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## Pre-eradication updated seabird survey including new records on Amsterdam Island, southern Indian Ocean

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1 **Pre-eradication updated seabird survey including new records on**

2 **Amsterdam Island, southern Indian Ocean**

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26 **Abstract**

27 An invasive predator eradication campaign is planned for 2024 on Amsterdam Island, one of  
28 world's top priority island for seabird conservation. In order to monitor the effects on seabird  
29 colonies post-eradication, a survey of burrow-nesting species and population monitoring of  
30 albatrosses, penguins, skuas and terns was organised pre-eradication. Several counting  
31 techniques and acoustic methods were used to infer presence/absence of burrow-nesting  
32 species and to estimate abundance of other species, as well as genetic methods for species  
33 identification. In total 14 breeding (or probably breeding) seabird species were detected on  
34 Amsterdam Island, among which eight burrowing petrels including two species never  
35 described on the island: the Juan-Fernandez petrel *Pterodroma externa* and the sooty  
36 shearwater *Ardenna grisea*. Based on these new data, the introduced mammal eradication  
37 campaign on Amsterdam, if successful, will likely be extremely beneficial for seabird  
38 conservation, and may also favor the colonization of Amsterdam by new seabird species.

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40 Key words *Pterodroma externa* · *Ardenna grisea* · acoustic survey · genetic analysis

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## 51 **Introduction**

52

53 Amsterdam and Saint-Paul Islands in the South Indian Ocean share zoogeographic similarities  
54 with the Tristan da Cunha group in the South Atlantic and to the Chatham and Juan Fernandez  
55 groups in the South Pacific (Bourne and David 1995; Jouventin et al. 2006; Masello et al.  
56 2022). Since its discovery in the 16<sup>th</sup> century, Amsterdam has experienced several human  
57 related ecological perturbations and damages (Jouventin 1994; Jaeger et al. 2018). At least 22  
58 bird species are known or suspected to have bred on Amsterdam prior to first human contact  
59 (Jouanin and Paulian 1960; Worthy and Jouventin 1999), but several species are now locally  
60 extinct among which endemic species (Micol and Jouventin 1995; Olson and Jouventin 1996).  
61 Today, a total of 10 bird species breed on Amsterdam, including one introduced passerine (the  
62 common waxbill *Estrilda astrild*) and nine seabird species (Worthy and Jouventin 1999;  
63 Duriez and Delord 2012): northern rockhopper penguin *Eudyptes moseleyi*, Indian yellow-  
64 nosed albatross *Thalassarche carteri*, endemic Amsterdam albatross *Diomedea*  
65 *amsterdamensis*, sooty albatross *Phoebastria fusca*, soft-plumaged petrel *Pterodroma mollis*,  
66 grey petrel *Procellaria cinerea*, Macgillivray's prion *Pachyptila macgillivrayi*, Antarctic tern  
67 *Sterna vittata sanctipauli*, and subtropical brown skua *Catharacta antarctica hamiltoni*.

68 Amsterdam is a critical breeding ground for four globally threatened seabird species: the  
69 Amsterdam albatross, Indian yellow-nosed albatross, sooty albatross and northern rockhopper  
70 penguin (Heerah et al. 2019). These last three species have worsened dramatically during the  
71 past decade, with extremely low reproductive success and declining populations (Barbraud et  
72 al. 2020; Weimerskirch et al. 2018). Declines are mainly caused by the occurrence of avian  
73 cholera (*Pasteurella multocida*) and possibly eysipelas (*Erysipelothrix rhusiopathiae*) that  
74 induces high chick mortality, and by introduced mammals that predate eggs and chicks  
75 (Jaeger et al. 2018; Micol and Jouventin 2002). Invasive house mice *Mus musculus*, brown

76 rats *Rattus norvegicus* and feral cats *Felis catus* occur throughout Amsterdam (Micol and  
77 Jouventin 1995). These constitute a major threat to seabird populations and their eradication is  
78 a priority conservation objective (Brooke et al. 2007; Holmes et al. 2019). On Amsterdam, an  
79 eradication campaign of all the three invasive mammal species is planned for 2024, as part of  
80 the RECI (Restauration des écosystèmes insulaire de l'océan Indien) project financed by  
81 European Union, French Development Agency (AFD) and French Southern and Antarctic  
82 Territories administration (TAAF). The eradication of those three invasive mammals' species  
83 is included in the National Plan of Actions to improve the conservation status of the  
84 Amsterdam albatross (2018-2027). Recent studies showed that to assess the success of  
85 invasive predators' management, research should provide a comprehensive feed-back,  
86 incorporating pre- and post-eradication dynamics of seabird populations (Brooke et al. 2017;  
87 Philippe-Lesaffre et al. 2023). Expected impacts of eradication campaigns on seabird  
88 populations are mainly due to 1) removal of predation due to invasive species, 2) diet changes  
89 in relation to elimination of substitute prey, and 3) potential negative effects of secondary  
90 poisoning for scavengers (Brooke et al. 2017). Therefore, on Amsterdam long-term seabird  
91 monitoring will be necessary to evaluate changes due to rodenticide application and due to the  
92 absence of invasive predators.

93 Penguins, albatrosses, and to a lower extent skuas, have been regularly monitored since  
94 the early 1970s on Amsterdam. The population trends and demographic processes are  
95 relatively well known for some of these species (e.g. Barbraud et al. 2020; Delord et al. 2021;  
96 Weimerskirch et al. 2018). In contrast, knowledge of burrow-nesting species is insufficient  
97 and fragmentary. Species belonging to this group are notoriously difficult to detect and census  
98 as they spend daytime offshore to feed and come back to their breeding colonies at night  
99 (Warham 1990). Moreover, burrows are often difficult to detect, particularly in dense and tall  
100 vegetation such as on Amsterdam. From fossil remains, several species have been identified

101 as originally breeding on Amsterdam: several species of genus *Pterodroma*, *Pachyptila*, and  
102 *Puffinus*, the common diving petrel *Pelecanoides urinatrix*, white-faced storm petrel  
103 *Pelagodroma marina*, white-bellied storm petrel *Fregetta grallaria*, and non-identifiable  
104 specimen of genus *Oceanites* (Worthy and Jouventin 1999). However, these petrel populations  
105 have declined dramatically or disappeared due to introduced predators. Only Macgillivray's  
106 prion, grey petrel and soft-plumaged petrel still appear to breed on Amsterdam, but in very  
107 low numbers and breeding sites remain poorly known (Bretagnolle 1995; Duriez and Delord  
108 2012).

