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Conserving European biodiversity across realms

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2

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72 **Abstract**

73 Terrestrial, freshwater, and marine ecosystems are connected via multiple biophysical and
74 ecological processes. Identifying and quantifying links among ecosystems is necessary for
75 the uptake of integrated conservation actions across realms. Such actions are particularly
76 important for species using habitats in more than one realm during their daily or life cycle.
77 We reviewed information on the habitats of 2,408 species of European conservation concern
78 and found that 30% of the species use habitats in multiple realms. Transportation and
79 service corridors, which fragment species habitats, were identified as the most important
80 threat impacting ~70% of the species. We examined information on 1,567 European Union
81 (EU) conservation projects, funded over the past 25 years, to assess the adequacy of efforts
82 towards the conservation of "multi-realm" species at a continental scale. We discovered that
83 less than a third of "multi-realm" species benefited from projects that included conservation
84 actions across multiple realms. To achieve the EU's conservation target of halting
85 biodiversity loss by 2020 and effectively protect multi-realm species, integrated conservation
86 efforts across realms should be reinforced by: 1) recognizing the need for integrated
87 management at a policy level, 2) revising conservation funding priorities across realms, and
88 3) implementing integrated land-freshwater-sea conservation planning and management.

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96 **Introduction**

97 Recent research has highlighted the importance of identifying and quantifying links among
98 the terrestrial, freshwater, and marine realms when planning for conservation and managing
99 ecosystems (e.g. Álvarez-Romero *et al.* 2011; Saunders *et al.* 2017). Multiple biophysical
100 and ecological processes connect realms, allowing for the movement of species and the
101 transfer of energy and matter across them (Beger *et al.* 2010). Concurrently, there are
102 numerous cross-realm threats to ecosystems, such as agricultural effluents impacting
103 freshwater and marine ecosystems (Álvarez Romero *et al.* 2011). Thus, the persistence of
104 species in one realm can be jeopardized by human activities occurring in another (Stoms *et*
105 *al.* 2005). To avert such risks, threat management and prioritization of conservation actions
106 require an integrated approach spanning all realms (Tallis *et al.* 2008, Adams *et al.* 2014,
107 Saunders *et al.* 2017).

108 The need for integrated conservation efforts is further pronounced when dealing with
109 organisms that use habitats in more than one realm during their daily activities or life cycle
110 (hereafter referred to as multi-realm species). For example, diadromous fishes that migrate
111 between freshwater and marine ecosystems, and dragonflies that move daily between
112 freshwater and terrestrial ecosystems. Identifying connections between ecosystems within
113 different realms is critical for the persistence of multi-realm species. For migratory animals,
114 such as several shorebird species, these connections can extend over broad spatial scales
115 and cross borders (Iwamura *et al.* 2013), making international collaboration necessary to
116 ensure cross-boundary species conservation (Kark *et al.* 2015).

117 Despite this, connections among realms have been broadly ignored when managing
118 ecosystems and conservation efforts have mainly focused on one particular realm (Álvarez-
119 Romero *et al.* 2011; 2015a). This is partly because collaboration between the various
120 governmental and non-governmental organizations that are responsible for the
121 implementation of management actions in different realms is poor (Álvarez-Romero *et al.*

122 2015a; Reuter *et al.* 2016). Consequently, some threatened multi-realm species have only
123 been protected in one realm that is associated with one stage of their life or daily cycle. For
124 example, most conservation efforts targeting sea turtles have primarily focused on protecting
125 nesting sites on land (Mazor *et al.* 2016). Although such conservation initiatives have been
126 successful, the current decrease of some sea turtle populations (e.g. Eastern and Western
127 Pacific leatherbacks) may be associated with the challenge of protecting these species
128 across their habitats (Mazaris *et al.* 2017a, Klein *et al.* 2017). Likewise, conservation efforts
129 for wetland-breeding amphibians that focused on wetlands without considering adjacent
130 terrestrial habitats have been ineffective (Dodd & Cane 1998).

