

1 **Artificial lights and seabirds: is light pollution a threat for the threatened Balearic**
2 **petrels?**

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24 **Abstract**

25 Petrels are among the most threatened group of birds. On top of facing predation by
26 introduced mammals and incidental bycatch, these seabirds have to deal with an
27 emerging threat, light pollution, which is increasing globally. Fledglings are
28 disorientated and attracted to artificial lights in their maiden night flights from their
29 nests to the sea. Once grounded, they are exposed to multiple threats leading to high
30 mortality. We report on numbers of three petrel species (Balearic shearwater *Puffinus*
31 *mauretanicus*, Scopoli's shearwater *Calonectris diomedea*, and European storm-petrel
32 *Hydrobates pelagicus*) rescued on the Balearic Islands, Mediterranean Sea, in the period
33 1999-2013. We assessed the proportion of grounded fledglings in the population and
34 colonies impact based on radiance levels measured from a nocturnal satellite image. We
35 also calculated the radius of light pollution impact. At least 304 fledgling birds were
36 found stranded due to attraction to artificial lights, 8.5% of them being fatally affected.
37 Proportion of grounded fledglings ranged between 0.13-0.56% of the fledglings
38 produced annually. The body mass of Balearic and Scopoli's shearwater fledglings
39 decreased with rescue date. Light-induced mortality increased during fledging period
40 for Scopoli's shearwaters. Birds were rescued at a mean distance of 4,833 m from the
41 nearest colony and between 30-47% of colonies were exposed to light-polluted areas.
42 Although impact seems to be low for all species, urban development and, consequently,
43 the increase in light pollution in the proximities of the colonies should be taken into
44 account to reduce as much as possible this emerging source of mortality.

45

46 **Keywords** artificial lights, attraction, Balearic Islands, disorientation, illumination, light
47 pollution, mortality, seabird

48

49 **Running Head**

50 Balearic seabirds attracted to lights

51 **Introduction**

52

53 Light pollution, i.e. the alteration of natural light levels at night as consequence
54 of human structures, is increasing worldwide and it has been recently recognized as a
55 threat for biodiversity (Hölker et al. 2010a,b). One of the negative effects of light
56 pollution on animals is disorientation in their movements, with consequences for their
57 fitness and survival (Longcore and Rich 2004; Gaston et al. 2014). Land-breeding
58 marine animals, such as sea turtles and seabirds, are strongly affected by lights when
59 hatchlings or fledglings direct toward the sea for the first time in their lives (Rich and
60 Longcore 2006). These events can cause high mortality in one of the most endangered
61 groups of birds, the petrels (Order Procellariiformes; Croxall et al. 2012), as fledglings
62 are grounded in lit areas and susceptible to collisions with human infrastructures or
63 vehicles, predation by introduced predators, starvation or dehydration (a phenomenon
64 called fallout; Reed et al. 1985; Telfer et al. 1987; Ainley et al. 2001; Le Corre et al.
65 2002; Rodríguez and Rodríguez 2009; Miles et al. 2010; Fontaine et al. 2011;
66 Rodríguez et al. 2014a). Because petrels are long-lived birds, population dynamics are
67 especially sensitive to adult survival. However, light pollution affecting mainly
68 fledglings has been recognized as an important mortality source, which, in addition to
69 other threats, could endanger the survival of petrel populations (Ainley et al. 2001;
70 Fontaine et al. 2011; Griesemer and Holmes 2011). Apart from attracting fledglings to
71 lit areas, light pollution could also modify the behaviour of predators of nocturnal
72 colony-visiting petrels. Burrow-nesting petrels visit colonies at night apparently to
73 avoid predators (Miles et al. 2013), and thus an increase in light levels at colonies as a
74 consequence of light pollution can increase the predation by diurnal predators (Oro et al.
75 2005).

76 Balearic Islands are among the most popular touristic destinations in the
77 Mediterranean Sea, highly populated and with increasing light pollution levels
78 (IBESTAT 2014; de Miguel et al. 2014). Despite high anthropogenic transformation of
79 the archipelago, four threatened procellariiform species breed there still relegated to the
80 most inaccessible places, mainly islets, marine rocks and coastal cliffs; including, as the
81 most significant values, the endemic and critically endangered Balearic shearwater
82 *Puffinus mauretanicus* and the largest populations of European storm-petrels
83 *Hydrobates pelagicus* in the Western Mediterranean (Madroño et al. 2004).