109 As part of the planned eradication program, we conducted several surveys on Amsterdam  
110 between 2021 and 2022 during seasonal breeding activities of seabirds with the aim of  
111 inventoring breeding seabird species, especially the nocturnal burrow-nesting seabirds. Here,  
112 we report some of the first results from these surveys documenting the unexpected discovery  
113 of new breeding species on Amsterdam Island.

114

## 115 **Material and methods**

116

117 Amsterdam Island (37°50' S; 77° 31'E) is a small (58 km<sup>2</sup>) uninhabited volcanic island  
118 situated in the southern Indian Ocean, north of the Subtropical Front and 85 km north of  
119 Saint-Paul Island (38°43'S, 77°31'E). For conspicuous surface-nesting seabirds (northern  
120 rockhopper penguin, Amsterdam albatross, Indian yellow-nosed albatross, sooty albatross,  
121 subtropical brown skua, Antarctic tern) we censused the whole island population using entire  
122 sampling methods. For these species, surveys were performed during the incubation period:  
123 late September 2022 for northern rockhopper penguins, late October 2021 for Indian yellow-  
124 nosed, late October 2022 for sooty albatrosses, mid-November 2021 for skuas and Antarctic  
125 terns, and April 2022 for Amsterdam albatross for which the entire population is monitored

126 annually (Rivalan et al. 2010). We recorded locations and counted all nests of Amsterdam  
127 albatrosses and skuas occupied by an incubating adult. For northern rockhopper penguins,  
128 Indian yellow-nosed albatrosses and sooty albatrosses, the number of occupied nests was  
129 determined from photographs taken from fixed points during the early incubation period. The  
130 presence of a bird on a nest was considered as indicative of a breeding bird sit on top of an  
131 egg (see Weimerskirch et al. 2018 and Barbraud et al. 2020 for further details). For Antarctic  
132 terns, which breed in coastal cliffs (Segonzac 1972), we censused most of the island coastline  
133 by visual surveys. Between late November and mid-December, an observer followed the  
134 coastal contour of the island and scanned for terns' nests or displays of territorial (alarm calls  
135 against observer or skuas) or nesting behaviors (birds with prey in the beak, adults in cavities,  
136 fledglings). Shorelines that could not be accessed on foot were scanned using binoculars.  
137 Territorial pairs and occupied nests were counted.

138 For burrow-nesting seabirds we used a combination of various methods to detect breeding  
139 sites. Our aim here was to assess species presence and breeding status but not abundance.  
140 First, we used passive acoustic monitoring to determine species presence (Dufour et al. 2016).  
141 We used autonomous digital recording devices called song meters (Model SM4, Wildlife  
142 Acoustics, Inc.). Song meters were programmed to record from dusk to dawn, starting 1 h  
143 before sunset and stopping 1 h after sunrise with 15 min on/off cycles. They were deployed in  
144 suitable habitat for burrow-nesting seabirds, but also near tall grassy slopes potentially  
145 providing shelter from wind and wave noise. Song meters were deployed at 65 different sites  
146 on the island. Most (88%) deployment sites were situated near coastal cliffs and SM4 were  
147 deployed every 500 to 1000 m. We mainly targeted coastal sites as on nearby Saint-Paul  
148 Island most burrowing petrels breed near coastal cliffs (Barbraud et al. 2021). The island was  
149 then divided into a grid 500 x 500 m to report the presence of song meters and the presence of  
150 species detected (Fig. 1). At each deployment site, audio recordings were carried out for at

151 least 20 nights in summer and/or in winter between January 2021 to December 2022 in order  
152 to cover the breeding period of all potential summer and winter breeding species (Fig. 1).  
153 Data were downloaded and sonagrams were compared by a human observer with publicly  
154 available recordings to identify species identity (eBird 2022; GBIF 2022). When vocalisations  
155 were detected from acoustic recordings, we searched for burrows in a 50 m radius circle  
156 around song meters. When one or more burrows were found, we deployed camera traps near  
157 the entrance of the burrows to determine occupancy and breeding status (Bird et al. 2021).  
158 Finally, we used video cameras with external displays (burrowscopes) to check burrow  
159 contents and to record breeding status (Lavers et al. 2019). In some cases, biometric  
160 measurements and blood samples were collected when acoustic criteria and photographs from  
161 camera traps were insufficient to identify species with certainty. Birds were captured by hand  
162 in or at the entrance of the burrows and were examined for: 1) presence/absence of brood  
163 patch, 2) morphometric measurements (bill length, bill width, bill depth and tarsus length with  
164 calipers  $\pm 0.1$  mm, wing length with a ruler  $\pm 1$  mm), 3) body mass (using a Pesola spring  
165 scale  $\pm 1$  g). A blood sample from the alar vein was taken after capture of the bird using a 25-  
166 gauge needle. Blood samples were stored on FTA cards until analysis. Birds were released at  
167 the entrance of the burrow immediately after processing. The entire process took around five  
168 minutes.

169 Opportunistic observations of birds not monitored in surveys described above were also  
170 recorded. For each opportunistic observation, number of individuals, date, time and GPS  
171 position were recorded.

172 For all species the breeding status was assigned according to the following criteria: a  
173 confirmed breeder was an individual seen with an egg or a chick or heard during all or most of  
174 the breeding season, a probable breeder was an individual seen in a burrow but without an egg



175 or chick or heard during a part of breeding season, a probable nonbreeder was an individual  
176 heard on rare occasions.