131 Moreover, the lack of coordinated conservation actions across political boundaries has often
132 been an obstacle in conserving effectively threatened species including multi-realm species
133 (Dallimer & Strange 2015, Runge *et al.* 2015). Barriers to international collaboration can be
134 removed when countries coordinate their conservation efforts through intergovernmental
135 institutions, such as the European Union (EU), which funds and supports trans-national
136 conservation initiatives across Europe. The EU has set policy targets to halt and reverse the
137 loss of biodiversity by 2020 (EC, 2011). Although the EU's 2020 Biodiversity Strategy is
138 explicitly linked to fisheries, agricultural, and forestry policies, the integration of these policies
139 and thus the explicit consideration of connections among realms is still lacking. Key steps
140 towards the effective conservation of multi-realm species, in Europe and elsewhere, include:
141 the identification of multi-realm species, the assessment of their threats, and the evaluation
142 of funding dedicated to cross-realm conservation actions as a measure of adequacy at
143 covering the special needs of the species.

144

145 **Identifying multi-realm species of European conservation concern and their threats**

146 We reviewed information on the habitats of 1,124 threatened species in Europe, i.e. species
147 classified in the European Red List (up to April 2016) with one of the following categories:
148 Critically Endangered (CR), Endangered (EN) or Vulnerable (VU), to identify multi-realm

149 species (see Appendix S1 and Table S1 in Supporting Information). Funded by the EU since
150 2006, the European Red List is compiled by the IUCN's Global Species Programme, in
151 collaboration with experts. The list identifies those species that are threatened with extinction
152 at the European level, so that appropriate conservation action can be taken to improve their
153 status. Additionally, we reviewed information on the habitats of 1,284 non-threatened
154 species that are listed in the EU Habitats (92/43/EEC) and Birds (2009/147/EC) Directives.
155 Threatened species listed in the Directives are also included in the European Red List, thus,
156 information on these species had already been reviewed. The two directives are the
157 cornerstones of Europe's nature conservation policy and guide the designation of the EU
158 wide Natura 2000 network of protected areas. Species listed in their annexes should receive
159 protection or be maintained in a favourable conservation status. Major threats for each multi-
160 realm species were identified by accessing the IUCN Red List of Threatened Species
161 database.

162 Nearly a third (n=778) of the species of European conservation concern assessed were
163 multi-realm species, belonging to three plant and 15 animal taxonomic groups (Appendix
164 S1). Species living in ecosystems at the intersection of multiple realms, e.g. vascular plant
165 species in estuaries, were also identified as multi-realm species. The largest group of multi-
166 realm species were birds (37%; n=289), with the vast majority of them (89%) being identified
167 as migratory birds. Freshwater molluscs were the second largest group (n=171) followed by
168 vascular plants (n=98). More than half of the multi-realm species (62%) depend on terrestrial
169 and freshwater habitats (n=481), 10% depend on terrestrial and marine habitats (n=79), and
170 8% require freshwater and marine habitats (n=65). About 20% of the species (n=153)
171 depend on habitats across all three realms.

172 A large number of multi-realm species were subject to common threats. Roads and other
173 "transportation and service corridors" impacted approximately 70% of the species (Table
174 S2). Other major threats were "energy production and mining" (affecting 56% of the species),

175 “agriculture and aquaculture” (56%), and “invasive and other problematic species, genes and
176 diseases” (47%).

177 **Assessing European investment in multi-realm species conservation**

178 Several funding sources are available to support biodiversity conservation in the EU, (e.g.
179 the European Agricultural Fund for Rural Development and the European Fisheries Fund)
180 but only the LIFE Program earmarks funds for actions directly related to the implementation
181 of biodiversity conservation (Kettunen *et al.* 2009, 2017). Consequently, LIFE has become
182 the main financial tool for the implementation of conservation projects in Europe (Hermoso *et*
183 *al.* 2017). Here, we used data from LIFE-Nature projects to estimate the extent of the
184 investment made for the conservation of multi-realm species at a continental scale.

