

1 Running head: Rare species suffer from climate change

2 **Rare species perform worse than common species under changed climate**

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24 **Abstract**

25 Predicting how species, particularly rare and endangered ones, will react to climate change is a
26 major current challenge in ecology. Rare species are expected to have a narrower niche width than
27 common species. However, we know little whether they are also less able to cope with new climatic
28 conditions. To simulate climate change, we transplanted 35 plant species varying in rarity to five
29 botanical gardens in Switzerland, differing in altitude. For each species we calculated the difference
30 in climate between their natural habitats and the novel climate of the respective botanical garden.
31 We found that rare species had generally lower survival and biomass production than common
32 species. Moreover, rare plant species survived less when the amount of precipitation differed more
33 from the one in their natural range, indicating a higher susceptibility to climate change. Common
34 species, in contrast, survived equally well under all climates and even increased their biomass under
35 wetter or drier conditions. Our study shows that rarer species are less able to cope with changes in
36 climate compared to more widespread ones, which might even benefit from these changes. This
37 indicates that already rare and endangered plant species might suffer strongly from future climate
38 change.

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40 **Keywords:** Plant–climate interactions, plant rarity and commonness, range size, species
41 abundance, climatic tolerance, climatic niche, fundamental niche, survival, plant performance

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44 **INTRODUCTION**

45 Understanding how species respond to a changing climate is one of the most important current
46 challenges for ecologists (Chevin et al. 2010, Chessman 2013, Pacifici et al. 2015). Rare, already
47 endangered species might be particularly vulnerable to climate change (Schwartz et al. 2006), and
48 information in how they respond to changes in climate is crucial to target conservation and
49 management efforts. For plants, the predicted changes in temperature and precipitation can have
50 profound implications for their growth and survival. An increase of 1 to 2°C in the global mean
51 surface temperature (IPCC 2014) along with a reduction in the average amount of precipitation,
52 and the occurrence of more extreme events such as droughts, directly impact plants and change
53 abiotic and biotic parameters. To survive climate change, plant populations may migrate to keep
54 track of favorable environmental conditions, or they can also tolerate the new climatic conditions
55 and adapt (Franks et al. 2014). Accordingly, many models predict that species will shift their ranges
56 in response to climatic modifications (e.g. Bakkenes et al. 2002, Thomas et al. 2004). However,
57 migration may be limited, e.g. by topographic boundaries such as mountains, the increasing
58 fragmentation of our landscapes (Jump and Peñuelas 2005), or for species with a long generation
59 time and low dispersal abilities (Aitken et al. 2008), and hence models hypothesize that a higher
60 number of plant species will be threatened in a close future by the loss of climatically suitable areas
61 (Thuiller et al. 2005). Therefore, tolerance to climate change might be of particular importance for
62 plant populations.

63 One of the main hypothesis aiming to explain why some plant species are rare while others range
64 widely is the niche-breadth hypothesis, which suggests that rare species are rare because they have
65 a smaller niche breadth, i.e. they are less able to maintain viable populations across a range of
66 environments, than more common species with a greater range size (Brown 1984, Slatyer et al.
67 2013). This hypothesis has achieved consistent support when quantifying the niche breadth based

68 on the current distribution of species, suggesting that a positive relationship between range size
69 and climatic niche breadth is a general pattern (Kambach et al. 2018). A species can have a large
70 climatic niche because it consist of many locally adapted populations that each are adapted to
71 different climatic conditions (Ackerly 2003) or because it consist of general-purpose genotypes
72 that thrive in a wide range of environmental conditions through phenotypic plasticity (Baker 1965).
73 Only the latter would enable plant populations to tolerate new climates when migration is hindered.
74 However, we lack empirical knowledge on whether individuals of more common species are more
75 tolerant to climatic variation, i.e. whether they have a larger fundamental niche due to general-
76 purpose genotypes, than more rare and endangered species do. This information is crucial if we
77 want to forecast the future composition of plant communities and to detect species that are
78 particularly sensitive to climate change. Answering this question requires experimental approaches
79 with many plant species (van Kleunen et al. 2014), however, empirical assessments of the
80 fundamental climatic niches are scarce.

81 In this study, we tested the response of 35 plant species differing in rarity from rare and endangered
82 to widespread species, to different climatic conditions. We used an altitudinal gradient in
83 Switzerland, with a dryer and warmer climate at low altitudes and a wetter and colder climate at
84 higher altitudes, to simulate climate change (Körner 2007). By transplanting the 35 plant species
85 to five different botanical gardens along an altitudinal gradient, we were able to follow their
86 survival and performance under various climatic conditions, which differed from the climatic
87 conditions of their natural range. Using this experimental multi-species multi-site approach, we
88 addressed the following specific questions: (i) Across different climatic conditions, do rare and
89 common plant species generally differ in their survival and performance? (ii) Do rare and common
90 plant species respond differently to changes in climatic conditions? We hypothesize that all species
91 should perform best when the climatic conditions match the ones of their natural range. However,

92 given that species with a small range size might also have a narrower fundamental niche width than
93 more widespread species (Brown 1984), we expect individuals of rare species to be less tolerant to
94 changes in climatic conditions, putting them at an even higher risk of extinction with climate
95 warming.