177 DNA was extracted from a blood sample obtained from an individual of genus *Pterodroma*  
178 suspected to be Juan Fernandez petrel *Pterodroma externa* (shown in Fig. 3) using an  
179 E.Z.N.A. Tissue DNA Kit (Omega Bio-Tek, Norcross, GA, USA). For this specimen, A 649bp  
180 fragment of cytochrome *b* was amplified by polymerase chain reaction (PCR) using primers  
181 aCytbPro5F-aCytbPro9R detailed in Pyle et al. (2011) in 15 $\mu$ L reaction volumes containing  
182 7.5 $\mu$ L 2x *Taq* PCR master mix (Qiagen, Hilden, Germany), 0.5 $\mu$ M of each primer, 4.5 $\mu$ L  
183 dH<sub>2</sub>O, and 2 $\mu$ L of template DNA. Cycling conditions followed instructions for the Qiagen  
184 *Taq* PCR master mix. PCR products were cleaned using ExoSAP-IT (Applied Biosystems,  
185 Waltham, MA, USA), and sequenced in both directions using an Applied Biosystems 3730  
186 DNA Analyzer. To confirm species identity, the obtained cytochrome *b* sequence was  
187 searched against the BLAST database (Altschul et al. 1990). Additionally, the sequence was  
188 aligned with sequences of other *Pterodroma* species and *Aphrodroma brevirostris* as an  
189 outgroup obtained from GenBank (Table S1). A phylogenetic tree was built under maximum  
190 likelihood using RAxML-NG 1.1.0 (Kozlov et al. 2019) with the GTR+I+G substitution  
191 model and 20 independent searches.

192

## 193 **Results**

194 Counts of occupied nest sites (and territorial pairs for terns) of surface-nesting species are  
195 shown in Table 1. The most abundant species was the Indian yellow-nosed albatross with  $\approx$  29  
196 700 breeding pairs, followed by the Northern rockhopper penguin ( $\approx$  4 100 breeding pairs)  
197 and the Sooty albatross with  $\approx$  500 breeding pairs. Other species were less abundant with <  
198 100 breeding paris.

199 A total of 4279 recording days were obtained from song meters, resulting in 21 395 h of  
200 recordings which were analysed. About 81% of sampled cells revealed acoustic contacts (34  
201 revealed acoustic contacts out a total of 42 grid cells with song meters). This resulted in 2359  
202 acoustic contacts corresponding to burrow-nesting seabird species (Table 2). Combining  
203 results obtained from all survey methods, a total of 11 burrow-nesting species were detected,  
204 of which six were breeding, two probably breeding and three likely not breeding (Table 3,  
205 Fig. 2). Eight of these burrow-nesting species were previously unrecorded from Amsterdam  
206 either as breeders or probable breeders or on land: the flesh-footed shearwater *Ardenna*  
207 *carneipes*, sooty shearwater *A. grisea*, Juan Fernandez petrel, black-winged petrel *P.*  
208 *nigripennis*, great-winged petrel *P. macroptera*, Spectacled petrel *Procellaria conspicillata*  
209 (Appendix S8), black-bellied storm petrel *Fregetta tropica*, and common diving petrel  
210 *Pelecanoides urinatrix*. Only one individual identified as a Juan Fernandez petrel (Fig. 3)  
211 could be captured in February 2022 for measurements (Table 4) and blood sampling.

212 Searching the obtained cytochrome *b* sequence of this *Pterodroma* individual against the  
213 BLAST database identified the best match as *Pterodroma externa* (GenBank accession  
214 U74339) with one substitution and 99.85% sequence identity. The next closest matches were  
215 two Galapagos petrel *P. phaeopygia* individuals (GenBank accessions HQ420319 and  
216 HQ420332) with 12 substitutions and 98.15% sequence identity. In a phylogenetic tree the  
217 individual placed with the *P. externa* individual found by BLAST searching, and these two  
218 sequences were sister to individuals of *P. phaeopygia* and Hawaiian petrel *P. sandwichensis*  
219 (Fig. 4). These results confirmed the identity of this individual as Juan Fernandez petrel.

220 A total of seven burrows used by flesh-footed shearwaters and between three and five  
221 burrows used by sooty shearwaters were detected with camera-traps. Data indicated the regular  
222 presence of birds at these burrows throughout the breeding season and territorial behaviour  
223 and matings were filmed. However, most of burrows were too deep to reach the nest chamber

224 using the burrowscope. One breeder of sooty shearwater with an egg was observed in one  
225 burrow with the burrowscope in December 2021. In the same period, an adult flesh-footed  
226 shearwater was observed in a burrow. Later in the season (early February) two young downy  
227 chicks were seen in these same two burrows. However, breeding was unsuccessful as no chick  
228 was later observed, neither during burrowscope inspection nor on views obtained from  
229 camera-traps placed in front of burrow. From camera-traps, up to three adults morphologically  
230 similar to the identified Juan-Fernandez petrel were observed on several occasions vocalizing  
231 and making courtships near a burrow, and one individual was observed digging another  
232 burrow nearby. However, the nest chamber was too deep for the burrowscope and could not be  
233 inspected. No chick or fledgling was detected on views taken by camera-traps.

234 One burrow frequented by a great-winged petrel and four burrows frequented by grey  
235 petrels were detected in cliffs but were inaccessible to be inspected using a burrowscope. One  
236 spectacled petrel was observed in flight at dusk in late April 2022 but was not re-observed  
237 later.

238

## 239 **Discussion**

240 Before this study, nine seabird species were known to breed regularly on Amsterdam (Duriez  
241 and Delord 2012) all of which were detected during our survey. Although in 2012, one pair of  
242 northern giant petrels *Macronectes halli* was breeding on Amsterdam and one pair of  
243 australasian gannets *Morus serrator* was reported trying to breed (Demay et al. 2014; CEBC  
244 unpublished data), none of these species were observed breeding during our survey in 2021  
245 and 2022.

246 We detected eight seabird species previously unrecorded from Amsterdam, all  
247 Procellariiformes and all burrow nesting species. These included two *Ardenna* shearwaters,  
248 three *Pterodroma*, one *Procellaria*, one *Pelecanoides*, and one *Fregetta* species. Among these

249 new recorded species, at least five were frequently detected during most of the breeding  
250 season with individuals regularly observed frequenting burrows. Therefore, it is extremely  
251 likely that these species were breeding on Amsterdam, although breeding could be confirmed  
252 only for the flesh-footed shearwater and sooty shearwater with individuals observed  
253 incubating an egg or a chick. We discuss below these new and confirmed records of  
254 burrowing species and changes in numbers of surface nesting species.

