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Camille Leclerc, Camille Magneville, Céline Bellard

► **To cite this version:**

Camille Leclerc, Camille Magneville, Céline Bellard. Conservation hotspots of insular endemic mammalian diversity at risk of extinction across a multidimensional approach. *Diversity and Distributions*, In press, 10.1111/ddi.13441 . hal-03428608

HAL Id: hal-03428608

<https://hal.science/hal-03428608>

Submitted on 15 Nov 2021

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1 **Conservation hotspots of insular endemic mammalian diversity at risk of extinction**
2 **across a multidimensional approach**

3 **Short running title:** Insular hotspots of multifaceted endemic mammal diversity

4

5 Camille Leclerc^{1,2,*}, Camille Magneville^{1,3}, Céline Bellard¹

6 ¹ Université Paris-Saclay, CNRS, AgroParisTech, Ecologie Systématique Evolution, 91405

7 Orsay, France.

8 ² Present address: INRAE, Univ. of Aix Marseille, UMR RECOVER, Aix- en- Provence,

9 France.

10 ³ Present address: MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, Montpellier, France.

11

12 * corresponding author: camille.leclerc@inrae.fr

13

14 **Abstract**

15 **Aim:** Islands are one of the most threatened worldwide biotas. Based on their taxonomic
16 diversity, some insular regions have been identified as key areas of conservation. Recently,
17 systematic conservation planning has advocated for the use of multiple biodiversity facets to
18 protect unique evolutionary and functional processes. Here, we identified priority areas for
19 threatened insular endemic mammals across three key dimensions of biodiversity (taxonomic,
20 phylogenetic, and functional), as well as their protection level and threats affecting them.

21 **Location:** Worldwide.

22 **Methods:** We applied diversity–area relationships to identify insular regions that harbored a
23 disproportionately high rate of threatened endemic mammal diversity (whether taxonomic,
24 phylogenetic, or functional) given their area for 1,799 islands across 19 insular regions. We

25 also assessed the level of protection and the threats affecting biodiversity within each insular
26 region.

27 **Results:** We showed a fairly good congruence between top-ranked insular regions based on
28 taxonomic, phylogenetic, and functional diversity. Specifically, we identified four hotspots
29 for endemic mammalian conservation through the three diversity facets: *Indo-Burma*,
30 *Madagascar and the Indian Ocean Islands*, *Mesoamerica and Galápagos Islands*, and
31 *Wallacea*. Except for *Mesoamerica and Galápagos Islands*, the protected areas coverage is
32 low (<8%) within the hotspots. We also showed that most of the mammal species occurring in
33 the hotspots was prone to either direct threats that affect their mortality or indirect threats that
34 only alter their habitat, while mixed threats such as biological invasions or climate change
35 were less represented in those regions.

36 **Main conclusions:** Our findings reinforce the importance of investigating the multiple
37 diversity facets in a conservation concern and to link with the associated threats to ensure an
38 effective conservation strategy.

39

40 **Keywords:** endemic species, functional diversity, hotspots, islands, phylogenetic diversity,
41 protected areas, taxonomic diversity, threats

42

43

44 **1 | INTRODUCTION**

45 Biodiversity is declining globally at rates accelerated and unprecedented in human history
46 (Barnosky et al., 2011). Current records showed that more than 8,850 vertebrate species are
47 decreasing in population size and range (Ceballos, Ehrlich, & Dirzo, 2017), and that 390
48 vertebrates have already disappeared in the last 500 years (Ceballos, García, & Ehrlich, 2010).
49 The main drivers of biodiversity loss are multiple, including agricultural expansion,

50 overexploitation and introduction of invasive alien species (Maxwell, Fuller, Brooks, &
51 Watson, 2016). One way to provide species protection against global changes is the
52 development of effective protected areas. Protected areas are the mainstay of the conservation
53 strategies and intend to provide biodiversity refuges to human pressure (Rodrigues et al.,
54 2004).

55 To date, systematic conservation planning is usually conducted on a site basis to protect
56 areas containing an exceptional concentration of biodiversity, measured by total species
57 richness, species endemism, or threatened species richness (Margules & Pressey, 2000). This
58 approach puts taxonomic diversity at the first front to decide conservation priorities.
59 However, by focusing only on taxonomic diversity we assume that all species are equivalent
60 entities, while they are a product of complex ecological and evolutionary processes that make
61 each of them particularly unique (Faith, 1992; Iknayan, Tingley, Furnas, & Beissinger, 2014;
62 May, 1990; Vane-Wright, Humphries, & Williams, 1991). This is particularly problematic as
63 it could lead to prioritizing areas with similar assemblage composition at the cost of areas
64 hosting unique assemblages (Brown et al., 2015; Kukkala & Moilanen, 2013). Therefore,
65 selecting regions based only on species richness may not be the best conservation strategy as
66 it does not capture other facets of diversity such as phylogenetic or functional diversities
67 (Díaz et al., 2007; Faith, 1992; Mazel et al., 2014). Phylogenetic diversity represents the
68 diversity in species genetic composition and evolutionary history (Faith, 1992; Vane-Wright
69 et al., 1991) essential to maintain evolutionary potential of communities (Purvis, Gittleman, &
70 Brooks, 2005), while functional diversity is the variation of ecological traits of species
71 (Tilman, 2001; Violle et al., 2007) needed to preserve community productivity, ecosystem
72 stability and ecosystem services (Oliver et al., 2015). If such diversities are not considered,
73 the possibility to have the right feature at hand as well as the resilient capacity in a future
74 changed environment is underlooked (Biggs et al., 2020; Forest et al., 2007), which could