185 Information on each of the 1,567 LIFE-Nature projects that were funded during the period
186 1992-2016 was sourced from <http://ec.europa.eu/environment/life/>. We identified all the
187 projects with at least one multi-realm species a beneficiary. Projects were further analysed
188 only when they included explicit conservation actions in multiple realms or interface habitats,
189 i.e. habitats in the intersection of realms (Table S1), because we considered that these
190 projects are more likely to conserve effectively the species in the highly human-dominated
191 EU environment. Acknowledging that some multi-realm species may face threats in a single
192 realm, we repeated the analysis with all projects targeting multi-realm species, including
193 projects whose actions were confined to a single realm.

194 Less than one third (n=537) of the LIFE-Nature projects covered multiple realms and
195 incorporated any of the 778 multi-realm species we identified. Moreover, within those 537
196 projects less than 30% of these species (n=229) were covered. Certain groups of multi-
197 realm species, e.g. beetles, were relatively well covered whereas others, such as mammals
198 and marine fishes, were among the least funded groups (Fig. 1). In particular, multi-realm
199 species belonging to the groups of marine molluscs, bees, grasshoppers, and medicinal
200 plants were not covered by any LIFE-Nature project. The vast majority (91%) of the species

201 funded under LIFE-Nature were listed in the annexes of the Habitats or Birds Directives. The
202 species that received the largest budget for protection (~56 million €) was the Eurasian
203 bittern (*Botaurus stellaris* Linnaeus, 1758; Fig. 2). This species was funded almost twice as
204 much as the second most funded species, the Atlantic salmon (*Salmo salar* Linnaeus, 1758).
205 The Eurasian bittern is listed as a priority species for funding under the LIFE program but
206 has an IUCN conservation status of “Least Concern (LC)”.

207 In fact, more than half of the LIFE-Nature projects' budget (61%) was allocated to species
208 classified as “LC” (Fig. 3a). Although the average budget allocated to threatened species
209 belonging to the categories “EN” and “VU” was higher than the one allocated to non-
210 threatened species (Fig. 3b), the vast majority of projects targeted very few “CR” multi-realm
211 species and focused on “LC” species (Fig. S2). Only 7% of multi-realm “CR” species
212 received funding, whereas funds were allocated for the conservation of 41% of the “LC”
213 species. About 65% of the projects benefiting a single species (n=115) targeted non-
214 threatened species.

215 Species that depend on terrestrial and freshwater habitats, representing 61% of the multi-
216 realm species assessed herein, received about 80% of the total budget (Fig. 3c). On
217 average, the 118 funded species belonging to this realm combination received ~3.9 million
218 €. Species requiring freshwater and marine habitats (n=18) on average received larger
219 budgets in comparison to species related to other realm combinations (Fig. 3d). However,
220 more than half the budget (57%) was dedicated to only two fishes, *S. salar* and *Alosa fallax*
221 (Lacepède, 1803). Species depending on terrestrial and marine habitats (n=21) received on
222 average the smallest budget, equivalent to ~2.2 million €. Nearly one third of the total budget
223 for this realm combination was allocated to the loggerhead sea turtle *Caretta caretta*
224 (Linnaeus, 1758), which is a priority species for funding under the LIFE program.

225 Even when considering all projects targeting multi-realm species (n=753), including those
226 projects whose actions were confined to a single realm, the percentage of multi-realm

227 species covered increased only slightly (34%). The total investment in multi-realm species
228 conservation increased from around 800 million to 1.2 billion Euros. The patterns of
229 investment revealed were similar to those found when only considering projects that
230 incorporated multiple realms, with more than half the projects' budget (57%) was allocated to
231 species classified as "LC" (Fig. S1). Species that depend on terrestrial and freshwater
232 habitats still received the highest proportion of the total budget (51%; Fig. S1).