96

97 **METHODS**

98 **Plant species and experimental design.** We used 35 plant species from 16 plant families (see
99 Table S1 in Supporting Information). Twenty-four of those were rare species with a conservation
100 priority in Switzerland (Moser et al. 2002), and 11 of them were common species which are
101 widespread in Switzerland. Seeds of rare plant species were collected in the wild (one population
102 per species) in Switzerland. Seeds of common species were collected in the wild or obtained from
103 commercial seed suppliers (Rieger-Hofmann GmbH, Germany and UFA Samen, Switzerland).

104 In March 2012, we germinated the seeds and planted 50 seedlings per species individually into 2-
105 L pots filled with potting soil. Plants were then placed in a common garden (Muri near Bern,
106 Switzerland) where they grew for another two months. In May 2012, we measured plant height to
107 account for initial size differences. In June 2012 we transported the plants to five Botanical Gardens
108 differing in altitude and climatic conditions (Table 1). In each garden, we placed 10 pots per species
109 (occasionally less, Table S2) and distributed them randomly into garden beds. In early summer
110 2013 we recorded the survival of the plants and collected aboveground biomass. Since watering
111 happened only in case of severe drought, we can assume that the observed differences in plant
112 growth between the gardens is due to differences in precipitation and temperature and is not biased
113 by the care taken by the botanical gardens.

114 **Rarity and climatic variables.** To obtain a continuous measure of plant rarity we used the range
115 size of each species in Switzerland. Range size was expressed as the number of 10 x 10 km grid

116 cells occupied by a given species in Switzerland (data provided by Info Flora). We used range size
117 in Switzerland because a continuous measure of European range sizes for our species is not
118 available yet. Nevertheless, for a subset of 21 species for which European range size is available,
119 Swiss and European range size were positively correlated ($r = 0.508$, $p < 0.001$, Text S1).

120 For each species we calculated climatic values, which characterize the climatic conditions in the
121 natural range of a species in Switzerland. We calculated the mean annual temperature and mean
122 annual level of precipitation per species (Table S1) by extracting climatic information at all known
123 locations of the species in Switzerland using precise coordinates (for complete details on the
124 climate data, see (Zimmermann and Kienast 1999). For each botanical garden, we also extracted
125 the mean annual temperature and mean annual level of precipitation (Table 1).

126 To define the difference in climate between a botanical garden and a species' natural range, we
127 calculated the temperature and precipitation differences by subtracting the climatic value of a
128 species range from the climatic value of a botanical garden. A negative value of a precipitation or
129 temperature difference indicates that the climate is dryer or colder, respectively, in a botanical
130 garden than in the species natural range. The range size of our species was not related to the mean
131 altitude ($r = 0.01$, $p = 0.95$) and the mean temperature ($r = -0.08$, $p = 0.64$) of their natural range.
132 Range size was positively related to the mean annual level of precipitation ($r = 0.40$, $p = 0.02$).

133 **Statistical analysis.** To test whether species with a larger range size also occurred in a wider range
134 of climates (i.e. whether they also have a larger climatic niche) we correlated range size with the
135 difference between the maximum and the minimum value of temperature and precipitation of the
136 species natural ranges. To test whether rare and common species generally differ in their survival
137 and aboveground biomass production, we used generalized linear mixed effects models (*glmer*)
138 with a binomial error distribution and linear mixed effects models (*lmer*) using the lme4 package
139 (Bates *et al.* 2014) in R (R Core Team 2014), with the range size of the species as fixed term, the

140 species identity nested into plant family (to account for taxonomy), and the botanical garden where
141 the plants grew, as random factors. We also included the initial height of the plants as covariate, to
142 control for initial size differences.

143 To test whether rare and common species respond differently in terms of their survival and
144 aboveground biomass production to climatic differences, we used range size, temperature
145 difference, precipitation difference, and the interaction between range size and climatic differences
146 as explanatory variables. We also included the quadratic terms for the climatic differences as we
147 expected a hump-shaped relationship with an optimum at a climatic difference of 0 (i.e. where the
148 climatic conditions in a garden match the ones of a species natural range). Further, we included the
149 interaction between the quadratic terms for the climatic differences and the range size of the
150 species. Although the climatic variables ‘temperature difference’ and ‘precipitation difference’
151 were correlated with each other ($r = -0.64$, $p < 0.001$), both explained a significant part of the
152 variation and were both kept in the model. We simplified the full models by removing non-
153 significant terms and we determined significances using likelihood-ratio tests comparing models
154 with and without the factor of interest. Non-significant linear terms were kept when the
155 corresponding interaction and quadratic terms were significant. We log-transformed the biomass
156 data and scaled all continuous variables to means of zeros and standard deviations of one for an
157 easier interpretation of the model estimates.

158

159 **RESULTS**

160 Range size strongly correlated with the species temperature and precipitation niche width, i.e. with
161 the difference between the maximum and the minimum temperature ($r = 0.83$, $p < 0.001$),
162 respectively precipitation ($r = 0.78$, $p < 0.001$) in the natural range. This confirms that more
163 widespread species occur in a wider range of climatic conditions than rarer species. Overall, species

164 with a larger range size survived better ($\text{Chi}^2 = 3.88$, $p = 0.049$) and produced more aboveground
165 biomass ($\text{Chi}^2 = 17.5$, $p < 0.001$, Fig. 1) than rarer species.