75 have large consequences for biodiversity and ecosystems (Díaz et al., 2007). Therefore, each
76 diversity facet offers valuable information that are all important to consider in order to
77 maximize diversity in the context of complementary reserve selection (Brum et al., 2017;
78 Pollock, Thuiller, & Jetz, 2017; Rodrigues & Gaston, 2002; Rodrigues et al., 2011), especially
79 that the different diversity facets are not necessarily good surrogates for each other. While
80 several studies have evidenced spatial congruence between each diversity facet (Rapacciuolo
81 et al., 2018; Rodrigues & Gaston, 2002; Sechrest et al., 2002), some others have not (Brum et
82 al., 2017; Devictor et al., 2010; Pollock et al., 2017). Taxonomic, phylogenetic, and functional
83 diversities could not be easily inferred from each other and yet may bring important properties
84 to protect biological communities. Consequently, conservation strategies need to rely on the
85 three facets to fully represent biodiversity.

86 A remarkable biota for conservation biology is islands as they contribute to global
87 biodiversity disproportionately to their land area. Even if they only represent 5% of the Earth
88 surface, insular ecosystems represent more than 20% of all known plant and vertebrate
89 species (Kier et al., 2009). Also, island ecosystems harbor a high level of uniqueness due to
90 the presence of many endemic species (Whittaker & Fernandez-Palacios, 2007). Most of them
91 are particularly vulnerable to extinction as they have a narrow geographical range, few
92 populations remaining, small population size and little genetic variability (Işık, 2011). In fact,
93 60% of species extinctions led by human activities took place on islands (Whittaker &
94 Fernandez-Palacios, 2007). As many island species are extremely restricted in space and
95 highly threatened by global changes, more than continental ones (Kueffer et al., 2010), urgent
96 protection is required (Calado et al., 2014).

97 Here, we aimed to identify (i) hotspots and coldspots of insular mammal diversity that are
98 at risk of extinctions through the taxonomic, phylogenetic, and functional diversities, (ii) their
99 level of protection and (iii) their threats. We used diversity–area relationships for 19 insular

100 regions (i.e. 1,799 islands) to account for expected area effects on the different diversity
101 facets, which is of particular importance to ensure a good cost-benefit ratio for conservation.
102 We focused our study on insular endemic mammal biodiversity (n=1,000) because among all
103 clades, mammals are particularly jeopardized by global changes (Ceballos et al., 2015;
104 Leclerc, Courchamp, & Bellard, 2020) and are characterized by limited dispersal abilities.
105 Also, a consequent amount of data (phylogeny and species traits) is available on this taxon.
106 By taking into account the different facets of diversity as well as protection level and threats
107 information, this study puts into perspective relevant conservation priorities of insular regions.

108

109 **2 | METHODS**

110 2.1 | Species data

111 The IUCN expert range maps were used to estimate species' geographic range of mammal
112 species (IUCN, 2020). By overlapping geographic range of species with mainland boundaries
113 and a global vector database of islands (larger than 1 km² and smaller than Greenland;
114 Weigelt, Jetz, & Kreft, 2013), we assigned an insularity-mainland status to each species (i.e. if
115 the species occurs on mainland and/or island(s)), and then we only keep species endemic to
116 one (i.e. single-island endemics) or many islands (i.e. multi-island endemics) because of their
117 key interest for conservation (Fattorini, 2017). A total of 1,000 mammal species distributed
118 among 1,799 islands worldwide from 19 insular regions (based on hotspots biodiversity
119 delimitation; CEPF, 2019) were considered (Figure S1; Table 1). More particularly, 459
120 mammal species are single-island endemics while the rest of the species (n = 541) are multi-
121 island endemics (mean \pm s.d.: 20 \pm 33 islands). Among them, 410 mammals were identified as
122 threatened (i.e. vulnerable, endangered, and critically endangered) by the IUCN Red List
123 (Table 1). The IUCN Red List assessed the conservation status of species worldwide through
124 a series of criteria such as population sizes and trends, geographic distribution, species'

125 ecology and habitat preferences (Rodrigues, Pilgrim, Lamoreux, Hoffmann, & Brooks, 2006).
126 Evaluation of species extinction risks has been done exhaustively for mammals (Meiri &
127 Chapple, 2016).

128

129 2.2 | Biodiversity indices

130 *Taxonomic diversity (TD)*. We used the number of threatened species occurring in each
131 region as taxonomic diversity metric.

132 *Phylogenetic diversity (PD)*. We relied on the Faith index that is the sum of phylogenetic
133 branch length of the studied species pool (Faith, 1992) to assess phylogenetic diversity
134 represented by threatened species from each insular region. We used a time-calibrated
135 molecular phylogeny of extant mammals (Upham, Esselstyn, & Jetz, 2019) to compute
136 phylogenetic diversity. From this phylogeny, 1,000 trees were generated to capture root-to-tip
137 uncertainty in topology and divergence times. Phylogenetic trees were pruned to the 1,000
138 species of the global pool. The *pd()* function of the *picante* package (Kembel et al., 2010) was
139 used to compute, through Faith index, the phylogenetic diversity represented by threatened
140 species of each insular region. Then, the multiple values of Faith index are averaged for each
141 species pool of insular regions.