233 The allocation of LIFE-Nature funds for the conservation of multi-realm species across EU
234 member states and across realm combinations varied greatly among countries (Fig. 4). In
235 Croatia and Lithuania, more than 80% of the total LIFE funds were allocated to projects that
236 targeted multi-realm species whereas in Cyprus, France, the Czech Republic, Italy and the
237 UK, the respective proportion was less than 15%. In Spain, LIFE funds dedicated to the
238 conservation of multi-realm species for all dual realm combinations (freshwater-terrestrial,
239 marine-terrestrial, marine-freshwater) were greater than in other member state. Species
240 depending on habitats in all three realms received the most coverage in Sweden. Similar
241 patterns were revealed when funds were adjusted using country-level purchasing power
242 parity (PPP) as in Lung *et al.* (2014) (Appendix S1; Fig S3). The most remarkable difference
243 being the substantial funds devoted in the combination of freshwater and marine ecosystems
244 in the UK.

245 Overall, our findings demonstrate that 1) LIFE-Nature projects have been covering a small
246 proportion of multi-realm species of conservation interest, 2) conservation effort is skewed
247 towards specific taxonomic groups, and 3) species that are most in need of conservation
248 effort receive disproportionately less funding.

249 **Reinforcing EU's integrated conservation efforts**

250 While the scientific recognition of the need for integrated conservation across realms gains
251 ground, the practical implementation of integrated conservation actions lags. To date, more
252 than 800 million Euros have been invested in LIFE-Nature projects targeting multi-realm

253 species and including conservation actions across realms. Although this is a substantial
254 contribution towards integrated conservation efforts, only 30-34% of multi-realm species of
255 conservation concern (i.e. multi-realm species listed in the European Red List and/or in the
256 Habitats and Birds Directives) have benefitted to date from LIFE-Nature funds. Whilst
257 acknowledging that other sources of funding exist and may benefit multi-realm species, the
258 LIFE-Nature programme remains the main financial instrument for biodiversity conservation
259 in the EU. Species action plans and funds from national sources of member states that could
260 contribute substantially to the conservation of multi-realm species have not been captured
261 here. Yet, species action plans often present taxonomic bias (Sitas et al. 2009), and
262 nationally or locally funded actions often miss coordination at larger spatial scales, even
263 though this is critical for ensuring the persistence of multi-realm species across national
264 borders. The EU provides a platform to coordinate conservation efforts across borders and
265 identifies priorities for conservation at a continental level. To reinforce integrated
266 conservation efforts across Europe we provide the following recommendations.

267 ***Policy recognition for the need of integrated conservation***

268 The EU, as a Party to the Convention of Biological Diversity (CBD), developed a biodiversity
269 strategy to meet its international commitments. The EU 2020 Biodiversity Strategy is directly
270 linked to the Common Agricultural Policy, the Common Fisheries Policy, the Water
271 Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (MSFD;
272 2008/56/EC). Yet, in none of these policies are connections of species populations and
273 human activities across realms explicitly considered. To date, most EU policy documents,
274 such as the MSFD, refer to activities and management measures that are confined to a
275 single realm. An exception is the recommendation of the European Parliament and of the
276 Council for integrated coastal zone management (2002/413/EC). In this policy document the
277 connections among the terrestrial and marine realms are explicitly stated as well as the need
278 for integrated management to ensure the sustainability of coastal ecosystems and their
279 services. Furthermore, with the EU Marine Spatial Planning Directive (2014/89/EU), a

280 framework for marine spatial planning and integrated coastal management was established
281 which considers the interaction between land- and sea-based activities. This is an important
282 step towards integrated conservation but coastal ecosystems are not the only systems that
283 can benefit from integrated management and planning across realms. Adams *et al.* (2014)
284 highlighted numerous benefits of applying integrated conservation planning and actions
285 across terrestrial and freshwater ecosystems. Therefore, we recommend that policy-makers
286 consider a broader array of ecosystems and their connections when formulating integrated
287 management policies and strategies.