84 In this study, we evaluate the effect of light pollution as a source of mortality for
85 fledglings of the three most abundant petrel species breeding on the Balearic Islands:
86 the critically endangered Balearic shearwater, as well as the regionally endangered
87 Scopoli's shearwater *Calonectris diomedea* and European storm-petrel (Madroño et al.
88 2004). These three species differ in size, abundance, breeding period and distribution
89 among islands. In addition, Balearic Islands constitute a different scenario from other
90 locations where fallout has been studied (e.g. Azores, Canary Islands, Hawaii, La
91 Reunion Island or Phillip Island), as light pollution levels are higher than reported
92 elsewhere (maximum radiance value: 197.3 nW/sr*cm² vs. 103.6 nW/sr*cm² on
93 Tenerife Island –the highest value where fallout has been studied; see Table 2 in
94 Rodríguez et al. 2014 for a comparison) and distribution of colonies are mainly located
95 on coastal areas. In this regard, petrel colonies can be located inland on typical oceanic
96 islands, such as Azores, Canaries, Hawaii or La Reunion. Thus, Balearic Islands are an
97 exceptional scenario to study a crucial conservation question in the human-wildlife
98 conflict of light pollution and seabirds. It has been proposed that fledglings could be
99 attracted to lights once they successfully reach the ocean (Podolski et al. 1998). It means
100 that fledglings from dark colonies are also vulnerable to light attraction because they
101 can be attracted back to land (Troy et al. 2011, 2013). However, the proportion of
102 fledglings attracted in this way does not seem to be considerable according to GPS-
103 tracked and banded birds from known colonies at the Canaries (Rodríguez et al. 2015).
104 Given the coastal distribution of the breeding colonies at Balearic Islands (mainly on
105 islets and marine rocks), the majority of birds grounded by lights must have flown over
106 the sea. Thus, if the proportion of affected birds in relation to annually produced
107 fledglings is high, it means that fledglings can be attracted back to land lights. On the
108 other hand, if the proportion of affected birds is low, the numbers of birds attracted back
109 to land would not be significant for the phenomenon of petrel attraction to artificial
110 lights.

111 Our specific aims are: 1) to estimate the proportion of fledglings grounded by
112 artificial lights with respect to the total fledglings annually produced by the population;
113 2) to study body condition and fatality in relation to rescue date; 3) to calculate the
114 radius of light pollution impact by assigning birds to the nearest breeding colony and
115 comparing with data coming from ringing programs conducted on two colonies of
116 Scopoli's shearwaters; and 4) to evaluate light pollution levels in the breeding colonies
117 proximities to quantify alterations of breeding habitats due to this emerging pollution.

118

119 **Material and Methods**

120

121 *Study area*

122

123 The Balearic Islands, western Mediterranean Sea, comprise four major islands
124 (Majorca, Minorca, Ibiza and Formentera) and several islets and rocks. More than one
125 million people inhabit the archipelago, the majority concentrated along the coast, and
126 approximately 13 millions tourists per year visit the archipelago (IBESTAT 2014).
127 According to the analyses of satellite imagery, light pollution levels have increased
128 during recent years (de Miguel et al. 2014).

129

130 *Species*

131

132 The Balearic shearwater *Puffinus mauretanicus* is the most threatened seabird in
133 Europe (1,750-2,125 breeding pairs, Sauleda 2006), the most critical threats being
134 predation by introduced mammals and fishery bycatch (Arcos 2011). Other threats,
135 including light pollution, have been mentioned in Balearic shearwater conservation
136 action plan, but limited information regarding their effects on populations has been
137 provided (Arcos 2011). In addition, some events of predation by peregrine falcons have
138 been recorded at night at the breeding colonies, which could be related to an artificial
139 increase of light levels (García 2009; Wynn et al. 2010).

140 The Scopoli's shearwater *Calonectris diomedea* is the largest and the most
141 abundant of the Balearic procellariiforms (100-125 cm wingspan and around 11,000
142 breeding pairs). Some references indicate that this species is grounded by light pollution
143 in some Mediterranean islands (Baccetti et al. 2005; Raine et al. 2007; Laguna et al.
144 2014), although no information on scientific literature is available for the Balearic
145 Islands.

146 The European Storm-petrel *Hydrobates pelagicus* is the smallest petrel breeding
147 on the Mediterranean basin (36-39 cm wingspan). The Balearic archipelago holds the
148 largest populations in the Western Mediterranean (2,916-4,046 breeding pairs, Sauleda
149 2006). This species can be affected by light pollution in two different ways: 1) attraction
150 and disorientation of juveniles (Laguna et al. 2014); and 2) increase of predation rates
151 by gulls in light polluted colonies (Oro et al. 2005).

152 A small mixed population of Yelkouan shearwater *Puffinus yelkouan* and
153 Balearic shearwater is breeding on Minorca. Despite several morphological and genetic
154 studies, taxonomic status of these birds is controversial (see Arcos 2011; Genovart et al.
155 2012). For this reason, we considered all *Puffinus* fledglings as Balearic shearwater
156 specimens.