166 Survival was highest at low precipitation differences, i.e. when the climatic conditions of a garden
167 were most similar to the ones of a species natural range. This effect was only driven by rare plant
168 species, whose survival decreased when the amount of precipitation in a garden differed from the
169 one of their natural range. In contrast, more common species were hardly affected by differences
170 in precipitation, maintaining a high average survival in all botanical gardens (significant range size
171 x squared precipitation difference interaction, Table 2, Fig. 2a).

172 Aboveground biomass of rarer species was hardly affected by differences in precipitation between
173 a botanical garden and the species natural range. Common species, however, produced more
174 biomass when the conditions were drier - and thus sunnier - and when the conditions were wetter
175 than in their natural range (Table 2, Fig 2b). This indicates that more common plant species are
176 able to plastically increase their biomass in these conditions whereas rarer plant species are less
177 plastic and show a relatively stable biomass production.

178 Overall, survival and biomass production was lowest when the temperature in a botanical garden
179 deviated most from the mean temperature of a species natural range (significant squared
180 temperature difference effect, Table 2, Fig. 3), and this did not differ for rare and common species.

181

182 **DISCUSSION**

183 **Rare plant species are less tolerant to changes in climate than common plant species.** Among
184 the most important hypotheses explaining species rarity and commonness is the niche breadth
185 hypothesis, which predicts that species that are able to maintain populations across a larger set of
186 environmental conditions can achieve larger geographic ranges than species with narrow ecological
187 niches (Brown 1984). Studies relating the range size of species to their realized niches supported

188 the predicted pattern (Kambach et al. 2018). However, whether this means that more common
189 species also consists of individuals, which generally have larger fundamental niches (general-
190 purpose genotypes) than have rare species, and therefore which have a higher ability to cope with
191 changing climatic conditions, remains unknown. In our experiment, plant species generally
192 survived better and had a greater biomass when the mean annual temperature of the botanical
193 gardens was similar to the one they experience in their natural range (Fig. 3), reflecting the
194 existence of a climatic niche due to physiological limitations, which is a key assumption for
195 predicting the impact of climate change on species distributions (Pearman et al. 2008, Petitpierre
196 et al. 2012). Similarly, plants survived better when the mean annual precipitation mirrored the one
197 from their natural range, however, this was only driven by rare plant species, which suffered from
198 differences in precipitation (when conditions were either dryer or wetter than the ones at their
199 origin). In contrast, more common species were not affected by precipitation differences, and
200 showed a similarly high survival at all precipitation levels, independent of the ones of their origin
201 (Table 2, Fig. 2a). Our results demonstrate that rarer species do indeed have a smaller fundamental
202 niche in terms of precipitation, i.e. a lower climatic tolerance due to physiological limitations, than
203 more common species. Since climate change is expected to increase wet and dry extreme events
204 (Knapp et al. 2008) this suggests that species, which are already threatened under the current
205 climate will suffer most from the effects of climate change.

206 Widespread species are likely to experience a larger range of ecological and climatic conditions
207 within their range (Gaston 2003). Indeed, a larger niche width – based on the current distribution
208 of a species – seems to be a general pattern in widespread species (Slatyer et al. 2013, Kambach et
209 al. 2018), and was also supported by our data (positive correlation between range size and the
210 climatic width). A species can accrue a larger niche breadth because it consists of many locally
211 adapted populations (Olsson et al. 2009) which partition the broad climatic tolerance exhibited by

212 the species as a whole. Moreover, species can be composed of phenotypically plastic genotypes,
213 general-purpose genotypes or individual generalists that perform well under a large range of
214 environmental conditions (Baker 1965, Ackerly 2003). Although in our experiment we cannot
215 entirely disentangle the factors leading to a higher climatic tolerance in common species, the fact
216 that we found this pattern by placing only a few individuals into the different botanical gardens
217 indicates that widespread species are more likely to be comprised of individual 'generalists'.
218 However, to fully understand the influence of broad tolerance and microevolution on niche width,
219 experiments simultaneously comparing climatic tolerance of many species, populations per
220 species, and genotypes per population are needed.

221 In contrast to results on survival, aboveground biomass production of rarer species hardly changed
222 in response to differences in precipitation. More common species, however, increased their
223 biomass particularly when the amount of precipitation was lower than in their natural range (Table
224 2, Fig. 2b). Possibly, a dryer climate implies a higher number of sunny days and therefore more
225 favorable conditions for plant growth. More common species therefore seem to be more able to
226 plastically increase their biomass under favorable growing conditions, whereas rarer species seem
227 to be less able to change their phenotypes in response to environmental variation. When
228 precipitation was higher than in their natural range, more common species were also able to
229 increase their biomass. This plastic response in more widespread species indicates that, in addition
230 to maintaining generally high survival under different climatic conditions, widespread species were
231 able to take advantage of both drier and wetter conditions. Widespread species have also been
232 shown to be better able to take advantage of an increase in nutrient availability than rare species
233 (Dawson et al. 2012) and, compared with species confined to river corridors, to better take
234 advantage of benign conditions of non-river corridor conditions (Fischer et al. 2010). Our study
235 therefore adds additional evidence that widespread species might be widespread as they are able to

236 take advantage of favorable climatic and environmental conditions than species of small range size,
237 and that this is a general pattern. Under future climate change, with a predicted increase in extreme
238 precipitation events (Easterling et al. 2000), our results indicate that more common species might
239 better take advantage of the changing climatic conditions and potentially outcompete rarer species.
240 This calls for developing measures to support rare species.