288 ***Recurrent revision of conservation funding priorities***

289 The first target of the EU 2020 Biodiversity Strategy is to fully implement the Habitats and
290 Birds Directives. More specifically it is stated that: “These two Directives are the
291 cornerstones of the EU’s biodiversity policy, enabling all 27 EU Member States to work
292 together, within the same legal framework, to conserve Europe’s most endangered and
293 valuable species and habitats across their entire natural range within the EU”. Yet, our
294 findings, in accordance with evidence from previous studies (e.g. Maiorano *et al.* 2015,
295 Hermoso *et al.* 2017, Jeanmougin *et al.* 2017), demonstrate that even the full
296 implementation of the two directives would not benefit the most endangered species. The
297 allocation of LIFE-Nature funds has been mainly driven by the Habitats and Birds Directives
298 but most of the species benefitting from these funds are “Least Concern” species. When
299 considering only the species listed in the two directives, we found that funds were not
300 allocated in respect to the species conservation status and the urgency of their conservation
301 needs. Moreover, many threatened species included in the European Red List (as CR, EN,
302 or VU) are missing from the directives' annexes. Therefore, we join the voices of our
303 colleagues and call for an adaptive revision of the conservation priorities set by the two
304 directives and their harmonization with the European Red List. Revisions should be
305 conducted periodically to capture the effectiveness of the actions financed by LIFE-Nature
306 projects and other conservation funding initiatives (Hochkirch *et al.* 2013). Effective

307 conservation actions may drive changes of species' status. Moreover, these periodic
308 assessments will allow the increase or decrease of threats to biodiversity to be reflected.
309 These changes should be taken into account when revising conservation priorities and
310 allocating the scarce conservation resources. Funds should be prioritized but not exclusively
311 dedicated to the conservation of threatened species as some non-threatened species play
312 important ecological roles in ecosystem functioning and the provision of ecosystem services.

313 ***Implementation of integrated conservation planning and management***

314 The EU's network of protected areas, Natura 2000, aims to ensure the long-term survival of
315 Europe's most valuable and threatened species and habitats, listed under the Habitats and
316 Birds Directives. Besides the urgent need for the revision of the species listed in the two
317 directives, we suggest that an integrative approach is adopted when designating new Natura
318 2000 sites across realms. Currently, the vast majority of Natura 2000 sites that include a
319 marine area are either extensions of terrestrial sites into the sea or cross-realm sites whose
320 coverage is highly biased towards land (Mazaris *et al.* 2017b). The selection of these sites
321 has often been driven by terrestrial rather than marine conservation needs (Giakoumi *et al.*
322 2012). Similarly, the conservation of freshwater ecosystems has been peripheral to
323 conservation goals developed for terrestrial ecosystems (Hermoso *et al.* 2016). Integrated
324 conservation planning allows to meet conservation needs in multiple realms in a more
325 balanced fashion and explicitly considers the trade-offs among alternative plans (e.g.
326 Álvarez-Romero *et al.* 2015b). To effectively implement integrated conservation planning,
327 species ranges across realms should be considered. Moreover, adopting cross-realm
328 management actions could benefit the conservation of multi-realm species and even species
329 whose activities are confined to one realm but face threats originating from multiple realms.
330 Our results show that many multi-realm species face common threats, thus, mitigating the
331 impacts of these threats may have positive conservation outcomes for many species
332 simultaneously.

333

334 In conclusion, the EU has invested substantial financial resources on conservation projects
335 for species that use multiple realms during their daily or life cycle. However, EU conservation
336 efforts should be reinforced and prioritized to conserve more species that need protection
337 across realms and that are most threatened. To do so, recognition of the need for integrated
338 policies across realms is needed as well as the implementation of integrated conservation
339 planning for multi-realm species.