157

158 *Rescue and ringing campaigns*

159

160 Data on rescued birds come from three wildlife rehabilitation centres located on
161 the three main islands (Majorca, Minorca and Ibiza) and sponsored by the regional
162 government (Consorci per a la Recuperació de la Fauna de les Illes Balears, Govern de
163 les Illes Balears). The study period extends from 1999 to 2013. Birds were collected by
164 the public or personnel of the wildlife rehabilitation centres and examined by qualified
165 staff for identification, ringing, assessment of condition and health status, and release
166 into the wild, if possible. Injured birds were admitted and held for rehabilitation or
167 euthanized. In contrast to other islands where petrels are severely affected by lights
168 (Telfer et al. 1987; Le Corre et al. 2002; Rodríguez and Rodríguez 2009; Fontaine et al.
169 2011; Rodrigues et al. 2012), no public dissemination of rescue campaigns is conducted
170 by local administrations to mitigate light pollution mortality on the Balearic Islands.
171 Thus, data presented here on the number of grounded birds should be interpreted as
172 minimum numbers, as some birds could be found by people unaware of light pollution-
173 seabird problem.

174 As part of a long-term programme for monitoring breeding success and
175 recruitment rate of Scopoli's shearwaters, nestlings of two colonies (Illot Pantaleu,
176 Majorca and Illa d'Aire, Minorca) are ringed at their nests before fledging. We used
177 ringing data from these colonies to estimate the rate of birds grounded by lights. A total
178 of 190 nestlings were ringed on Illa d'Aire in the 2002-2006, 2009-2010 and 2012-2013
179 breeding seasons. On Illot Pantaleu, 1,084 nestlings were ringed in the 2000-2009 and
180 2011-2012 seasons.

181

182 *Impact on the populations*

183

184 To roughly estimate the impact of artificial light attraction at fledging and
185 compare with other studies, we followed formulas given by Le Corre et al. (2002). We

186 first determined the total number of fledglings annually produced by the population of
187 the three species. We multiplied productivity (proportion of pairs laying an egg that
188 produced a fledgling) by breeding population size, taking into account the probability of
189 reproduction skipping (Table 1). Then, we divided the number of annually grounded
190 birds by the number of fledglings produced by the population for each species. Finally,
191 we calculated 95% confidence intervals for the smaller estimated population sizes.

192 We used population size and productivity from literature (Table 1), and we
193 assumed they were constant among years. Estimating breeding population size of
194 burrow-nesting petrels is challenging and some of them could be overestimated (e.g. the
195 European Storm-petrel; see Madroño et al. 2004). Some grounded fledglings could
196 never be found by rescuers. Fledglings look for hiding places during daylight hours,
197 could ground in or reach not-frequented places or may be unreported by unaware
198 people. Thus, our estimates should be interpreted with caution and as minimal numbers.
199 Despite constraints (i.e. assumptions on constant population size and productivity, and
200 the presumably underestimated numbers of grounded birds), estimates give us a rough
201 idea of the magnitude of the problem and allow comparison with other studies which
202 follow the same methodology (See Table 2 in Rodríguez et al. 2014).

203

204 *Environmental information and variables*

205

206 Information on spatial distribution of species was taken from BioAtlas, Govern
207 de les Illes Balears (available at <http://bioatles.caib.es>). Resolution was based on a 1x1
208 km grid size. Light pollution levels were taken from a cloud-free composite of VIIRS
209 nighttime lights corresponding to April and October of 2012 and produced by the Earth
210 Observation Group, National Oceanic and Atmospheric Administration (NOAA)
211 National Geophysical Data Center (available at
212 http://ngdc.noaa.gov/eog/viirs/download_monthly.html). VIIRS imagery with a spatial
213 resolution of 742 x 742 m and no saturation constitutes an improvement to the previous
214 DMSP satellite imagery (Elvidge et al. 2013).

215 Geographical analyses to obtain distances from colonies to rescue location and
216 light pollution levels of colonies and rescue locations were conducted in QGIS version
217 2.0.1 (Open Source Geospatial Foundation Project, <http://qgis.osgeo.org>). Because the
218 majority of rescued birds were not ringed at their colonies, we assumed that birds were
219 coming from the nearest colony, following Rodrigues et al. (2012). To determine light

220 pollution levels at colonies we used centroids of 1x1 km square cells having a colony of
221 at least one species. We report the single value of the pixel intersected with the
222 centroids, but also the mean and maximum values in a 4 km radius buffer centred at the
223 centroid of the 1x1 km cells representing a breeding colony.

224

225 *Statistical analysis*

226

227 To test the effect of rescue date (explanatory variable) on the status of birds
228 (response variable with two levels; released vs. dead), we used generalized linear
229 models (GLM) with binomial error structure and logit link function for each species.
230 The significance of the model was assessed by a likelihood ratio test, comparing
231 deviance with the null model (comprising only the intercept). We run Pearson's
232 correlations to test for relationships between body mass and date of rescue for the
233 Balearic and Scopoli's shearwaters (data on storm-petrel body mass were unavailable).
234 To test for differences in distances to colonies and light pollution levels among species,
235 we conducted linear models. Variables were transformed to meet normality and
236 homoscedasticity assumptions. 'Distance to nearest colony' and 'light pollution level'
237 were log (i.e. $\ln(x + 1000)$) and square root-transformed, respectively.

238 Statistical analyses were conducted in R version 3.0.3 (R Foundation for
239 Statistical Computing, Vienna, Austria).