241 In most cases, widespread species experience a wider range of climatic conditions in their natural
242 ranges than species with a more restricted range size. Therefore, the mean altitude, mean annual
243 precipitation and mean temperature of the 11 species common in Switzerland was intermediate
244 among those of the 25 rare species, some of which only occur in alpine or lowland regions (Figure
245 S1). This reduced the range of data points in climatic differences for common species and might
246 have affected extrapolations of our models at the extreme ends of climatic differences. To control
247 for such potential bias, we analyzed a subset of our data by keeping only those rare species that
248 occur within the same climatic range than our common species (Table S3). This analysis confirmed
249 the effects of climatic differences and their interaction with range size found for the whole dataset,
250 which suggests that our finding that more widespread species have a wider climatic tolerance than
251 rarer ones is robust.

252 Experimental tests of environmental tolerance of multiple plant species as the one we present here,
253 and particularly of rare and common native species, are extremely rare (Slatyer et al. 2013). A few
254 studies assessed the tolerance to different germination conditions (fundamental germination niche
255 widths) of rare and common plant species and found either a positive (Brändle *et al.* 2003; Luna *et*
256 *al.* 2012), negative (Luna and Moreno 2010) or no relationship with range size (Thompson and
257 Ceriani 2003, Gaston and Blackburn 2007). Our results therefore highlight that plant rarity is
258 related to the fundamental climatic niche of species, and calls for a more differentiated view when
259 predicting the future distribution of different species to climate change.

260 **Rare plant species have lower survival and lower biomass than common plant species.** Why
261 some species are rare while others are common has fascinated ecologists for decades (Brown et al.
262 1996, Webb and Gaston 2003). Differences in species characteristics have repeatedly been
263 suggested to explain the distribution and abundance of plant species in nature (Murray et al. 2002,
264 Kempel et al. 2018). In our study, overall, rare plant species showed lower survival and lower
265 biomass production than common plant species. This variation in the intrinsic general performance
266 of plants could be a major driver of rarity and commonness at large spatial scales. Lower biomass
267 of rare species has also been found in other studies (Murray et al. 2002, Lavergne et al. 2003,
268 Cornwell and Ackerly 2010, Dawson et al. 2012, Kempel et al. 2018) and indicates that rare species
269 have slower growth rates (Cornelissen et al. 2003), a trait that is often attributed to slower nutrient
270 uptake and hence lower competitive ability in productive habitats (Grime 1977). By using a
271 continuous gradient of rarity and commonness with many species originating from different
272 habitats, our approach suggests that a positive relationship between plant performance and plant
273 range size is a general pattern. Future studies that take various aspects of rarity into account,
274 including small and large populations of plant species differing in range size, are needed to
275 ultimately test whether a lower general performance of species of small distribution range is a result
276 of small population sizes and hence reduced genetic diversity (Leimu et al. 2006), or whether
277 generally lower general fitness of such species is responsible for their small distributional ranges.

278 **Conclusion.** Using a large number of plant species differing in their range size in Switzerland, we
279 provide experimental evidence that more widespread species indeed have larger climatic niches
280 than rarer species. We showed that rare species not only have generally lower survival and biomass
281 production than more common species but that they are also more susceptible to a changing
282 climate. On the contrary, more widespread species survived equally well under all climates and
283 could even take advantage of favorable growing conditions by plastically increasing their biomass.

284 Our multi-species experiment suggests that this is a general pattern. We conclude that already rare
285 and endangered plant species have a lower climatic tolerance than more widespread species and
286 might suffer strongly from the forecasted climatic changes.

287
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294

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- 398

399 **TABLES**

400 **Table 1.** Location, altitude and climatic conditions of the five botanical gardens.

Botanical garden	Coordinates (CH1903)	Altitude (m)	Average annual precipitations (mm)	Average annual temperature (°C)
Basel	610797 - 267566	269.4	787.3	9.48
Geneva	500516 - 120219	372.2	909.5	9.53
Pont-de-Nant	500516 - 120219	1262.9	1451.1	5.98
Champex	574742 - 97996	1532.6	1376.9	4.19
Schynige Platte	636229 - 166947	1963.7	1630.6	1.61

401

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403

404 **Table 2.** Results of a linear mixed effects model and a generalized linear mixed effects model
 405 testing for an effect of range size, temperature difference between natural sites and botanical garden
 406 (Δ Temperature), precipitation difference (Δ Precipitation), the quadratic terms of Δ Temperature
 407 and Δ Precipitation, and their interactions on biomass production and plant survival of plants of 35
 408 species planted to five botanical gardens. We removed all non-significant terms, unless the
 409 respective quadratic or interaction term was significant. All explanatory variables are scaled. The
 410 parameters of the main factors that were present in significant interactions were derived from
 411 models where all higher order interactions were removed.