142 *Functional diversity (FD)*. Functional diversity can be seen as the value and range of
143 organism traits that influence their performance and thus ecosystem functioning (Hooper et
144 al., 2005; Violle et al., 2007). It can be estimated through a multidimensional niche space that
145 encompasses all trait values of a species pool (Villéger, Mason, & Mouillot, 2008). Here, the
146 measure of functional diversity of threatened species from each insular region relied on the
147 measure of functional richness (FRic). This index reflects the proportion of occupied space by
148 the studied pool of threatened species compared to the volume occupied by the global species
149 pool (n=1,000) (Villéger et al., 2008). Based on scripts developed by Villéger (2017), we

150 computed the FRic index using a matrix of species' presence and absence information within
151 insular regions and a matrix of species' traits information. We used five traits: body mass,
152 habitat niche breadth, foraging niche, foraging period and dominant diet (for more details
153 about the variables, see Table S1 and Leclerc, Villéger, et al., 2020). Because all traits were
154 coded using few categories, species were then gathered into 270 functional entities (FE: group
155 of species that share the same trait values) that hosted between 1 and 48 species. Once FEs
156 were determined, we computed the pairwise functional distances between each FE of species
157 using the Gower dissimilarity index (Gower, 1971), which gives the same weight to each
158 variable. Then, based on the distance matrix, a functional space of four dimensions was built
159 thanks to the PCoA method. This functional space has a good representation of the initial
160 distance for all pairs of FEs (error rate between initial and final functional distances is about
161 10% here; Maire et al., 2015) while being able to calculate FRic values for a large number of
162 insular regions (n=16). Due to mathematical constraints in computing convex hulls in the
163 four-dimensional space, FRic was not computed for insular regions harboring threatened
164 species that are represented by less than five FEs (*i.e. Bering and East Siberian Sea Islands,*
165 *New Caledonia, and Taiwan*).

166

167 2.3 | Diversity Area Relationships

168 In order to identify insular regions with high endemic mammalian diversity at risk of
169 extinction, we used the Diversity–Area Relationship approach (DAR; Mazel et al., 2014). The
170 DAR is one of the most valuable biogeographical tools available to conservationists in order
171 to identify key areas of conservation concern and provides a basis for setting priorities for
172 allocating limited resources (Guilhaumon, Gimenez, Gaston, & Mouillot, 2008). Using DAR
173 is mandatory in a wide range of conservation applications that require the comparison of
174 diversity patterns (whether taxonomic, phylogenetic, or functional) when regions differ in

175 area (Smith, 2010). Larger regions are more likely to represent more diversity because they
176 are more likely to hold more diverse habitats (Kallimanis et al., 2008). Thus, biodiversity
177 comparisons among insular regions need to take into account the effect of area. By applying
178 the DAR approach, we attempt to identify regions that have a higher threatened diversity than
179 expected given area to identify insular conservation priorities. The DAR approach requires
180 standardized diversity value and information about area. Here, threatened diversity data for
181 each of the three facets has been standardized (between 0 and 1) by the maximum value of
182 diversity found within insular regions. We also calculated the area of each insular region as
183 the sum of the area of the islands based on data from Weigelt et al., (2013).

184 Most of the DAR studies are using a power model to fit data of diversity and area.
185 However, the power model is not always the best model and other models have been reported
186 by studies to provide better fit (Matthews, Triantis, Whittaker, & Guilhaumon, 2019).
187 Therefore, 20 DAR models, described in the literature and using linear and non-linear
188 regressions, were tested on our data using the *sars* package (Matthews et al., 2019). DAR
189 models are selected based on residual normality and heterogeneity tests, and any model that
190 fails the tests is not considered. Based on those criteria, all of the 20 models were selected for
191 taxonomic, phylogenetic, and functional diversity. Then, a multimodel-averaged DAR curve,
192 that is a linear combination of the individual models weighted by the Akaike information
193 criterion (AIC) was computed for each diversity facet. Finally, from the multimodel-averaged
194 DAR for taxonomic, phylogenetic, and functional diversity, residuals were calculated between
195 observed and predicted diversity values of each insular region. A positive residual for a given
196 insular region means that observed threatened diversity is higher than expected given its area.
197 On the contrary, a negative residual for a given insular region means that observed threatened
198 diversity is lower than expected given its area. Then, insular regions were ranked according to
199 their residual values to identify hotspots (regions with the highest residual values) and

200 coldspots (regions with the lowest residual values) (Mazel et al., 2014). A consensus ranking
201 was obtained by summing up the ranking for each region based on the different facets. To test
202 congruency between diversity facets, we examined relationships between residual values of
203 taxonomic, phylogenetic, and functional diversity, using Spearman's rank correlation test. We
204 also compared rank of insular regions based on DAR approach with rank of insular regions
205 based on raw diversity indices to discuss the advantages of using the DAR approach.

206

207 2.4 | Threats and protection level

208 To take into account the different threats that are affecting the insular endemic mammals
209 studied, we used the list of direct threats provided by the IUCN, which are proximate human
210 activities or processes impacting the status of the taxa being assessed (Salafsky et al., 2008).
211 This framework classified threats into 11 broad types (Table S2). We reclassified the IUCN
212 threats into three general categories: (1) direct – threats that directly affect species' survival or
213 fecundity; (2) habitat – threats that only modify or destroy the habitat; (3) mixed – threats that
214 affect species survival or fecundity and that modify or destroy the habitat. Reclassifying
215 threats into broader categories allows us to provide conservation recommendations according
216 to the general threatening mechanisms by disentangling threats that impact extrinsic (i.e.
217 habitat) and/or intrinsic (i.e. survival, fecundity) characteristics of species. We calculated, for
218 each region, the diversity of threatened species affected by each threat category through the
219 three biodiversity indices previously described. Afterward, we computed a representativeness
220 index (RI) for each threat category within insular regions ($RI_{Thr_i} = DivThr_i / \sum_{i=1}^3 DivThr_i$).
221 This index is based on the threatened diversity impacted by a threat category (DivThr)
222 compared to the threatened diversity impacted by the three threat categories. The
223 representativeness index is calculated separately for each diversity metric (taxonomic,
224 phylogenetic, and functional) and is then averaged. Representativeness of direct, habitat and

225 mixed threats informs on the importance of a threat compared to others within a region.
226 Concerning the level of protection, the percentage of protected areas coverage among insular
227 regions was assessed. Information on protected areas come from the WDPA (World Database
228 on Protected Areas, available at <http://protectedplanet.net/>; see Supporting Information for
229 more details).