340

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348

349 **Supporting Information**

350

351 Additional Supporting Information may be found in the online version of this article at the
352 publisher's web site:

353 **Appendix S1**

354 Methods.

355 **Table S1**

356 Habitat classification.

357 **Table S2**

358 Threats to multi-realm species.

359 **Figure S1**

360 LIFE-Nature investment (including single realm projects) per IUCN category and realm
361 combination.

362 **Figure S2**

363 Species benefitting from increasing number of projects.

364 **Figure S3**

365 Distribution of LIFE-Nature investment across EU member states adjusted using PPPs.

366

367

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475

476 **Figure Legends**

477 **Figure 1.** Proportion of multi-realm species within each taxonomic group targeted for
 478 conservation by at least one LIFE-Nature project in the period 1992-2016. Blue bar sections
 479 correspond to the proportion of species that have received funding from LIFE-Nature
 480 projects (dark blue: proportion of species included in the Annexes of the Birds and Habitats
 481 Directives, light blue: threatened species not included in the Annexes). Red bar sections
 482 show proportions of species that have not received LIFE-Nature funding (dark red:
 483 proportion of species included in the Annexes of the Birds and Habitats Directives, light red:
 484 threatened species not included in the Annexes). The last column refers to the total number
 485 of species identified as multi-realm species of European conservation concern. Numbers on
 486 top of the bars refer to the total number of these species in each group.

487 **Figure 2.** Multi-realm species that received the most LIFE-Nature funds per realm
 488 combination. The overall estimated budget allocated for the conservation of: (A) the
 489 Eurasian bittern (*Botaurus stellaris* Linnaeus, 1758), a bird species using terrestrial &
 490 freshwater habitats, was 56,363,932 €; (B) the Atlantic salmon (*Salmo salar* Linnaeus,
 491 1758), a marine fish using freshwater & marine habitats, was 30,607,947 €; (C) the common
 492 kingfisher (*Alcedo atthis* Linnaeus, 1758), a bird using terrestrial & freshwater & marine

493 habitats, was 13,921,416 €; and (D) the loggerhead turtle (*Caretta caretta* Linnaeus, 1758),
494 a reptile using terrestrial & marine habitats, was 11,405,033 €. Photo credits: (A) Mike Barth
495 <https://www.mikebarthphotography.com>, (B) Hans-Peter Fjeld, (C) Andreas Trepte, (D)
496 Konstantinos Papafitsoros.

497 **Figure 3.** Proportion of (A, C) and average (B, D) LIFE-Nature budget of projects spent for
498 multi-realm species in each IUCN category (A, B) and realm combination (C, D). The
499 projects included in the analyses are those including actions in more than one realm.

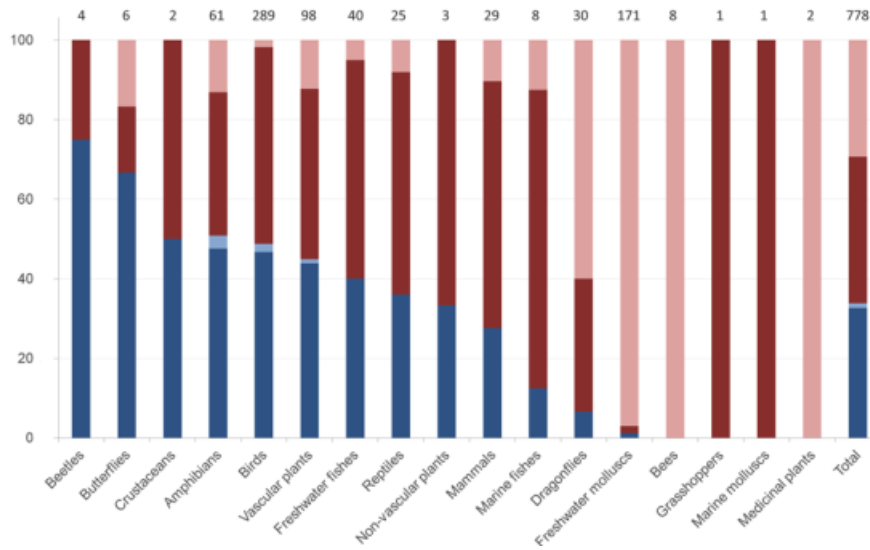
500 **Figure 4.** Distribution of LIFE-Nature investment across EU member states. For each
501 member state, average investments were calculated by considering total funds received over
502 the time period the member state was eligible for LIFE projects. Maps show distribution of
503 (A) LIFE-Nature funds, (B) proportion (%) of LIFE-Nature funds for multi-realm species, and
504 (C-F) LIFE-Nature funds per realm combinations (C: Terrestrial & Freshwater, D: Terrestrial
505 & Marine, E: Freshwater & Marine, F: Terrestrial & Freshwater & Marine) across EU member
506 states for the period 1992-2016. Landlocked countries in the realm combinations including a
507 marine component are illustrated in light blue.