240

241 **Results**

242

243 *Magnitude, geographic and timing of fallout*

244

245 A total of 304 fledgling birds were found stranded due to attraction to artificial
246 lights on the Balearic Islands in the period 1999-2013. The most abundant species was
247 the Scopoli's shearwater (199 birds), followed by the Balearic shearwater (66 birds) and
248 the European storm-petrel (39 birds). The percentage of fledglings grounded by
249 artificial lights was lower than 1% for the three species (Table 1). Despite of the lower
250 breeding population size, the critically endangered Balearic shearwater was the most
251 affected species. The highest number of grounded birds was reached in Minorca (147
252 birds), followed by Ibiza (92), Majorca (61) and Formentera (4). The birds were rescued
253 mainly in the periods 13-20 October, 4-14 July and 20 August-5 September for

254 Scopoli's shearwater, Balearic shearwater and European storm-petrel, respectively,
255 coinciding with the fledging season of each species (1st and 3rd quartiles; Fig. 1).

256

257 *Mortality and body condition*

258

259 Twenty-six (8.5%) out of 304 birds were fatally affected by lights. No
260 differences in mortality frequency were detected between species ($\chi^2 = 3.364$, d.f. = 2, P
261 = 0.186). Only the GLM explaining the relationship between probability to die and
262 rescue date for Scopoli's shearwater was significant as compared to the null model
263 (likelihood ratio test: $\chi^2 = 11.484$, $P < 0.001$) and it showed that probability to die
264 increased with the fledging season (Estimate \pm SE: 0.205 ± 0.053 ; $\chi^2 = 3.887$, $P <$
265 0.001). The remaining GLMs for the Balearic shearwater and the European storm-petrel
266 were not significantly better than their respective null models (likelihood ratio tests: $\chi^2 =$
267 0.004 , $P = 0.949$ and $\chi^2 = 0.608$, $P = 0.435$, respectively). The body mass of Balearic
268 and Scopoli's shearwater fledglings decreased with rescue date ($r = -0.762$, $P < 0.002$, n
269 = 13; and $r = -0.501$, $P < 0.001$, $n = 45$, respectively).

270

271 *Distances from rescue locations to colonies*

272

273 Birds were rescued at a mean distance of 4,833 m from the nearest colony
274 (median= 4,206, 1st and 3rd quartiles = 1,581 and 5,644 m, $n = 303$; Figs. 2 and 3). Mean
275 distances were different between species ($F_{2, 300} = 5.438$, $P = 0.005$), Scopoli's
276 shearwater being rescued at closer locations ($4,219 \pm 6,701$ m, mean \pm SD) than the
277 other two species ($5,943 \pm 7,094$ m for the Balearic shearwater and $6,075 \pm 5,413$ m for
278 the European storm-petrel). However, information coming from Scopoli's shearwater
279 ringings indicates they flew shorter distances. Only 10 out of the 1274 Scopoli's
280 shearwater fledglings ringed at their natal colonies were recaptured, and all within a 4
281 km radius from colonies (eight and two birds from Pantaleu and Illa d'Aire colonies
282 respectively; see inset in Fig. 2). In addition, one ringed Balearic shearwater fledgling
283 was recovered at a distance of 1,581 m from its natal colony, Mola de Maó, Minorca.

284

285 *Light pollution levels at rescue locations and colonies*

286

287 Light pollution levels at rescue locations ranged between 0.2 and 123.4
288 nW/sr*cm² (mean= 24.6, median= 21.0, 1st and 3rd quartiles = 5.2 and 38.1 nW/sr*cm²,
289 n = 303) and no significant differences were detected between species ($F_{2, 300} = 2.522$, P
290 = 0.082; Figs. 2 and 3). In general, colonies were exposed to low light pollution levels,
291 only 2-4 out of the 10-15 colony buffers (depending on species) showed mean radiance
292 values higher than 1 nW/sr*cm². However, a higher proportion (30-47%) of colonies
293 showed areas with high levels of light pollution, i.e. higher than 10 nW/sr*cm², within a
294 4 km radius (Table 1). One hundred and ninety-eight birds (65% out of the total fallout)
295 were assigned to colonies exposed to radiance values higher than 10 nW/sr*cm² within
296 a radius of 4 km. No significant differences were observed between the light pollution
297 levels at colonies of the three species (Mean values: $F_{2, 34} = 0.163$, $P = 0.850$; Max.
298 values: $F_{2, 34} = 0.471$, $P = 0.629$; log-transformed variables).