230

231 All analyses were performed with R software (version 3.3.1, R Development Core Team,
232 2008).

233

234 **3 | RESULTS**

235 3.1 | Hotspots and coldspots of insular endemic mammals at risk of extinctions through
236 the three diversity facets

237 All endemic threatened diversity–area relationships had a convex up shape (Figure 1a-c).
238 Our analysis revealed that ten, eight, and five out of 19 insular regions are characterized by
239 positive residuals based on taxonomic, phylogenetic and functional facets, respectively.
240 Among insular regions showing positive residuals, only four could be considered as hotspots
241 across the three diversity facets: *Wallacea*, *Madagascar and the Indian Ocean Islands*,
242 *Mesoamerica and Galápagos Islands*, and *Indo-Burma* (Figure 1a-d). At the other end, the
243 insular coldspots were *Japan* and *Tasmania and New Zealand Islands* as they showed lowest
244 negative residuals across the three diversity facets. In addition, we found that *Gulf of Guinea*
245 *Islands* is characterized by positive residuals based on both taxonomic and phylogenetic
246 facets, and *Philippines* is the sole insular region to present positive residuals for both
247 phylogenetic and functional facets. Although for some insular regions, residual values can be
248 negative or positive according to the diversity facet, the residual values of diversity facets are
249 correlated to each other (Spearman’s $\rho > 0.7$; Figure S2). We can also notice that the two

250 largest regions in terms of area (i.e. *Sundaland* and *Papua New Guinea*) were not necessarily
251 the regions with the highest value of threatened diversity (Figure 1; Table 1 but see *Sundaland*
252 for phylogenetic diversity). However, such insular regions are important in terms of raw
253 diversity harbored (Table 1). Thus, the rank of insular regions differs depending on whether
254 the raw diversity values or the diversity values corrected by area are used, and especially for
255 taxonomic diversity index (Spearman's $\rho < 0.7$; Figure S3).

256

257 3.2 | Level of protection and threatened diversity of endemic mammals within insular
258 regions

259 *Wallacea* and *Madagascar and the Indian Ocean Islands* represented insular regions
260 harboring both high value of residual (> 0) and standardized (> 0.5) threatened diversity of
261 endemic mammals (Figure 2). However, these regions have low protected area coverage
262 ($< 8\%$). In addition, although *Sundaland* and *Papua New Guinea* are characterized by negative
263 residual values, these regions also harbor important values of absolute threatened diversity
264 compared to other regions (standardized threatened diversity > 0.5) and yet, the protected
265 areas coverage is low, respectively 9% and 6% within these two regions. The other 15 insular
266 regions are characterized by both low values of residual and/or standardized threatened
267 diversity of endemic mammals. However, among these regions, five of them had a protected
268 area cover higher than 25%: *California Islands*, *Mesoamerica and Galápagos Islands*, *Gulf of*
269 *Guinea Islands*, *Sri Lanka*, and *Tasmania and New Zealand Islands*.

270

271 3.3 | Threats pressure within insular regions

272 The relative importance of direct, habitat and mixed threats varies according to insular
273 regions (Figure 3). We can disentangle a first group composed of six insular regions including
274 *Mesoamerica and Galápagos Islands*, which is mostly associated with mixed threats

275 (representativeness > 0.5; Figure 3) such as biological invasions, climate change, or human
276 intrusions and disturbance (Figure S4). A second group of insular regions identified include
277 the rest of the hotspots of diversity (i.e. *Wallacea*, *Madagascar and the Indian Ocean Islands*,
278 *Indo-Burma*, but also *Sundaland* and *Papua New Guinea*), is mainly associated with both
279 direct (biological resource use) and habitat threats (agriculture, urbanization)
280 (representativeness >0.4; Figure 3; Figure S4). Overall, the representativeness of each threat
281 category (mixed, habitat, and direct) is linked to the threatened diversity hosted by insular
282 regions. The higher the threatened diversity harbored by the insular region, the lower the
283 representativeness of mixed threats. An inverse pattern is observed for direct threats and
284 habitat threat even if it is less marked (Figure S5).

285

286 4 | DISCUSSION

287 Our investigation of priority insular regions for endemic mammals at risk of extinction
288 revealed four hotspots that are similar for the three diversity facets. Indeed, *Indo-Burma*,
289 *Madagascar and the Indian Ocean Islands*, *Mesoamerica and Galápagos Islands* and
290 *Wallacea* harbored a threatened diversity higher than expected given their area. Our results
291 reaffirm the importance of those regions for conservation programs that should pay particular
292 attention to them to ensure protecting their highest endemic mammal diversity. Such regions
293 have already been depicted as priority areas based on taxonomic, phylogenetic and functional
294 diversity of worldwide mammals (Brum et al., 2017; Pollock et al., 2017). We also showed
295 that two insular regions are considered as coldspots across the three diversity facets: *Japan*,
296 *Tasmania and New Zealand Islands*. It was not surprising because none of these regions
297 harbor an important species richness of mammals, either global or threatened (Ceballos &
298 Ehrlich, 2006; Jenkins, Pimm, & Joppa, 2013), and recently it has also been showed for
299 phylogenetic and functional diversity facets (Brum et al., 2017; Pollock et al., 2017).