508

509

Figures

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 513 by at least one LIFE-Nature project in the period 1992–2016. Blue bar sections correspond to the
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 516 not included in the Annexes). Red bar sections show proportions of species that have not received
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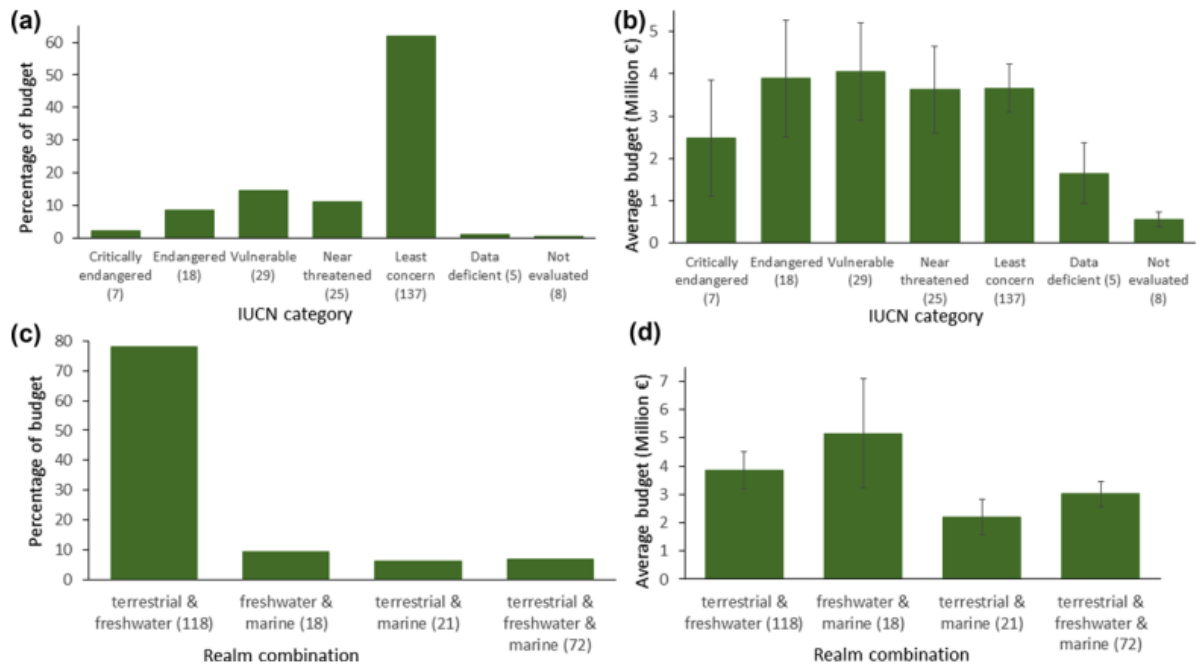