299

300 **Discussion**

301

302 *Magnitude of fallout*

303

304 Our study provides baseline information on the light-induced mortality of three
305 petrel species on the Balearic Islands, including the critically endangered Balearic
306 shearwater. The numbers reported here are low in comparison to those from other
307 islands and species, where thousands of fledglings are involved in a single fledging
308 season (e.g. Day et al. 2003; Fontaine et al. 2011; Rodríguez et al. 2012b). This figure
309 seems to be general in the Mediterranean Sea where low affection rates have been
310 recorded (Baccetti et al. 2003; Raine et al. 2007; Laguna et al. 2014). Distribution of
311 colonies seems to play a crucial role in the fallout numbers. In the Balearic Islands, as in
312 many other Mediterranean islands, breeding colonies are mainly located on islets and
313 rocks offshore or on coastal sectors at low altitudes, and thus, many fledglings
314 successfully reach the ocean. According to this, petrel fledglings are not massively
315 attracted back to land lights (but see Troy et al. 2013). A similar case occurs with other
316 species mainly breeding at coastal sectors, such as the wedge-tailed shearwater *Ardenna*
317 *pacifica* on La Reunion, Indian Ocean (Le Corre et al. 2002), or the short-tailed
318 shearwater *Ardenna tenuirostris* on Phillip Island, Australia (Rodríguez et al. 2014),
319 where a small proportion of annually produced fledglings are grounded by lights.

320 However, on islands where fledglings from inland colonies must fly over cities to reach
321 the ocean, the rate of grounded birds by lights is higher (Rodríguez et al. 2014).

322

323 *Mortality and body condition*

324

325 Without human intervention (rescuing), all grounded birds would die because
326 most probably any would have reached the sea for themselves (Le Corre et al. 2002).
327 Mortality rate at rescue was similar to other studies conducted elsewhere, which ranges
328 between 4 and 14% of rescued birds (Rodríguez et al. 2014). However, we have to note
329 that light-induced mortality is underestimated because 1) an unknown number of the
330 grounded birds are never found, and 2) rescue campaigns based on the collaboration of
331 the general public are biased toward the collection of live birds, i.e. lay people do not
332 report (or collect) dead birds (Podolski et al. 1998; Rodríguez et al. 2014). Thus, if an
333 active rescue patrol for dead and live birds had been conducted in the Balearic Islands,
334 the mortality rate would have increased as recorded for the Newell's shearwater
335 *Puffinus newelli* or the short-tailed shearwater *Ardenna tenuirostris* (assuming no
336 species-specific differences in attraction to light; Ainley et al. 2001; Rodríguez et al.
337 2014).

338 As previously recorded for Cory's shearwaters *Calonectris borealis* (Rodríguez
339 et al. 2012a), we found that both the probability of releasing back to the wild a rescued
340 bird and the body mass decreased with the date of admission at the rehabilitation centre.
341 Given that body mass at fledging seems crucial for recruitment into the breeding
342 population (Mougin et al. 2000), an effort should be made to rescue the birds as soon as
343 possible reducing the probability of dying and improving their fitness. In this sense,
344 rescued fledglings of the endangered Newell's shearwater are admitted for rehabilitation
345 and feeding if they fall below a minimum body mass threshold (Griesemer and Holmes
346 2011). A similar action could be undertaken with those birds rescued late at the fledging
347 season, especially for the critically endangered Balearic shearwater.

348

349 *Distances and light pollution levels*

350

351 The distances observed in the Balearic Islands are similar to those reported for
352 GPS-tracked Cory's shearwaters on Tenerife, Canary Islands (mean distance = 5,108 m
353 for birds with a known origin; Rodríguez et al. 2015), but longer than mean distance

354 (2,387 m) estimated in Sao Miguel, Azores (Rodrigues et al. 2012). The higher light
355 pollution levels of the Balearic Islands and Tenerife could explain these differences, as
356 the higher the intensity of light pollution the further away the birds are attracted from
357 (Rodríguez et al. 2015). In addition, the higher spread distribution of colonies at Sao
358 Miguel in comparison to the confined colonies on Balearic Islands could also explain
359 the differences in distances.

360 In general, colonies showed low mean light pollution levels, but 30-47% of them
361 were exposed to radiance values higher than $10 \text{ nW/sr}\cdot\text{cm}^2$ (percentages vary on
362 species; Table 1). That is a very conservative estimate of light pollution affection on
363 colonies because of the cut-off points used: 1) more than a third of birds are grounded in
364 areas with radiance values lower than $10 \text{ nW/sr}\cdot\text{cm}^2$ (104 out of 304 found birds); and
365 2) 54% of birds were rescued farther away than 4 km from the nearest colony (163 out
366 of 304 found birds). Despite this conservative threshold, colonies exposed to radiance
367 values higher than $10 \text{ nW/sr}\cdot\text{cm}^2$ were the main contributors to the fallout (65% of
368 rescued birds were assumed to be born at these colonies), which points to the validity of
369 our approach.

370 Finally, we should note that light-induced mortality is not limited to coastal
371 cities. Fledglings can also be attracted to lights of ships or oil platforms, extending the
372 problem of light pollution at sea (Wiese et al. 2001; Merkel and Johansen 2011; Glass
373 and Ryan 2013). In this sense, the increase of recreational vessels and cruise ships,
374 which are currently an important touristic resource for the archipelago, and oil-drilling
375 plans of the Spanish Government around Balearic waters, will not only increase the
376 mortality of birds by light attraction, but also due to the inevitable oil spills and marine
377 litter from ships (Ronconi et al. 2014).