300 However, coldspots can also play an important ecological role by contributing to many
301 ecosystem services (Jung et al., 2021) or hosting species with a special interest for the global
302 mammal phylogenetic diversity (Robuchon et al., 2021). Thus, by focusing exclusively on
303 biodiversity hotspots, the risk is to neglect areas with other types of conservation value.
304 Although conservation strategy will always need a measure to determine priorities to be
305 effective, future perspectives to set out an optimal conservation network is a complex task that
306 requires to include both areas with high levels of diversity as well as coldspots that might be
307 ecologically important (Marchese, 2015).

308 We also found that *Sundaland* and *Papua New Guinea* are relatively less important
309 compared to other regions based on threatened endemic mammal diversity standardized by
310 area, though they are among the largest regions in terms of area that harbor the highest
311 number of threatened species. Our results differed from previous studies that identified these
312 regions as priority areas based on multiple diversity of terrestrial mammals (Brum et al.,
313 2017; Rosauer, Pollock, Linke, & Jetz, 2017) but did not focus exclusively on endemic
314 species. Moreover, while the other studies identified conservation priorities based on the
315 biological value of sites having similar area surface (Brum et al., 2017; Pollock et al., 2017),
316 in our case, we focused on insular regions of different area surfaces and highlighted that
317 *Sundaland* and *Papua New Guinea* harbored lower threatened diversity than expected given
318 their area. Thus, the choice of metrics and spatial scale to define hotspots is an important and
319 sensitive issue that may lead to different conclusions regarding the identification of
320 biodiversity-rich areas (Marchese, 2015). However, to compare diversity between sites of
321 varying size, removing the effect of area is mandatory as diversity is known to increase with
322 area at a decelerating rate (i.e. a nonlinearity relationship between area and diversity). Even if
323 the diversity-area ratio seems to be the most intuitive way to identify areas containing an
324 exceptional concentration of biodiversity, this method is only based on an assumption of a

325 simple linear relationship between area and diversity (Brummitt & Lughadha, 2003; Ovadia,
326 2003). Thus, the DAR approach is valuable to determine priority areas for biological
327 conservation (Guilhaumon et al., 2008) even if no area-based approach alone can prevent
328 mass extinction (Boyd et al., 2008). Nevertheless, as insular regions with the biggest areas
329 and harboring the highest diversity values were not necessarily identified as hotspots, area did
330 not seem to be a good predictor for a high endemic mammal diversity in some insular regions.
331 Diversity can be related to environmental and latitudinal conditions but also to geological
332 histories, biogeographical processes and spatial structure of islands (Ficetola, Mazel, Falaschi,
333 Marta, & Thuiller, 2021; Whittaker & Fernandez-Palacios, 2007; Willig & Presley, 2018). For
334 instance, Kalmar & Currie (2006) found that 87% of the global variation in non-marine bird
335 species richness among worldwide islands was related to island size but also to climate and
336 island isolation. Moreover, the spatial configuration of islands and archipelagos may also
337 explain why the sole total area of islands is insufficient to predict diversity. Therefore, further
338 studies accounting for environmental variables are needed to determine diversity conservation
339 priorities, even if in a conservation concern, maximizing biodiversity on a given surface to
340 protect seems the best strategy.

341 The identification of priority insular regions for endemic mammals at risk of extinction is
342 based on residual values from the DAR. We found a strong congruency between residual
343 values of the three diversity facets revealing that TD can be used effectively as a proxy for PD
344 and FD in the conservation framework of insular endemic mammals at risk of extinction. This
345 confirms previous studies that showed species diversity can be a good surrogate for
346 conserving both the phylogenetic and functional diversity facets (Rapacciuolo et al., 2018;
347 Rodrigues & Gaston, 2002; Sechrest et al., 2002). However, for some insular regions, residual
348 values can be either negative or positive according to the diversity facet, which can have
349 repercussions on the ranking priority among insular regions if only one diversity facet is

350 considered. For instance, *East Melanesian Islands* is the third priority region based on TDAR
351 but is the tenth priority region based on PDAR and FDAR due to negative residuals. It means
352 that despite high species richness values found in this region, it is of lower importance
353 concerning the other dimensions. This result might be partially explained by more
354 phylogenetically and functionally clustered mammal assemblage owing to particular
355 environmental conditions or biogeographical processes for example (Jacquet, Mouillot,
356 Kulbicki, & Gravel, 2017; Qian et al., 2019). In addition, the magnitude of match and
357 mismatch along the three diversity facets may depend on the metric of diversity considered
358 (Daru et al., 2019; Mazel et al., 2014). Thus, it is important to consider multiple diversity
359 facets and metrics to determine comprehensive rankings of areas containing an exceptional
360 concentration of biodiversity.