412

<i>Fixed terms</i>	<i>Biomass</i>			<i>Survival</i>		
	estimate	Chi ²	p-value	estimate	Chi ²	p-value
Range	0.24	11.2	<0.001 ^{***}	0.14	1.91	0.17
Δ Temperature	-0.05	1.59	0.206	-0.01	2.95	0.086
Δ Precipitations	-0.23	11.6	0.03 [*]	-0.16	0.05	0.831
Δ Temperature ²	-0.13	67.8	<0.001 ^{***}	-0.55	32.2	<0.001 ^{***}
Δ Precipitations ²	0.04	0.58	0.446	-0.27	8.85	0.003 ^{**}
Range x Δ Temperature	-	-	-	-	-	-
Range x Δ Precipitations	0.01	15	<0.001 ^{***}	-	-	-
Range x Δ Temperature ²	-	-	-	-	-	-
Range x Δ Precipitations ²	0.09	26.2	<0.001 ^{***}	0.2	4.54	0.033 [*]
<i>Random terms</i>		<i>Variance</i>			<i>Variance</i>	
Species		0.265			1.88	
Family		<0.001			<0.001	
Botanical Garden		0.016			0.924	

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416 **FIGURES LEGENDS**

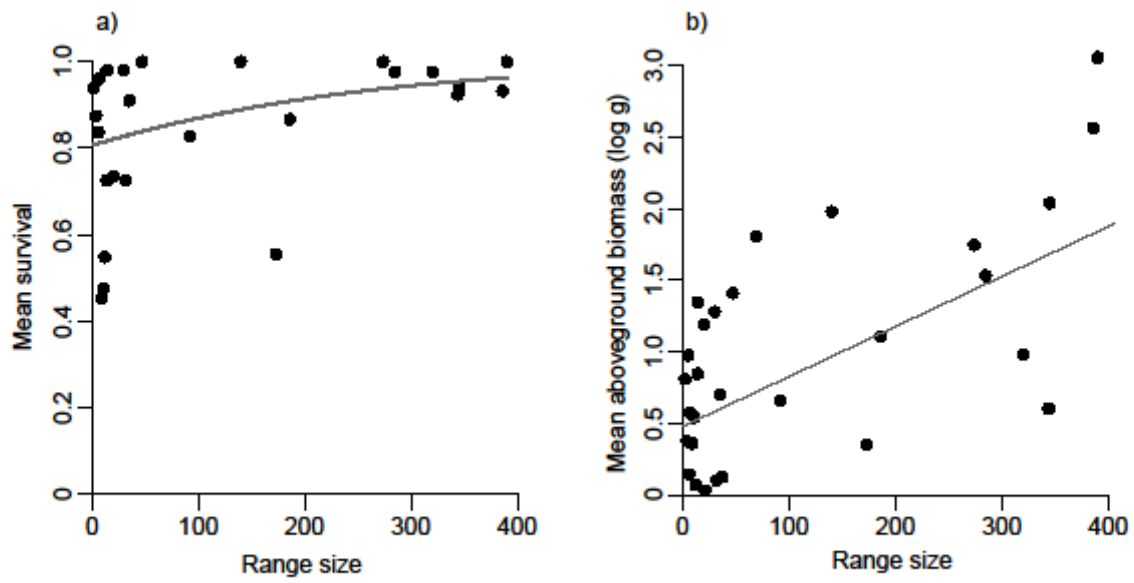
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418 **Figure 1.** Effect of range size on a) mean survival, and b) mean aboveground biomass (expressed
419 in g on a log-scale) for 35 species planted to five botanical gardens. Each point represents the mean
420 biomass or survival per species, the line is obtained from the predicted values of the models. Range
421 size is calculated as the number of 10x10km grid cell occupied by a given species in Switzerland.
422 The curved line describing the relationship between range size and survival is obtained from the
423 transformation of the binomial survival data into a continuous distribution of the probability of
424 survival.

425
426 **Figure 2.** a) Survival and b) biomass production of 35 species in relation to precipitation difference
427 between natural range size and botanical garden. The surfaces represent the predicted survival,
428 respectively biomass, from the model. Biomass is expressed in g on a log-scale. A negative
429 precipitation difference (mm year^{-1}) indicates that the conditions in a garden are dryer than the ones
430 in a species natural range.

431
432 **Figure 3.** Effect of the temperature differences ($^{\circ}\text{C}$) on a) mean survival and b) mean aboveground
433 biomass of 35 species planted in five botanical gardens. Each point represents the average
434 aboveground biomass (in g on a log-scale) or survival per species per garden in 2013. The line is
435 obtained from the predicted values of the models. To represent the effect of temperature difference,
436 we fixed the value of precipitation difference to its mean when calculating the predicted values of
437 the models.