378

379 *Recommendations and conclusions*

380

381 Although numbers of birds grounded by lights are not high, reducing mortality
382 by anthropogenic causes should be a priority for the management and conservation of
383 these threatened species. To mitigate light-induced mortality and to have a better idea of
384 its effect, we recommend establishing a rescue campaign during the fledging seasons,
385 especially for the Balearic shearwater. Rescue campaigns should, at least, focus on the
386 nearest urban areas to breeding colonies. Educational campaigns to make the general
387 public aware of the economic, environmental and health consequences of light pollution

388 should accompany rescue campaigns. Regional governments should legislate to
389 preserve the natural night sky, reducing light pollution levels as low as possible,
390 especially in the proximities of colonies. These measures would help to save limited
391 economic resources, but also to preserve the natural and crucial fledging processes of
392 nocturnal seabirds.

393

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395

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406

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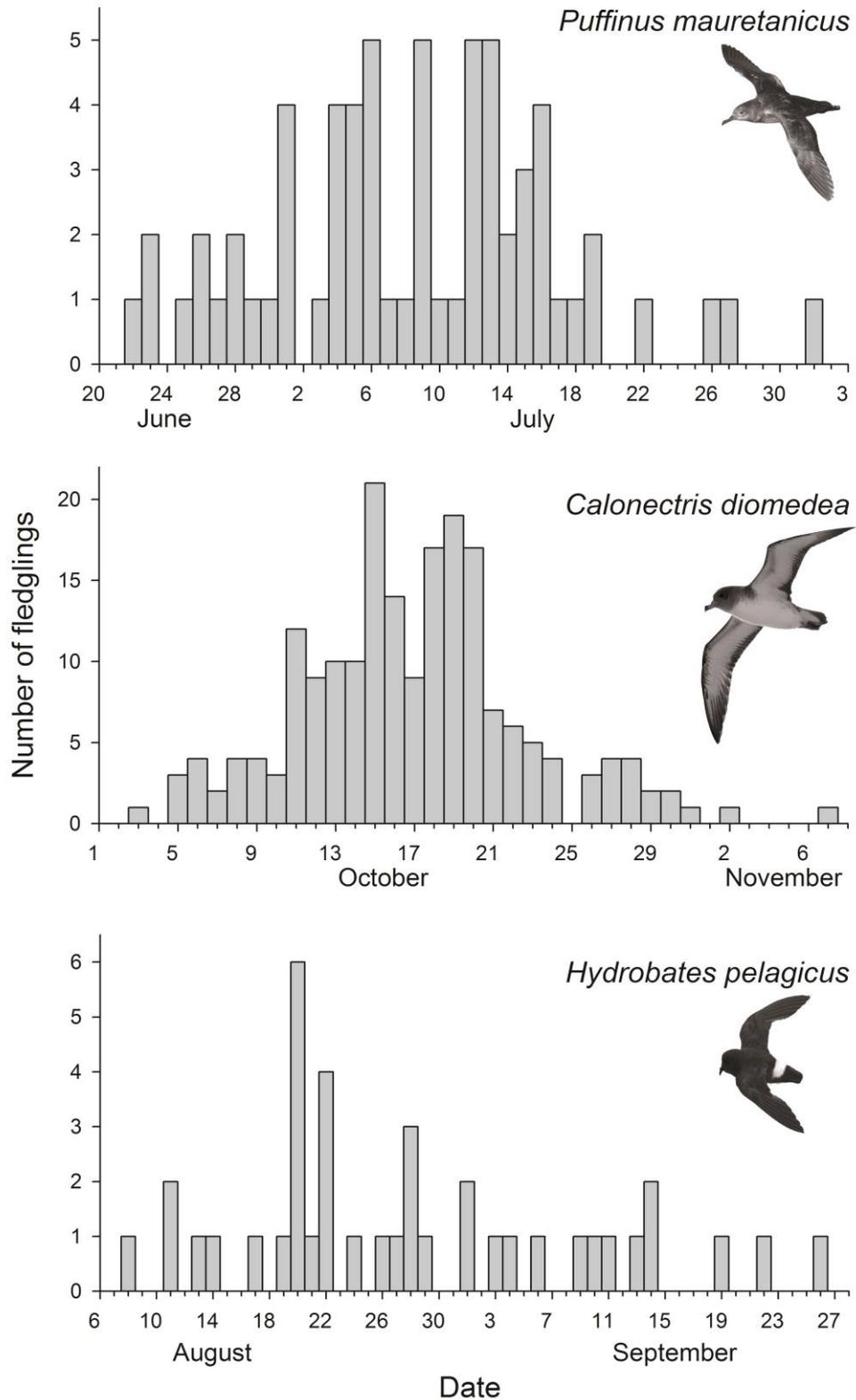
534 **Table 1** Affection levels of light pollution on annually produced fledglings and colonies for three petrel species on the Balearic Islands during
 535 the period 1999-2013.
 536