361 Regarding the protection on diversity within insular regions, the coverage rate of protected
362 areas was overall low (~19%) and distributed unevenly. Only five insular regions out of the
363 19 had a protected area cover higher than 25%, and these regions have not been identified as
364 hotspots. Thus, expanding protected areas may be required to protect threatened endemic
365 mammal diversity particularly when protected areas are one of the cornerstones of
366 conservation actions (Godet & Devictor, 2018). Such a conservation measure is much-needed
367 for the identified hotspot areas of multifaceted diversity such as *Madagascar and the Indian*
368 *Ocean Islands* or *Wallacea* in order to reduce or halt habitat loss and fragmentation (Supriatna
369 et al., 2020; Vieilledent et al., 2018). However, further investigations must be undertaken to
370 better evaluate spatial overlap at a local scale between protected areas and multifaceted
371 diversity of endemic mammals at risk of extinction. As historically reserves were not selected
372 to protect multiple forms of diversity, it has been shown that currently worldwide protected
373 areas network poorly represents the three facets of mammalian biodiversity (Brum et al.,
374 2017; Daru et al., 2019; Pollock et al., 2017). For instance, of the 4.6% of the area identified

375 as priority for conservation of mammal biodiversity across all facets only 1% is currently
376 covered by protected areas (Brum et al., 2017). A slight expansion of protected areas could
377 remedy the existing gaps in the coverage for each facet of diversity and can thus potentially
378 protect a more important range of species or phylogenetic or functional units (Pollock et al.,
379 2017). Even if protected areas are a solution to conserve biodiversity, they are not optimal and
380 vary in the extent to which they can contribute to preventing extinctions face global changes,
381 and other conservation actions should be taken to avert species' declines (e.g. habitat
382 restoration, control of invasive species or pathogens, limitation of human activities, Godet &
383 Devictor, 2018; Le Saout et al., 2013; Maxwell et al., 2020).

384 To implement pertinent conservation actions, it is essential to identify the mechanisms
385 responsible for the changed state of a population, community, or ecosystem (Williams,
386 Balmford, & Wilcove, 2020). By disentangling threats that impact extrinsic and/or intrinsic
387 characteristics of species, we showed that the importance of threats varies among insular
388 regions. Thus, the conservation responses to set up in order to protect diversity (taxonomic,
389 phylogenetic, and functional) can differ from one region to another. The insular regions
390 harboring high threatened diversity of endemic mammals, such as *Madagascar and the Indian*
391 *Ocean Islands* or *Wallacea*, showed a lower representativeness of mixed threats compared to
392 other regions. Given that those regions are mainly associated with direct (biological resource
393 use) and habitat threats (agriculture, urbanization), as already shown (Leclerc, Courchamp, &
394 Bellard, 2018), enforcing protected areas and/or improving law enforcement to combat illegal
395 wildlife trade would help to protect threatened diversity. In contrast, insular regions like
396 *Caribbean Islands* and *Polynesia-Micronesia*, are mainly associated with mixed threats like
397 biological invasions or climate change. For those regions although protected areas can help
398 species to follow/track their favorable climate, as part of the islands, this action could be
399 limited because of physical barriers. Thus, to preserve species in the face of climate change,

400 other actions should be considered such as potential translocations (Thomas, 2011). Further
401 investigations to determine effective management strategies are needed at the individual
402 threats scale (e.g. pollution, invasive alien species, etc.), as their effects and impacts differ in
403 time and space. For instance, in the years to come, climate change and its impact on endemic
404 mammal diversity should increase in all insular regions (Bellard, Leclerc, & Courchamp,
405 2014; Leclerc, Courchamp, et al., 2020).

406 Regarding the present study, some limitations need to be acknowledged. We identified
407 priority insular regions for conservation taking into account only insular endemic mammal
408 diversity information. However, optimal identifying sites for conservation must take into
409 account numerous potentially competing priorities ranging from biological to sociological and
410 economical (Bennett et al., 2014; Faith & Walker, 2002; Herrera, 2017). Such an approach,
411 which integrates multiple sources of information is particularly valuable, especially if it
412 identifies high-priority sites that were undervalued when using species diversity-centric
413 approaches. Also, data-deficient species represent 14.3% of our dataset. We did not consider
414 data-deficient species as threatened, which can lead to an underestimation of the species
415 considered at risk of extinction, especially that it has been shown that 63.5% of the data-
416 deficient species can be threatened with extinction (Bland, Collen, Orme, & Bielby, 2015).

417 Despite these limitations, our study allows to identify priorities of insular endemic
418 mammalian diversity across several facets, and their level of protection and the threats that
419 affect them. Because most conservation planning are undertaken at a local scale (though
420 biodiversity hotspots attract billions over the years; Mittermeier, Turner, Larsen, Brooks, &
421 Gascon, 2011; Myers, 2003; Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000), we
422 call for further study of local spatial distribution of three diversity facets within insular
423 regions to target areas of high diversity and see how it overlaps with protected areas network
424 and with each anthropogenic threat.

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656 ACKNOWLEDGEMENTS

657 We are thankful to Ana S. L. Rodrigues for comments and the fruitful discussion about the
 658 manuscript. This work was supported by grants from the ANR (14-CE02-0021-01) and the

659 Fondation BNP Paribas (INVACOST), and more generally this was funded by our salaries as
660 French public servants.

661

662 **CONFLICT OF INTEREST**

663 The authors declare no conflicts of interest.

664

665 **DATA ACCESSIBILITY STATEMENT**

666 The IUCN Red List data are available from the IUCN website
667 (<https://www.iucnredlist.org>), which includes information about IUCN Red List status,
668 identity of the threats, list of occupied habitats and species range. Body mass, foraging niche,
669 foraging period and dominant diet traits used in this study are freely available from
670 EltonTraits 1.0 (<https://esapubs.org/archive/ecol/E095/178/>). We also used mammals
671 phylogeny in open access from www.vertlife.org. The R scripts and data are available at:
672 <https://doi.org/10.5281/zenodo.5616745>

673

674 **BIOSKETCH**

675 Camille Leclerc is a postdoctoral researcher working at INRAE – UMR RECOVER. The
676 overarching aim of her research is to investigate the effects and the impacts of global change
677 drivers on biodiversity patterns, at species and community scale.