255 *Antarctic tern*. This species breeds on islands throughout the Southern Ocean and the  
256 Antarctic Peninsula (Harrison et al. 2021). Although breeding colonies were reported since  
257 the early 1930s on Amsterdam (Aubert de la Rüe 1932) there is no accurate count of the  
258 island breeding population. During our survey all coastal areas were prospected except about  
259 half of the length of the western coast which remains inaccessible. Thus, our estimate of 92  
260 territorial pairs and occupied nests was considered as a minimum of number of breeding pairs.  
261 The breeding population on nearby Saint-Paul with more than 500 pairs in 2018 have  
262 dramatically increased following the eradication of black rats (*Rattus rattus*) (Barbraud et al.  
263 2021).

264 *Subtropical brown skua*. This subspecies breeds on Tristan and Gough archipelagos and on  
265 Amsterdam and Saint-Paul (Harrison et al. 2021; Barbraud et al. 2021). The breeding  
266 population at Amsterdam has been increasing since the early 1970s when less than 10 pairs  
267 were breeding on the island (Segonzac 1972). The species was persecuted until it was  
268 declared protected in 1972 by the Terres Australes et Antarctiques Françaises administration.  
269 Since then, breeding numbers have increased from 15 pairs in 1983 to 78 in 2021

270 corresponding to a 1.04 (*i. e.*  $\frac{78}{15}^{\left(\frac{1}{38}\right)}$ ) annual population growth rate. Several factors may  
271 explain this increase, such as the protected species status and the sharp increase of  
272 subantarctic fur seals *Arctocephalus tropicalis* (Guinet et al. 1994; Pacoureaux et al. 2017) as  
273 skuas feed on seal placentas and carcasses.

274 *Northern rockhopper penguin*. In the southern Indian Ocean this species breeds only on  
275 Amsterdam and Saint-Paul (Harrison et al. 2021). Other breeding localities are situated in the  
276 southern Atlantic Ocean (Tristan da Cunha and Gough Islands). Results of the 2022 count  
277 indicate that the population decline is ongoing on Amsterdam, with a 66% decrease in the  
278 number of breeding pairs since 2015 (i.e. a 12% annual decline) when 12 161 breeding pairs  
279 were counted (Barbraud et al. 2020). The decline of northern rockhopper penguins at  
280 Amsterdam has probably occurred since the early 1950s. Segonzac (1972) estimated the entire  
281 Amsterdam population at 100 000 breeding pairs in the early 1970s, and there is evidence that  
282 one colony went extinct between the early 1950s and the early 1980s. The causes of decline  
283 were discussed in Barbraud et al. (2020) and include predation of eggs and chicks by  
284 introduced Norway rats and feral cats and by native subtropical brown skuas, and infectious  
285 agents (*Pasteurella multocida* and *Erysipelothrix rhusiopathiae*). However, the decline was  
286 relatively important (29%) between 2021 (5791 breeding pairs) and 2022 and may have partly  
287 resulted from an additional cause of mortality. Indeed, in February 2021, while adult northern  
288 rockhopper penguins were molting on Amsterdam, a fire occurred in Entrecasteaux cliffs  
289 where most penguins molt. Short visits to this site after the fire revealed the presence of burnt  
290 corpses of penguins on molting sites hit by the fire.

291 *Amsterdam albatross*. This endemic species from Amsterdam Island has been increasing  
292 since its discovery in the early 1980s (Jaeger et al. 2018), and our count data indicate that the  
293 population is still growing with a record number of 65 breeding pairs in 2022. Although the at  
294 sea distribution of this species largely overlaps with long-line fisheries (Thiebot et al. 2014),  
295 individuals are not or very poorly susceptible to bycatch (Rivalan et al. 2010; Corbeau et al.  
296 2021). Moreover, this species does not seem to be impacted by infectious diseases present on  
297 Amsterdam or by introduced predators (Jaeger et al. 2018).

298 *Sooty albatross*. This species breeds on several islands of the southern Indian and Atlantic  
299 oceans (Harrison et al. 2021). Only three counts of the entire breeding population are  
300 available for Amsterdam (2003: 474 pairs, 2012: 394 pairs; this study: 515 pairs). Thus,  
301 although a previous study based on counts of the entire population suggested a decrease over  
302 the past 20 years (Weimerskirch et al. 2018), our recent population count and data from  
303 demographic study plots (Jaeger et al. 2018) rather suggest a stable population on Amsterdam.  
304 *Indian yellow-nosed albatross*. The species breeds on several islands of the Crozet,  
305 Kerguelen, Marion and Prince Edward archipelagos in addition to Amsterdam and Saint-Paul  
306 (Harrison et al. 2021). The population on Amsterdam Island has been decreasing over the last  
307 34 years (Weimerskirch et al. 2018) mainly due to infectious disease and predation by  
308 introduced mammals (Jaeger et al. 2018). Yet, compared to previous counts of the entire  
309 population in 2006 ( $\approx 27\,000$  pairs) and 2015 ( $\approx 22\,800$  pairs), our count in september 2021  
310 suggests that the population trend is relatively stable during the past 15 years despite these  
311 persisting threats. Contrary to northern rockhopper penguins, adult Indian yellow-nosed  
312 albatrosses were poorly affected by the fire at Entrecasteaux cliffs in February 2021, where  
313 only chicks died from fire resulting in a very low breeding success (2 %, CEBC unpublished  
314 data). Thus, the relatively high number of breeding pairs in 2021 may be partly due to the  
315 high breeding propensity of individuals that failed earlier during that year.