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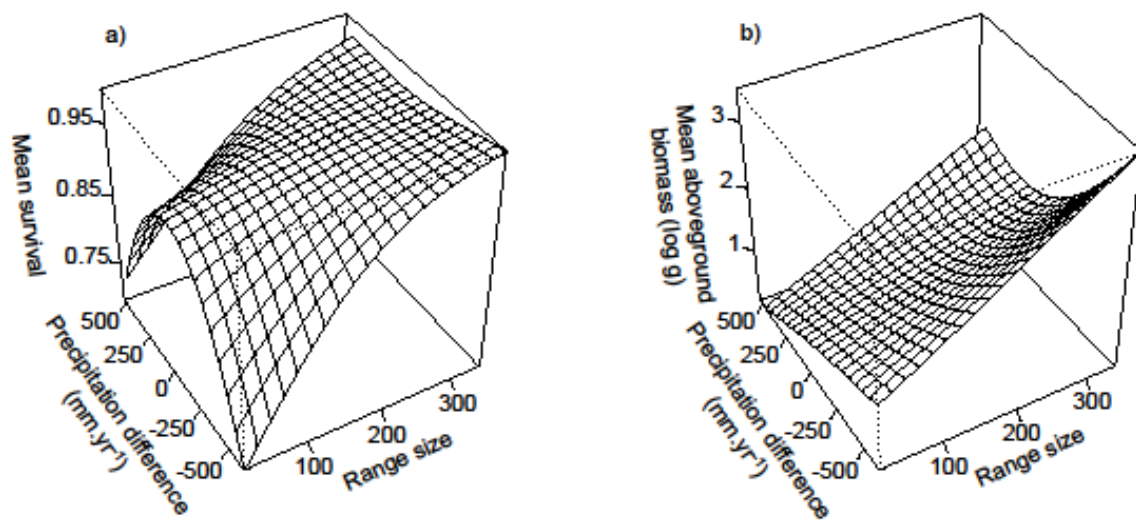
441 Figure 1



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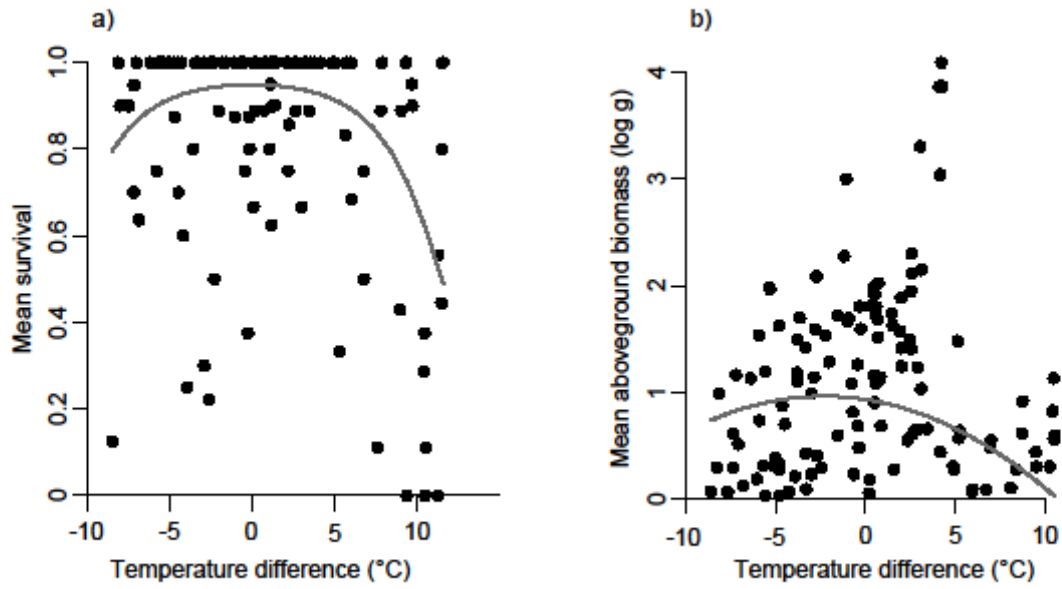
444 Figure 2



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446

447 **Figure 4**



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450 **Table S1.** List of the 24 rare and 11 common species (indicated by *) studied in this experiment,
 451 including their plant family, range size in Switzerland (number of 10x10 kilometers grid cells
 452 occupied by a species in Switzerland, see Methods), mean altitude, mean annual amount of
 453 precipitation and temperature of the species natural range, and the IUCN category of threat in
 454 Switzerland (LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered; CR:
 455 Critically Endangered).
 456