678 Camille Magneville is a PhD student at the University of Montpellier - UMR MARBEC. She
679 is currently working on functional diversity of fishes and its importance for marine coastal
680 ecosystems. She is developing a new methodological and conceptual approach to study the
681 temporal variability of fish diversity and functional rarity. She then applies this framework to
682 study two cases of anthropic impact: biological invasion and exploitation.

683 Céline Bellard is a CNRS researcher at Paris-Saclay University. She is particularly interested
 684 in species response to climate change and biological invasions, insular biodiversity and
 685 macro-ecology in general.

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687

688 **TABLES**

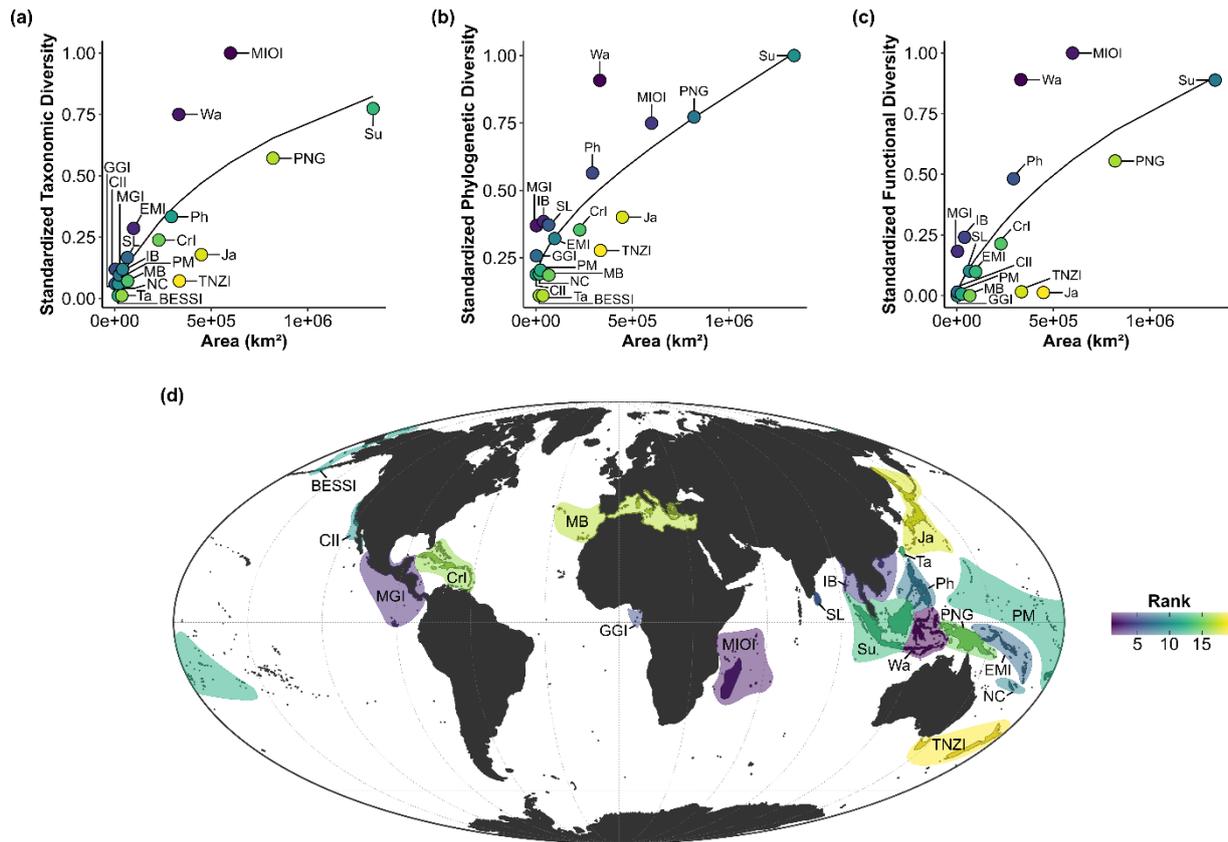
689 **TABLE 1.** Information about the 19 insular regions considered in the study.

Insular regions	Abbreviation	Area (km²)	Number of islands	Number of endemic mammals	Number of threatened endemic mammals
Bering and East Siberian Sea Islands	BESSI	17,735	13	6	1
California Islands	CII	2,315	20	11	10
Caribbean Islands	CrI	227,796	211	47	20
East Melanesian Islands	EMI	97,485	215	70	24
Gulf of Guinea Islands	GGI	2,805	2	6	5
Indo-Burma	IB	39,846	25	11	10
Japan	Ja	448,483	133	46	15
Madagascar and the Indian Ocean Islands	MIOI	599,736	82	146	84
Mediterranean Basin	MB	66,907	33	8	6
Mesoamerica and Galapagos Islands	MGI	3,165	12	11	10
New Caledonia	NC	18,502	8	7	5
Papua New Guinea	PNG	819,801	255	205	48
Philippines	Ph	293,368	302	120	28
Polynesia-Micronesia	PM	23,843	77	10	8
Sri Lanka	SL	65,627	6	16	14
Sundaland	Su	1,338,195	216	169	65
Taiwan	Ta	36,007	5	14	1
Tasmania and New Zealand Islands	TNZI	334,742	26	9	6
Wallacea	Wa	331,347	158	182	63