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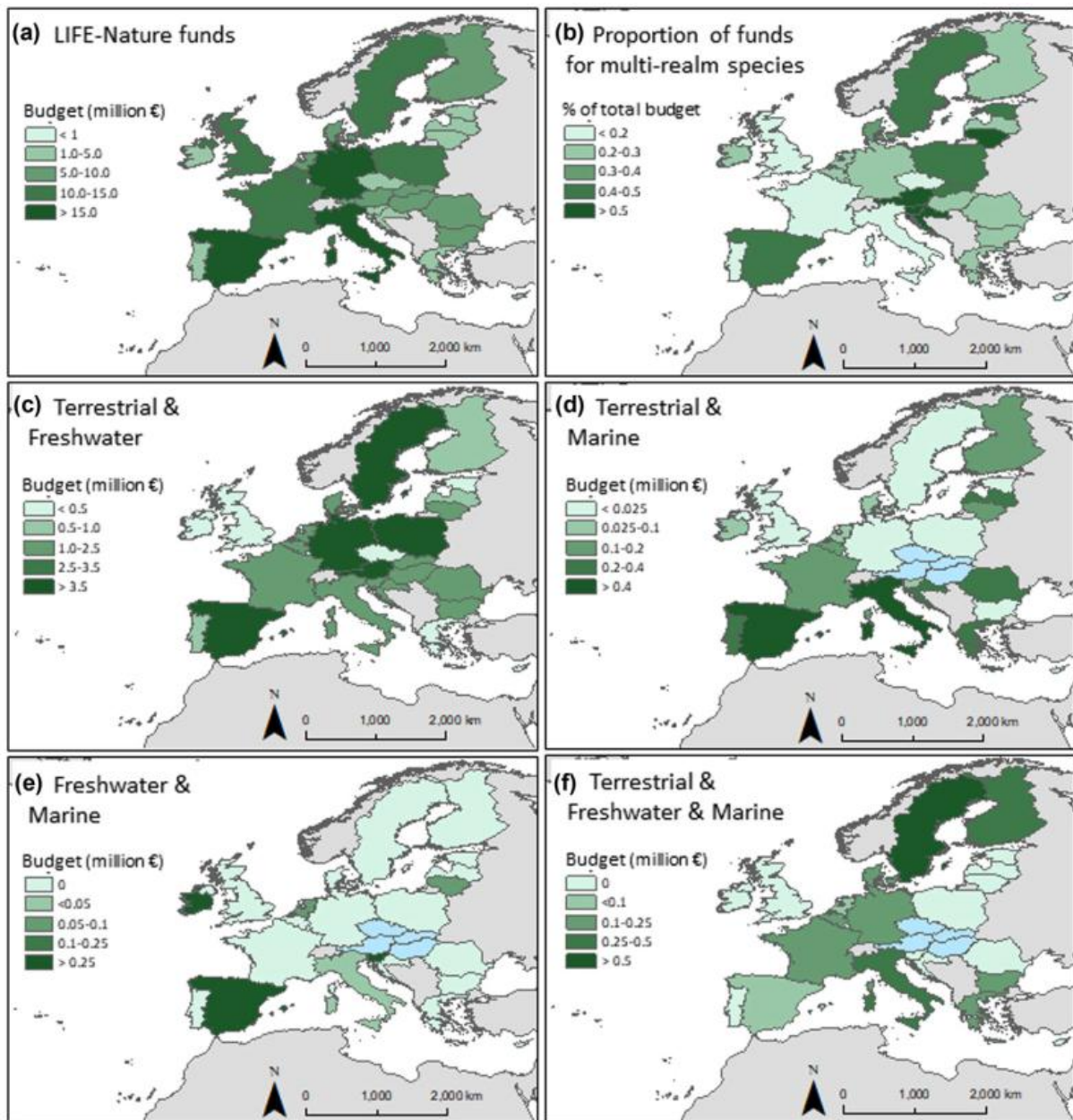
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 543 combinations (c: Terrestrial & Freshwater, d: Terrestrial & Marine, e: Freshwater & Marine, f:
 544 Terrestrial & Freshwater & Marine) across EU member states for the period 1992–2016. Landlocked
 545 countries in the realm combinations including a marine component are illustrated in light blue

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