316 *Black-bellied storm-petrel*. The species breeds on several Antarctic and subantarctic islands  
317 as well as on Tristan da Cunha and Gough Islands (Harrison et al. 2021). The taxonomy of  
318 *Fregatta* storm petrels is highly debated, as *F. tropica* and *F. grallaria* co-occur at some  
319 localities and because of plumage polymorphism in *F. grallaria* (Robertson et al. 2016).  
320 However, both species can be easily differentiated from sonagrams, and the sonagram from  
321 Amsterdam matches well with a black-bellied storm petrel. There is no fossil remain  
322 corresponding to black-bellied storm petrel on Amsterdam (Worthy and Jouventin 1999), and

323 the species is only rarely observed at-sea nearby the island, generally in April (Roux and  
324 Martinez 1987; CEBC unpublished data). However, an individual with an incubation patch  
325 was captured on Saint-Paul in December 2018 (Appendix S1; C. Barbraud and K. Delord  
326 unpublished data) and another was also captured in December 2017 (H. Weimerskirch pers.  
327 comm.). This, combined with the acoustic contacts detected during our survey in May,  
328 October, and December, although they were few, indicate that individuals visit Amsterdam  
329 and Saint-Paul, and eventually suggest the possibility that the species breeds in few numbers  
330 on these islands.

331 *Macgillivray's prion*. Macgillivray's prion was known from a single population on Saint-  
332 Paul but recent genetic and morphological studies found that Gough Island medium-billed  
333 prions belong to the same evolutionary lineage as *macgillivrayi*, representing a new  
334 population of Macgillivray's prion that originated through a colonization event from Saint-  
335 Paul (Masello et al. 2022). Macgillivray's prions breed in high numbers (several 100 000s  
336 pairs) on Gough Island in the South Atlantic where they were recently discovered (Masello et  
337 al. 2022). On Amsterdam, we only recorded this species in January and October with very few  
338 contacts. Macgillivray's prions were breeding in high numbers on Amsterdam as evidenced by  
339 the abundant fossil record (Worthy and Jouventin, 1999), and are still known to breed as a  
340 relict population due to the presence of introduced mammalian predators (Jouventin 1994).  
341 Our few observations of this species suggest that the detected individuals were likely not  
342 breeding or were prospectors visiting the island. Indeed, breeding numbers on the nearby  
343 Saint-Paul Island have largely increased over the past 20 years following the eradication of  
344 black rats (Barbraud et al. 2021). Moreover, remains of Macgillivray's prions have been found  
345 in pellets of brown skuas on Amsterdam Island in 2019 and 2020 (CEBC unpublished data).

346 *Black-winged petrel*. The species breeds on several islands of the Southwest Pacific where  
347 it is abundant (Harrison et al. 2021) and seems to be expanding into the Indian Ocean with

348 birds seen breeding on Round Island off Mauritius (Brooke 2004), several individuals  
349 observed on Saint-Paul (Thiebot et al. 2010; Bigonneau 2013), and two sightings made at-sea  
350  $\approx$ 300 km northwest of Amsterdam and Saint-Paul in November 2018 (C. Barbraud  
351 unpublished data). Our single acoustic record in January suggests that the species is likely not  
352 breeding on Amsterdam but shows that individuals are visiting the island. Yet, we cannot  
353 entirely exclude that a breeding population of black-winged petrels could have been  
354 overlooked on Amsterdam or Saint-Paul (Thiebot et al. 2010).

355 *Juan Fernandez petrel*. This endemic species breeds at Juan Fernandez Island (Southeast  
356 Pacific) in high numbers (Brooke 2004) and the population appears stable (Hodum 2009). The  
357 species is one of the most commonly sighted seabirds in the subtropical southeast Pacific  
358 Ocean (Balance et al. 1997), and during breeding individuals undertake northward trans-  
359 equatorial migration in the North Pacific (Carboneras et al. 2020). Thus, our record at  
360 Amsterdam is well outside the expected range of the species. Nevertheless, recent records in  
361 French Polynesia (Flood et al. 2021), and in Chatham Islands and Tristan da Cunha (Imber et  
362 al. 1991; Miskelly 2013; Harrison et al. 2021) provide evidence that it very occasionally  
363 ranges westward at mid latitudes. Our data show the regular presence of the species on  
364 Amsterdam from December to May, thus covering most of the known breeding season at Juan  
365 Fernandez (September to May). Observations of several individuals in burrows strongly  
366 suggest that the species breeds on Amsterdam. Given that the species was never observed at  
367 sea offshore Amsterdam and Saint-Paul, it is likely that this constitutes a relatively recent  
368 colonization event. Interestingly, Worthy and Jouventin (1999) indicated the former presence  
369 of one large *Pterodroma* species on Amsterdam based on fossil remains, potentially  
370 corresponding to the size of *P. externa*. Worthy and Jouventin (1999) attributed these fossil  
371 bones to *P. macroptera*, but our record suggests that some may belong to *P. externa*. Genetic  
372 analyses of fossil bones are needed to confirm this suspicion. Yet, we cannot exclude that a



373 breeding population of Juan Fernandez petrel could have been overlooked as Amsterdam  
374 surveys have been incomplete. Observations at dusk of a large gadfly petrel with whitish  
375 underparts on Amsterdam in January and February 2003 (T. Deville pers. comm.) may  
376 correspond to a Juan Fernandez petrel, and similar observations made on Saint-Paul in April  
377 2013 with an individual observed landing in a cliff, which may suggest that the species is also  
378 present on Saint-Paul (Bigonneau 2013). Moreover, one sighting at-sea  $\approx$ 800 km north of  
379 Crozet in January 2003 and 2 sightings  $\approx$ 1400 km and  $\approx$ 1700 km northwest of Kerguelen in  
380 February 2004 indicate the presence of the species in the Indian Ocean (CEBC unpublished  
381 data).

382 *Soft-plumaged petrel*. This species breeds in several islands of the Southern Ocean, *i.e.*  
383 Gough, Tristan da Cunha, Antipodes and Maatsuyker (Tasmania) islands (Harrison et al.  
384 2021). Soft-plumaged petrel is known to persist as a breeding species on Amsterdam (Roux  
385 and Martinez 1987; Bretagnolle 1995) but suffers from predation by rats and cats on adults,  
386 eggs and chicks (Roux and Martinez 1987). Fossil remains suggest that the species was  
387 abundant on Amsterdam (Worthy and Jouventin 1999). Our data show the regular presence of  
388 the species almost all year round, from July to April, with a peak of contact records from  
389 October to December. Observations of several individuals in burrows with camera-traps from  
390 our survey, regular visual and auditory records, and remains of skulls predated by cats or rats  
391 (CEBC unpublished data) indicate that the species still breeds on Amsterdam. An adult soft-  
392 plumaged petrel was captured on Saint-Paul after calls of the species were heard (Thiebot et  
393 al. 2010), but breeding has not been confirmed (Barbraud et al. 2021).