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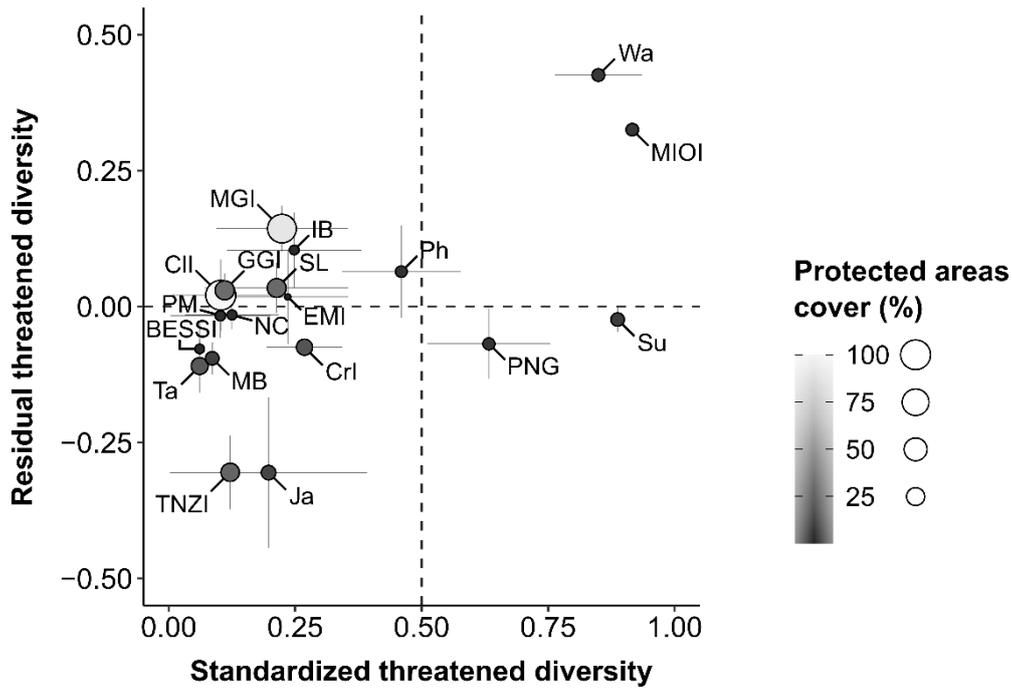
692 **FIGURES LEGENDS AND EMBEDDED FIGURES**



693

694 **FIGURE 1:** Endemic mammalian threatened diversity–area relationship for (a) taxonomic,
 695 (b) phylogenetic, (c) functional facets, and (d) map of the insular regions ranked according to
 696 the residual values of the three facets. Color gradient scale represents the ranking of insular
 697 regions based on residual values of (a) taxonomic diversity, (b) phylogenetic diversity, (c)
 698 functional diversity, and (d) the three diversity facets. For the abbreviation of insular regions,
 699 see Table 1.

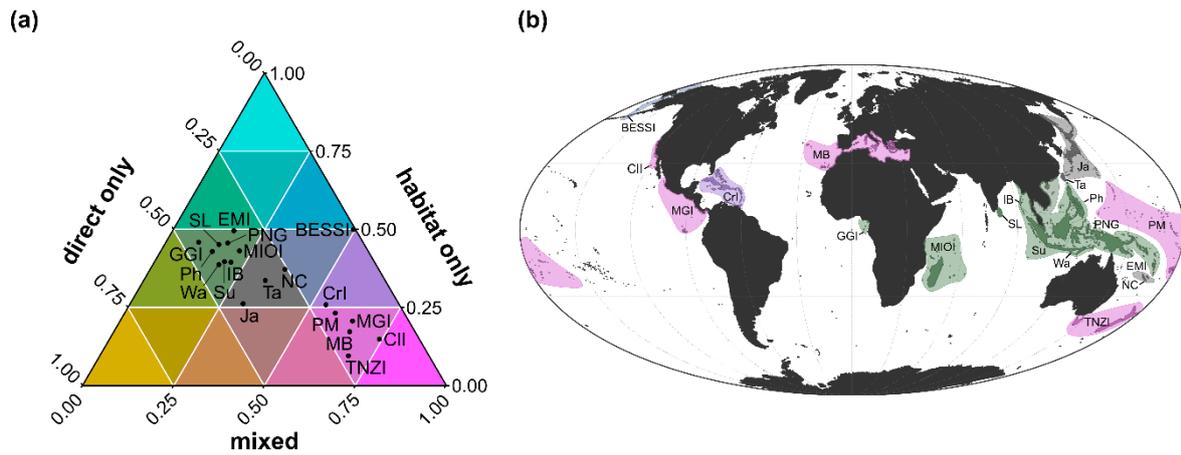
700



701

702 **FIGURE 2:** Relationship between threatened residual and standardized diversity of endemic
 703 mammals within insular regions. The node size and shade inform on the protected areas cover
 704 (%) within insular regions. Standardized threatened diversity of endemic mammals refers to
 705 the observed threatened diversity of each insular region divided by the maximal threatened
 706 diversity among the 19 insular regions. Residual threatened diversity of endemic mammals
 707 refers to the residual values that come from the DARs. Threatened diversity of endemic
 708 mammals for each insular region (standardized or residual) is represented by the mean of the
 709 different diversity facets (taxonomic, phylogenetic, and functional) and its associated standard
 710 deviation. For the abbreviation of insular regions, see Table 1.

711



712

713 **FIGURE 3:** Representativeness of direct, habitat and mixed threats based on endemic
 714 mammalian diversity at risk of extinction within insular regions. (a) Ternary plot of the threats
 715 representativeness within insular regions. (b) Map of the insular regions colored according to
 716 the threats representativeness. For the abbreviation of insular regions, see Table 1.