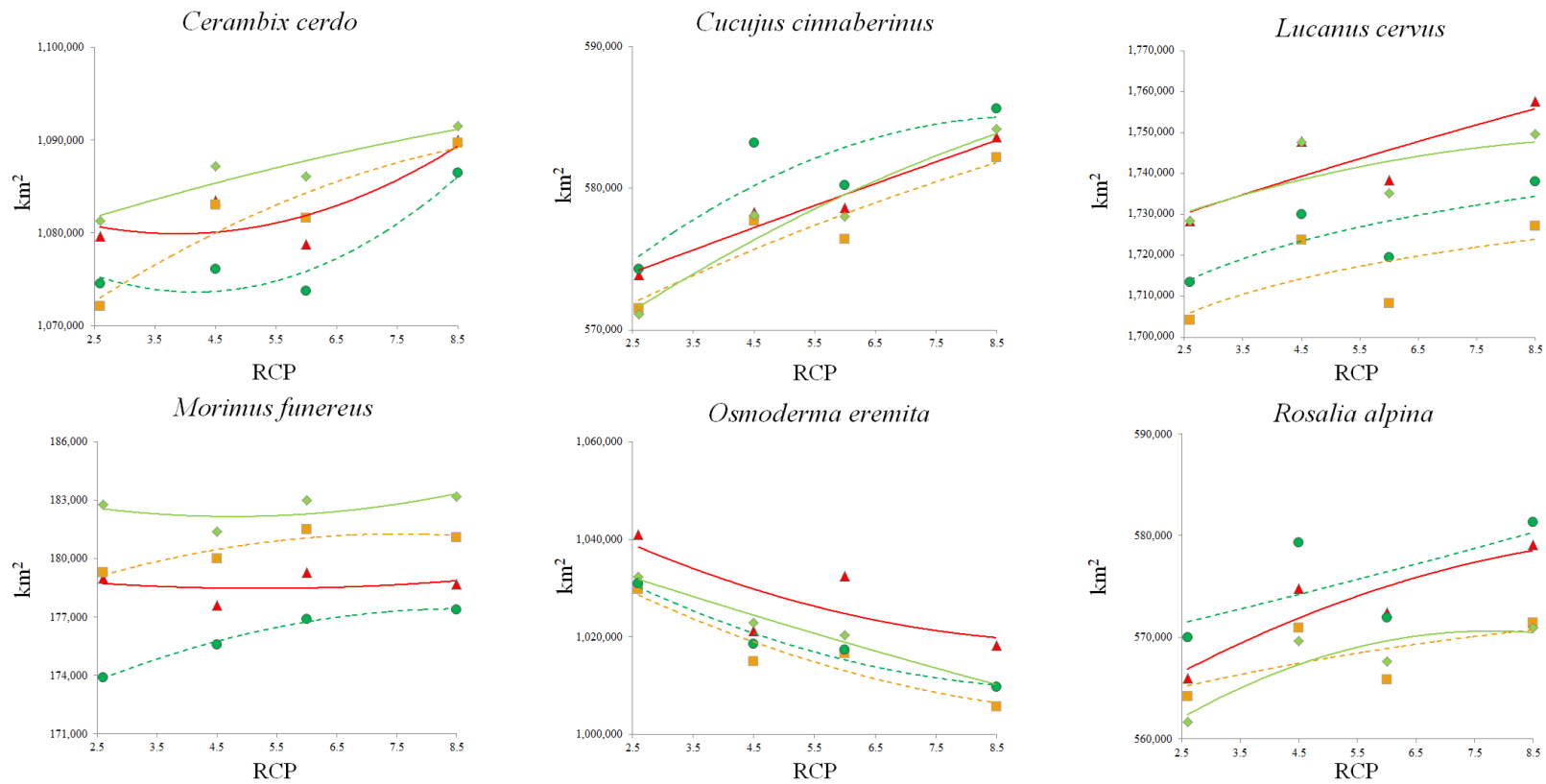
694   Additional supporting information may be found online, in the Supporting Information

695   section at the end of the article.