Species	English name	Conservation status		Breeding population size ^c	Productivity	Probability of skipping	% of grounded fledglings (95% C.I.)	Light pollution levels at colonies	
		IUCN ^a	National ^b					colonies with mean values > 1	colonies with max values > 10
<i>Puffinus mauretanicus</i>	Balearic shearwater	Critically endangered	Critically endangered	1,750-2,125	0.61 ^d	0.26 ^d	0.46-0.56 (0.381-0.733)	2	5
<i>Calonectris diomedea</i>	Scopoli's shearwater	Least concern	Endangered	10,000-11,000	0.42 ^e	0.15 ^f	0.34-0.37 (0.256-0.488)	4	7
<i>Hydrobates pelagicus</i>	European storm-petrel	Least concern	Vulnerable	2,912-4,046	0.50 ^g	~ 0 ^h	0.13-0.18 (0.093-0.265)	2	3

537

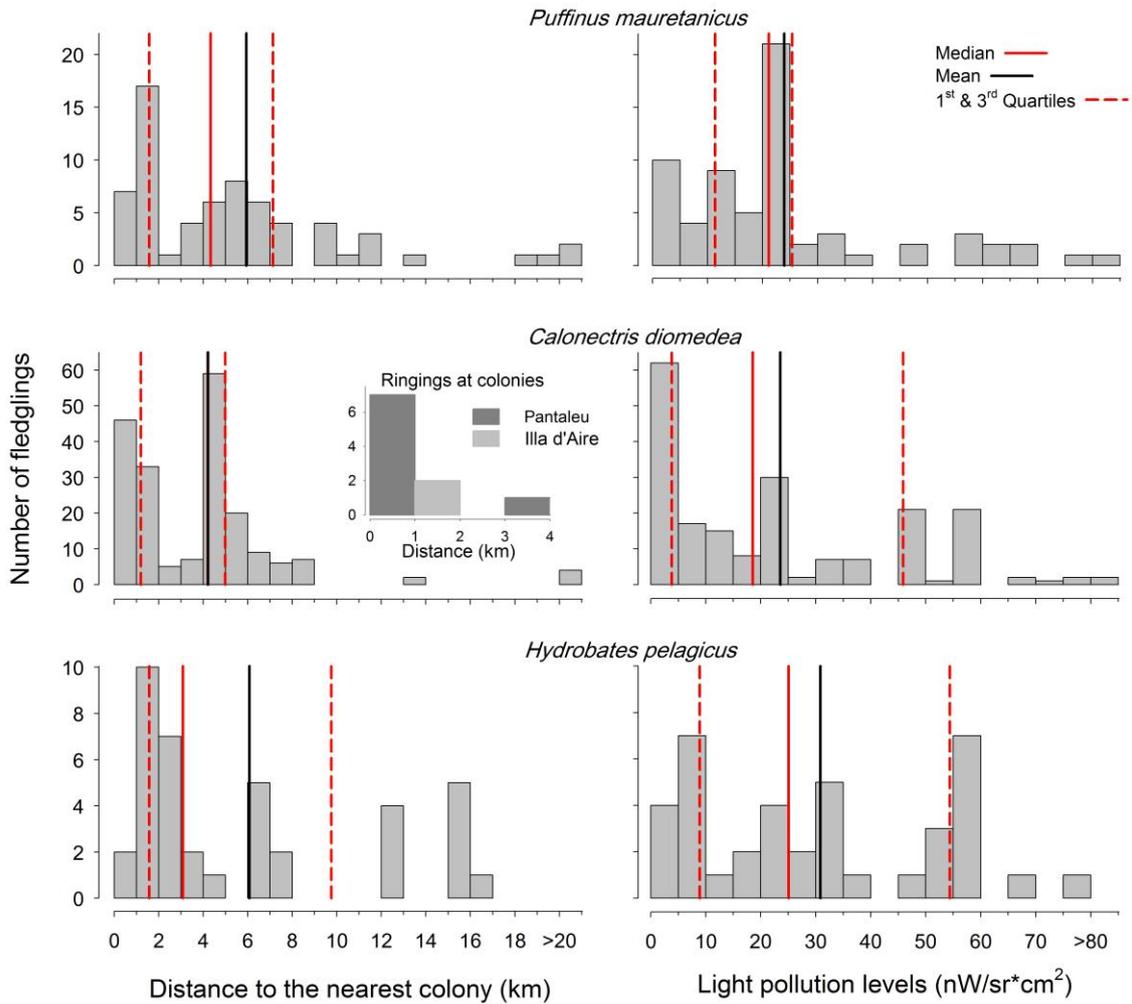
538 ^a BirdLife International (2015); ^b Madroño et al. (2004); ^c Sauleda (2006); ^d Oro et al. (2004); ^e Amengual and Aguilar (1998); ^f Aguilar et al.
 539 (2011); ^g Sanz- Tavecchia et al. (2008); ^h Sanz-Aguilar et al. (2008).