394 *Great-winged petrel*. This species breeds on several subantarctic islands, Southwest  
395 Australia, Amsterdam and Saint-Paul, Tristan da Cunha and Gough (Harrison et al. 2021).  
396 Abundant fossil remains suggest that great-winged petrels were formerly abundant on  
397 Amsterdam (Worthy and Jouventin 1999). The species is regularly seen offshore Amsterdam

398 from February to April and between July and September (Roux and Martinez 1987; CEBC  
399 unpublished data) and has been regularly recorded during the austral winter on Amsterdam  
400 since the 1980s (Thiebot 2011; CEBC unpublished data). Our data show the regular presence  
401 of the species on Amsterdam from February to July. Observation of an occupied burrow and  
402 of individuals with camera-traps from our survey indicates that species still breeds on  
403 Amsterdam. Great-winged petrels breed on Saint-Paul with 130-150 occupied burrows  
404 (Barbraud et al. 2021).

405 *Grey petrel*. The species breeds on many islands of the Southern Ocean and South Atlantic  
406 as well as Antipodes and Campbell Islands in the Pacific (Harrison et al. 2021). Our data  
407 confirm that the species breeds on Amsterdam as it was frequently recorded and observed  
408 entering burrows from February to September. The species has regularly been observed at  
409 dusk flying on land or entering burrows (Daycart and Furet 1986; Roux and Martinez 1987;  
410 Duriez et al. 2005; Thiebot 2011; CEBC unpublished data) where it it breeds in small  
411 numbers (Jouventin 1994), a remnant of what may once have been a much larger population  
412 (Worthy and Jouventin 1999). However, the species frequent areas in steep slopes and cliffs  
413 making the access to burrows extremely difficult. It is also a probable breeder in small  
414 numbers on Saint-Paul (Barbraud et al. 2021).

415 *Spectacled petrel*. Only one visual observation on land was made in April, thus outside the  
416 breeding season, and no acoustic or camera-trap record was obtained for this species.  
417 Therefore, it is likely not breeding on Amsterdam and no fossil remain was found (Worthy  
418 and Jouventin 1999) suggesting it has never bred or perhaps in extremely small numbers. The  
419 species is endemic from Inaccessible Island (Tristan da Cunha) in the South Atlantic, where  
420 its breeding numbers are increasing following the eradication of feral pigs *Sus scrofa* (Ryan et  
421 al. 2019). Tracking studies suggest that the species stays in the southern Atlantic Ocean during  
422 both the breeding and non-breeding periods (Reid et al. 2014; Bugoni et al. 2009), albeit

423 sample sizes of tracked individuals were low. Nevertheless, spectacled petrels appear to  
424 frequent occasionally the Indian Ocean as individuals are very occasionally observed  
425 offshore Amsterdam (Shirihai 2009, N. Gasco pers. comm.) and Kerguelen (Gasco et al.  
426 2019).

427 *Flesh-footed shearwater*. The main breeding populations are situated on islands off South  
428 and Western Australia and north New Zealand to Cook Strait where they have been declining  
429 (Waugh et al. 2013; Lavers 2015). Although the species breeds on Saint-Paul, there were very  
430 few observational records on Amsterdam, apart from fossil records suggesting that the species  
431 formerly bred (Worthy and Jouventin 1999). One adult was captured on Amsterdam in 1953  
432 (Segonzac 1972), and another was found on the ground nearby the Martin de Vivies research  
433 station in October 2016 (CEBC unpublished data), but their status was unknown. The  
434 discovery of a chick is proof that the species reproduces in Amsterdam. The species may have  
435 gone locally extinct and has been recolonizing the island relatively recently. Indeed, the  
436 population of flesh-footed shearwaters has been increasing on Saint-Paul since the early  
437 1980s where at least 2000 pairs were breeding in 2018 (Barbraud et al. 2021).

438 *Sooty shearwater*. This species occurs in all oceans and breeds in South Chile, Falkland  
439 Islands, Tristan da Cunha, Southeast Australia and New Zealand (Harrison et al. 2021).  
440 Although this is an extremely numerous species there are persistent signs of current decline  
441 (Brooke 2004; Waugh et al. 2013). This new breeding species for Amsterdam was only known  
442 from extremely few fossils remains (Worthy and Jouventin 1999) and occasional observations  
443 at sea offshore Amsterdam and Saint-Paul (Roux and Martinez 1987; Duriez et al. 2005;  
444 CEBC unpublished data). Therefore, as for the flesh-footed shearwater, it is possible that the  
445 species was breeding on Amsterdam but in very few numbers and remained undetected or that  
446 it went locally extinct and has been recolonizing the island relatively recently.

447        *Common diving petrel*. This species breeds in high numbers on subantarctic and  
448 subtropical islands of the Southern Hemisphere (Harrison et al. 2021). Fossil remains were  
449 found at several places, suggesting the species formerly bred at Amsterdam (Worthy and  
450 Jouventin 1999). A female was captured in November 1955 (Segonzac 1972), a dead  
451 individual was found in December 1984 (Roux and Martinez 1987) and Micol and Jouventin  
452 (1995) suspected that the species breeds at Amsterdam. Acoustic records from our survey  
453 indicate the regular presence common diving petrels during the breeding season from August  
454 to December, which suggests that a small population still breeds on Amsterdam. Surprisingly,  
455 there is only one at-sea observation of the species  $\approx 300$  km south of Amsterdam, and the  
456 species has never been observed on or nearby Saint-Paul (CEBC unpublished data). Indeed,  
457 the species breeds at Tristan da Cunha, where it is regularly observed at-sea (Ryan et al.  
458 2022), but breeding numbers are relatively high at this locality (Brooke 2004). During  
459 breeding, the foraging range of common diving petrel can reach more than 200 km (Fromant  
460 et al. 2021) and individuals come back to colonies at night to avoid predators. This and the  
461 likely very small breeding numbers on Amsterdam might explain the quasi-absence of at-sea  
462 observations.