Species	Family	Range size	Mean altitude (m a.s.l.)	Mean annual precipitation (mm)	Mean annual temperature (°C)	IUCN status
<i>Carex bohemica</i>	Cyperaceae	2	429.9	1036.8	9	CR
<i>Bidens radiata</i>	Asteraceae	3	495	1091.6	8.7	CR
<i>Inula spiraeifolia</i>	Asteraceae	4	661.1	1774.9	9.9	VU
<i>Rumex maritimus</i>	Polygonaceae	5	431.1	1038.2	9	CR
<i>Ephedra helvetica</i>	Ephedraceae	6	612.6	726.9	9.3	VU
<i>Potentilla multifida</i>	Rosaceae	7	2659.4	1307.5	-1	VU
<i>Artemisia glacialis</i>	Asteraceae	9	2599.8	1291.4	-0.7	NT
<i>Cleistogenes serotina</i>	Poaceae	11	457.8	1294.1	10.2	VU
<i>Senecio halleri</i>	Asteraceae	12	2463.5	1356.2	0	NT
<i>Peucedanum venetum</i>	Apiaceae	14	635.4	1563.7	9.8	VU
<i>Artemisia vallesiaca</i>	Asteraceae	14	717.5	820.4	8.7	NT
<i>Oenanthe lachenalii</i>	Apiaceae	20	422.3	1177.8	9	CR
<i>Ludwigia palustris</i>	Onagraceae	21	384.1	1171.7	9.8	CR
<i>Rumex hydrolapathum</i>	Polygonaceae	30	448.4	1013.2	8.8	EN
<i>Astragalus leontinus</i>	Fabaceae	32	2155.1	1063.8	1.4	NT
<i>Juncus arcticus</i>	Juncaceae	35	2251.7	1237.5	0.8	VU
<i>Nigella arvensis</i>	Ranunculaceae	37	667.8	874.1	8.4	EN
<i>Seseli annuum</i>	Apiaceae	47	768.4	1005.8	8	VU
<i>Polycnemum majus</i>	Amaranthaceae	69	608	707	9.2	EN
<i>Bidens cernua</i>	Asteraceae	76	632.7	1249.9	8	EN
<i>Sedum villosum</i>	Crassulaceae	92	2175.3	1327.2	1.1	VU
<i>Stachys annua</i>	Fabaceae	102	489.5	1037.9	8.9	VU
<i>Bidens tripartita</i> *	Asteraceae	118	478.1	1069.9	8.9	NT
<i>Artemisia absinthium</i> *	Asteraceae	140	1132.6	907	6.4	LC
<i>Cyperus fuscus</i>	Cyperaceae	151	433.1	1064.3	9.3	VU
<i>Cyperus flavescens</i>	Cyperaceae	155	374	1356.5	10.1	VU
<i>Artemisia umbelliformis</i> *	Asteraceae	173	2406.5	1568.6	0	LC
<i>Sedum alpestre</i> *	Crassulaceae	186	2534.1	1530.8	-1	LC
<i>Rumex crispus</i> *	Polygonaceae	274	867.1	1361.9	7	LC
<i>Linaria vulgaris</i> *	Plantaginaceae	285	735.1	1270.9	7.5	LC
<i>Centaurea scabiosa</i> *	Asteraceae	320	746.8	1259.5	7.5	LC
<i>Juncus articulatus</i> *	Juncaceae	344	961.9	1495.5	6.6	LC
<i>Bromus erectus</i> *	Poaceae	345	889.8	1189.7	6.9	LC
<i>Trifolium repens</i> *	Fabaceae	386	1178.7	1523.9	5.4	LC
<i>Trifolium pratense</i> *	Fabaceae	390	1193.2	1600.8	5.3	LC

457 **Table S2.** Number of plants per species grown in each botanical garden.

Species	Botanical gardens				
	Geneva	Basel	Pont-de-Nant	Champex	Schynige Platte
<i>Artemisia absinthium</i>	8	7	6	7	9
<i>Artemisia glacialis</i>	9	8	9	7	9
<i>Artemisia umbelliformis</i>	9	8	4	8	8
<i>Artemisia vallesiaca</i>	10	10	10	10	11
<i>Astragalus leontinus</i>	9	7	7	9	9
<i>Bidens cernua</i>	10	10	10	10	10
<i>Bidens radiata</i>	10	10	11	10	10
<i>Bidens tripartita</i>	9	7	8	8	9
<i>Bromus erectus</i>	7	6	9	7	7
<i>Carex bohémica</i>	20	20	20	20	20
<i>Centaurea scabiosa</i>	9	8	8	8	9
<i>Cleistogenes serotina</i>	8	8	8	8	8
<i>Cyperus flavescens</i>	9	9	10	9	9
<i>Cyperus fuscus</i>	20	20	20	20	20
<i>Ephedra helvetica</i>	10	9	10	10	10
<i>Inula spiraeifolia</i>	10	9	10	10	10
<i>Juncus arcticus</i>	20	20	20	20	20
<i>Juncus articulatus</i>	8	9	5	9	8
<i>Linaria vulgaris</i>	9	8	7	9	9
<i>Ludwigia palustris</i>	9	10	10	9	10
<i>Nigella arvensis</i>	9	11	10	9	10
<i>Oenanthe lachenalii</i>	10	10	9	10	10
<i>Peucedanum venetum</i>	10	10	9	10	10
<i>Polycnemum majus</i>	10	10	9	10	10
<i>Potentilla multifida</i>	10	10	10	10	10
<i>Rumex crispus</i>	8	9	9	9	9
<i>Rumex hydrolapathum</i>	10	10	10	10	10
<i>Rumex maritimus</i>	10	10	10	10	10
<i>Sedum alpestre</i>	9	9	9	9	9
<i>Sedum villosum</i>	4	7	6	7	6
<i>Senecio halleri</i>	6	7	5	6	8
<i>Seseli annuum</i>	10	10	10	10	10
<i>Stachys annua</i>	10	9	10	10	10
<i>Trifolium pratense</i>	7	9	8	9	8
<i>Trifolium repens</i>	9	9	9	9	9

458

459

460 **Table S3.** Effect of climatic differences on the biomass production and the survival of a subset of
 461 31 species. The rare species used in this experiment naturally occur in a wider range of climatic
 462 conditions than the common species used in this experiment (Fig. S4). We re-analyzed our data
 463 with a dataset including all the common species and a subset of 20 rare species, keeping only those
 464 which occur inside a precipitation range of 900 to 1600 mm.yr⁻¹. We considered the precipitation
 465 values to define this climatic range because it was the climatic variable which interacted with range
 466 size. The results did not differ qualitatively from the analysis of the entire dataset.