540 **Figure 1** Frequency distribution of petrel fledglings found grounded in the Balearic
 541 Islands during the period 1999-2013 for the three species: Balearic shearwater *Puffinus*
 542 *mauretanicus*, Scopoli's shearwater *Calonectris diomedea* and European storm-petrel
 543 *Hydrobates pelagicus*.



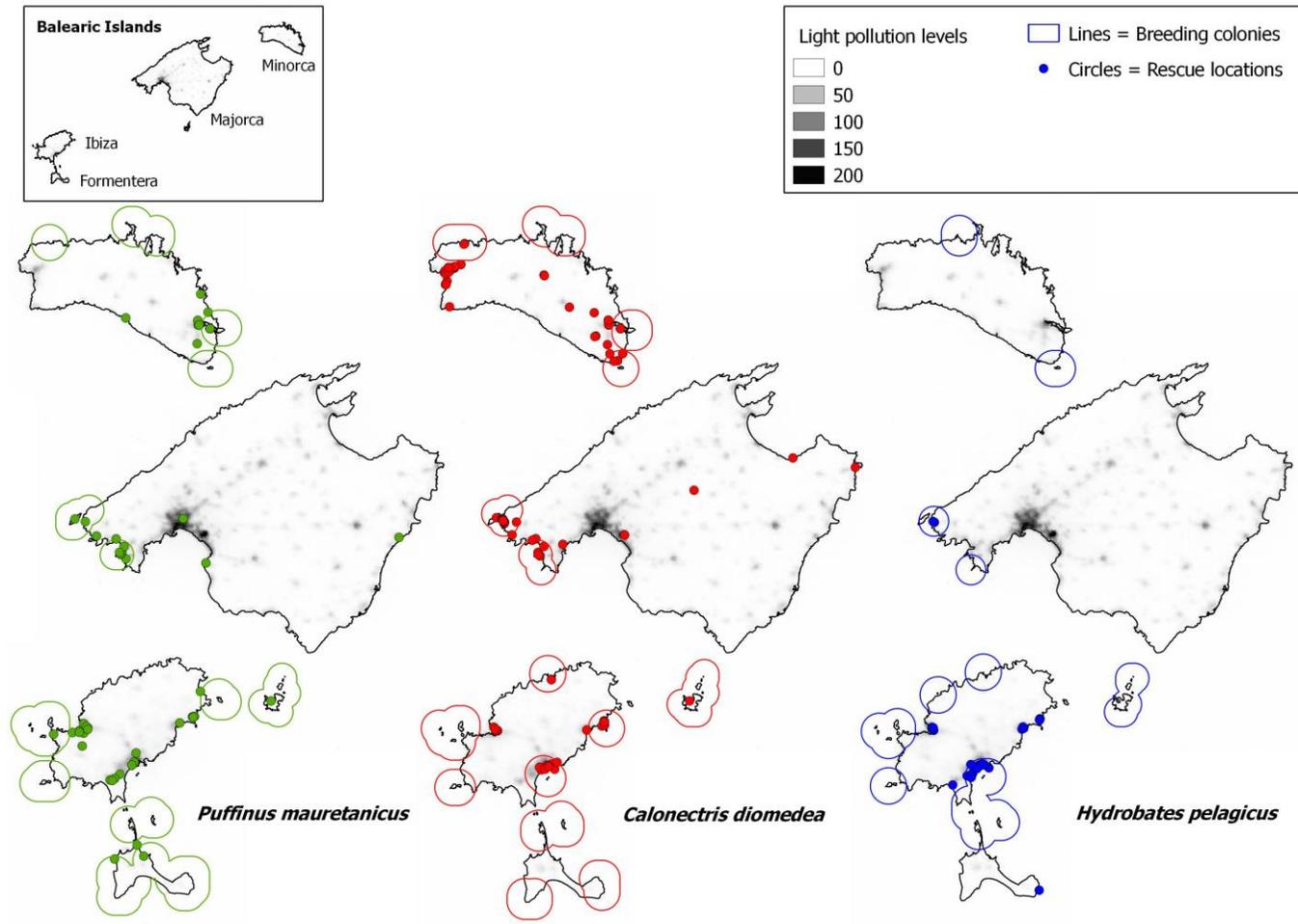
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546 **Figure 2** Histograms of distances and light pollution levels. Inset corresponds to
 547 distances from natal colonies to rescue locations of ringed Scopoli's shearwater.
 548 Distances correspond to the length in a straight line between rescue locations and the
 549 nearest colonies. Light pollution levels correspond to radiance values taken from a
 550 nocturnal satellite image produced by the Earth Observation Group, NOAA National
 551 Geophysical Data Center at rescue locations (see text).
 552



553

554 **Figure 3** Rescue locations and breeding colonies of three seabird species on the Balearic Islands, Mediterranean Sea. Light pollution levels
555 correspond to radiance values ($\text{nW}/\text{sr} \cdot \text{cm}^2$) taken from a satellite image from National Geophysical Data Center. Lines represent a 4 km buffer
556 around breeding colonies.



557