463        To conclude, this pre-eradication survey on Amsterdam revealed the presence of five  
464 unrecorded species and suggests the breeding of four additional species compared to Duriez  
465 and Delord (2012), the island totalizing at least 14 breeding seabird species. Acoustic  
466 recording devices were extremely useful to identify and locate burrow-nesting and nocturnal  
467 species, offering several advantages such as being easy to deploy and retrieve and recording  
468 simultaneously at multiple sites (Buxton and Jones 2012). Other surveys are needed to better  
469 evaluate the breeding status of some of these species and to obtain tissue samples to assess the  
470 phylogenetic status of their populations. Surprisingly, we did not detect the presence of  
471 species for which relatively abundant fossil bones were found, as the little shearwater

472 (*Puffinus assimilis*), white-faced storm petrel (*Pelagodroma marina*), and white-bellied storm  
473 petrel (*Fregetta grallaria*) (Worthy and Jouventin 1999). It is also surprising to note that some  
474 species breeding on Saint-Paul (85 km away) were not identified on Amsterdam: the white-  
475 bellied petrels (*Fregetta grallaria*), fairy prion (*Pachyptila turtur*), and especially the  
476 subantarctic shearwater (*Puffinus elegans*) that is increasing on Saint-Paul, (Barbraud et al.  
477 2021). Individuals assumed to belong to *Puffinus assimilis* were observed in flight on  
478 Amsterdam in 1956 (Segonzac 1972), but there is no recent record on any of the two islands.  
479 Fresh remains of white-faced storm petrels are regularly found in pellets of brown skuas on  
480 Amsterdam (CEBC unpublished data) suggesting the presence of the species on the island, yet  
481 to be discovered. Finally, based on these new records and on seabird population trends  
482 observed on Saint-Paul following eradication of invasive mammals (Barbraud et al. 2021), the  
483 introduced mammal eradication campaign on Amsterdam will be extremely beneficial for  
484 seabird conservation, if successful, and may also favor the colonization of Amsterdam by new  
485 seabird species in the future.

486

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493

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648 **Table 1** Numbers of occupied nest sites (including territorial pairs for Antarctic terns) of surface-nesting seabird species on Amsterdam Island. \*

649 indicates that the survey was incomplete for this species. LC: least concern, EN: endangered

Common name	Scientific name	IUCN status	Occupied nest sites	Year
Antarctic tern	<i>Sterna vittata</i>	LC	92*	2021
Subtropical brown skua	<i>Catharacta antarctica hamiltoni</i>	LC	78	2021
Northern rockhopper penguin	<i>Eudyptes moseleyi</i>	EN	4 109	2022
Amsterdam albatross	<i>Diomedea amsterdamensis</i>	EN	65	2022
Sooty albatross	<i>Phoebastria fusca</i>	EN	515	2022
Indian yellow-nosed albatross	<i>Thalassarche carteri</i>	EN	29 671	2021

650 **Table 2** Number of acoustic contacts obtained for burrow-nesting seabirds using song meters between January 2021 and December 2022 on  
651 Amsterdam Island. Also indicated is the number of 500 x 500 m cells in which the species was detected. \*Calls of flesh-footed shearwaters and  
652 sooty shearwaters are very similar and could not always be distinguished on the recordings obtained from sing meters. LC: least concern, NT:  
653 near threatened, VU: vulnerable, CR: critically endangered

Common name	Scientific name	IUCN status	N of acoustic contacts	N of cells	
Black-bellied storm petrel	<i>Fregetta tropica</i>	LC	3	3	Appendix S1
Macgillivray's prion	<i>Pachyptila macgillivrayi</i>	CR	2	2	Appendix S2
Black-winged petrel	<i>Pterodroma nigripennis</i>	LC	1	1	Appendix S3
Juan Fernandez petrel	<i>Pterodroma externa</i>	VU	155	2	Appendix S4
Soft-plumaged petrel	<i>Pterodroma mollis</i>	LC	594	21	Appendix S5
Great-winged petrel	<i>Pterodroma macroptera</i>	LC	903	20	Appendix S6
Grey petrel	<i>Procellaria cinerea</i>	NT	157	15	Appendix S7
Flesh-footed shearwater	<i>Ardenna carneipes</i>	NT	36	2	Appendix S9
Sooty/Flesh-footed shearwater*	<i>Ardenna grisea/carneipes</i>	NT	453	4	Appendix S10
Common diving petrel	<i>Pelecanoides urinatrix</i>	LC	35	6	Appendix S11
Undetermined species			20		

654 **Table 3** Burrow-nesting species detected in Amsterdam Island between January 2021 and December 2022. B: confirmed breeder; B\*: probable  
655 breeder; NB\*: probable nonbreeder. Numbers indicate the number of contacts obtained from all survey methods combined, empty cells indicate  
656 that the species was not detected, grey cells indicate the breeding period from arrival to the colonies to chick fledging from Brooke (2004). A:  
657 identified from acoustic sonagram; CT: identified from camera-trap; V: observed on land (with binoculars or not); S: observed using a  
658 burrowscope; G: identification confirmed based on genetic analysis. Bold characters indicate new records for Amsterdam Island

Species	Status	Detection method	Detection between January and December												
			J	F	M	A	M	J	J	A	S	O	N	D	
Macgillivray's prion <i>Pachyptila macgillivrayi</i>	B	A	1										1		
<b>Spectacled petrel</b> <i>Procellaria conspicillata</i>	<b>NB*</b>	<b>V</b>				<b>1</b>									
Grey petrel <i>Procellaria cinerea</i>	B	A, V		1	9	89	49	13	7	3	8				
Flesh-footed shearwater <i>Ardenna carneipes</i>	B	A, CT, V, S	107	106	16	7						62	178	90	70
<b>Sooty shearwater</b> <i>Ardenna grisea</i>	<b>B</b>	<b>A, CT, V, S</b>	<b>65</b>	<b>79</b>	<b>5</b>								<b>22</b>	<b>51</b>	<b>31</b>