<i>Fixed terms</i>	<i>Biomass</i>			<i>Survival</i>		
	estimate	Chi ²	p-value	estimate	Chi ²	p-value
Range	0.19	7.37	0.006**	0.63	0.75	0.391
Δ Temperature	-0.09	0.71	0.4	1.17	1.86	0.173
Δ Precipitations	-0.28	5.73	0.017*	-	-	-
Δ Temperature ²	-0.15	82.8	<0.001***	-0.58	30.8	<0.001***
Δ Precipitations ²	0.01	1.75	0.186	-0.18	0.08	0.778
Range x Δ Temperature	-	-	-	-	-	-
Range x Δ Precipitations	0.05	11.4	<0.001***	-	-	-
Range x Δ Temperature ²	-	-	-	-	-	-
Range x Δ Precipitations ²	0.11	30.1	<0.001***	0.2	5.22	0.022*
<i>Random terms</i>		<i>Variance</i>			<i>Variance</i>	
Species		0.284			17.63	
Family		<0.001			<0.001	
Botanical Garden		0.018			1.818	

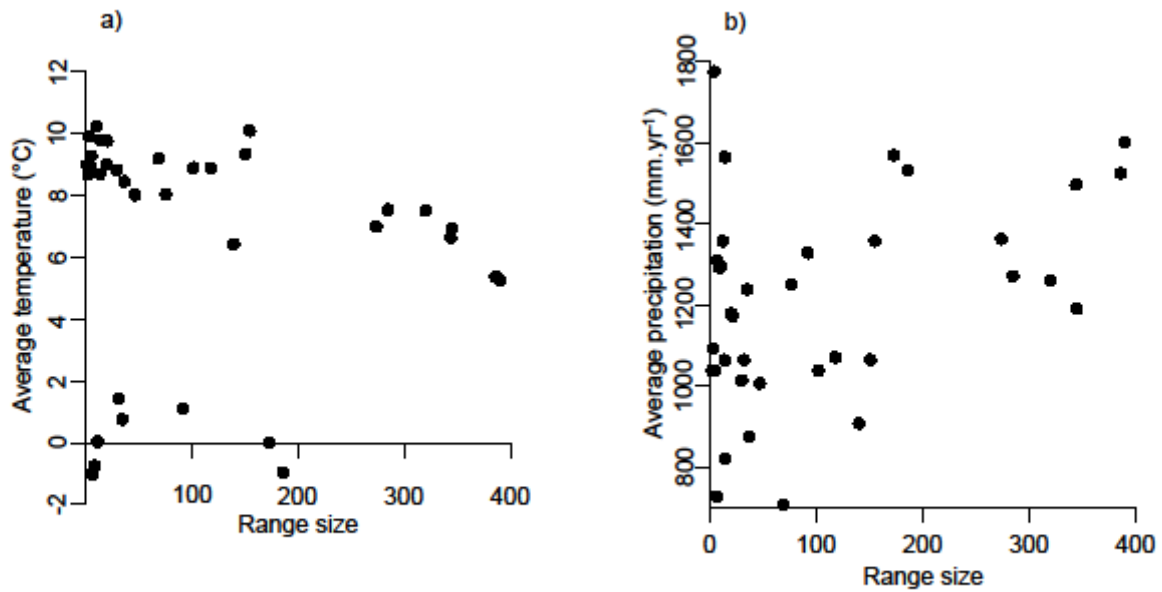
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 477 **Text S1.** To test whether range size in Switzerland is correlated with the European range size of
 478 our study species, we used map-derived area estimates from the Atlas Europeae (Meusel *et al.*

479 1978) for the 21 species for which these maps were available. We assessed the number of pixels of
480 a species European distribution and cross-referenced these using islands, for which the exact
481 surface values are known. Range size in Europe was correlated with range size in Switzerland ($r =$
482 0.508 , $p < 0.001$).

483
484 Meusel, H., Jäger, E. J., Rauschert, S. & Weinert, E. (1978). *Vergleichende Chorologie der*
485 *zentraleuropäischen Flora. Bd. 2, Text u. Karten.* Gustav Fischer Verlag, Jena.

486

487 **Figure S1.** Correlations between a) mean temperature (°C) and b) mean annual level of
488 precipitation (mm.year⁻¹) in the natural range of our 35 species, and their range size. Common
489 species showed more intermediate values than rarer species, although there was no correlation
490 between range size and mean temperature ($r = -0.08$, $p = 0.64$), and the correlation between range
491 size and mean annual precipitation ($r = 0.40$, $p = 0.02$) was not strong.



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