<b>Juan Fernandez Petrel</b> <i>Pterodroma externa</i>	<b>B</b>	<b>A, CT, V, S, G</b>	<b>75</b>	<b>86</b>	<b>85</b>	<b>64</b>	<b>9</b>						<b>34</b>
Soft-plumaged petrel <i>Pterodroma mollis</i>	<b>B</b>	<b>A, CT, V</b>	<b>7</b>	<b>3</b>	<b>1</b>	<b>4</b>		<b>9</b>	<b>40</b>	<b>85</b>	<b>152</b>	<b>180</b>	<b>133</b>
Great-winged petrel <i>Pterodroma macroptera</i>	<b>B</b>	<b>A, V</b>		<b>9</b>	<b>184</b>	<b>275</b>	<b>328</b>	<b>102</b>	<b>10</b>				
<b>Black-winged petrel</b> <i>Pterodroma nigripennis</i>	<b>NB*</b>	<b>A</b>	<b>1</b>										
<b>Black-bellied storm-petrel</b> <i>Fregatta tropica</i>	<b>NB*</b>	<b>A</b>					<b>1</b>				<b>1</b>		<b>1</b>
Common diving-petrel <i>Pelecanoides urinatrix</i>	<b>B*</b>	<b>A</b>							<b>1</b>	<b>8</b>	<b>25</b>	<b>2</b>	<b>1</b>

660 **Table 4** Measurements of the Juan Fernandez petrel captured on Amsterdam Island and  
661 measurements reported in Brooke (2004) with mean  $\pm$  SD (min-max)

	Amsterdam Island	Brooke (2004)
Wing length (mm)	311	319 $\pm$ 6.77 (303-329)
Tarsus length (mm)	42.2	40.1 $\pm$ 1.47 (37.1-43.4)
Bill length (mm)	37.1	38.2 $\pm$ 1.16 (35.6-41.0)
Hook height (mm)	13.8	
Head + bill length (mm)	90.1	
Body mass (g)	500	428 $\pm$ 48.8 (310-555)

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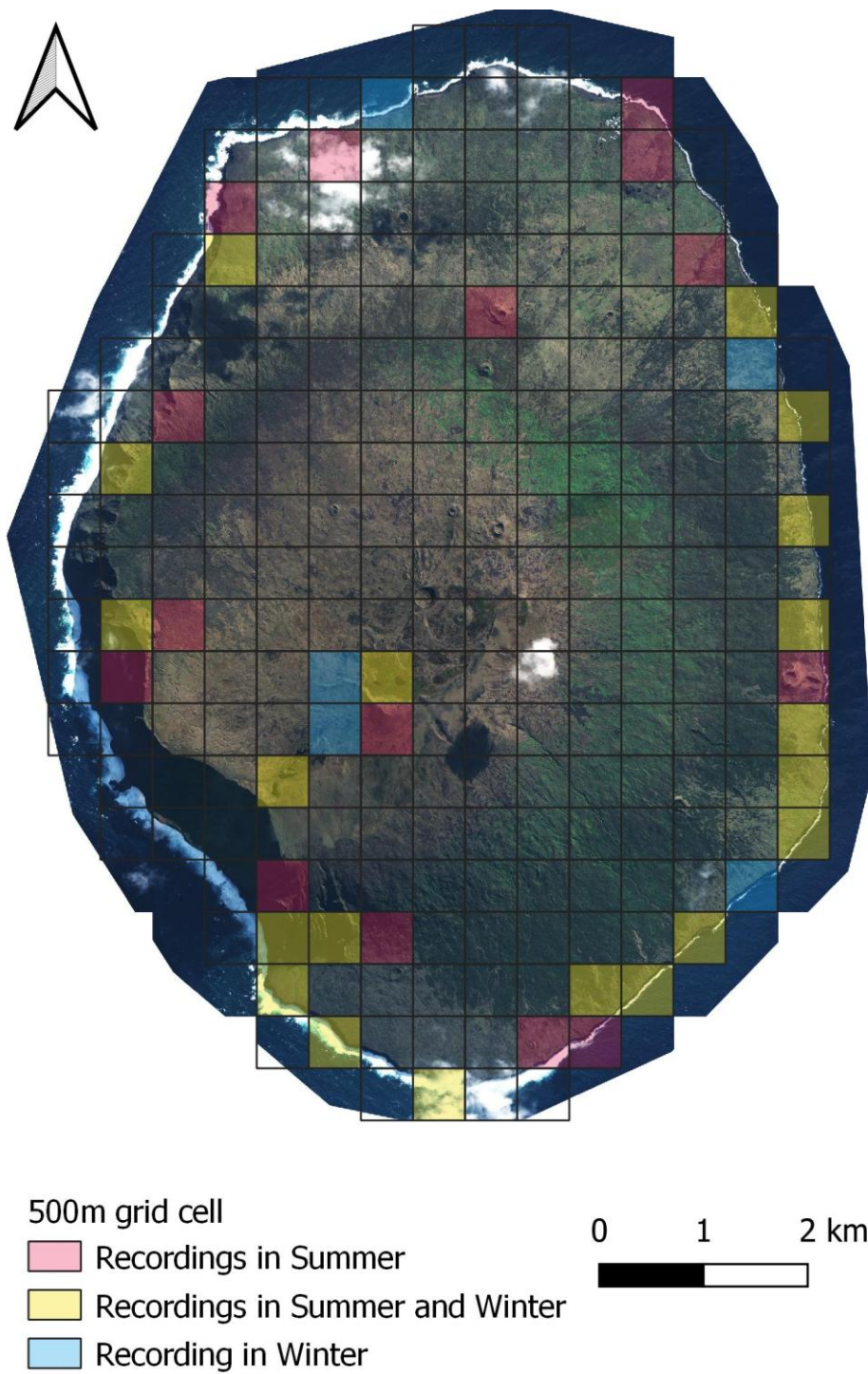
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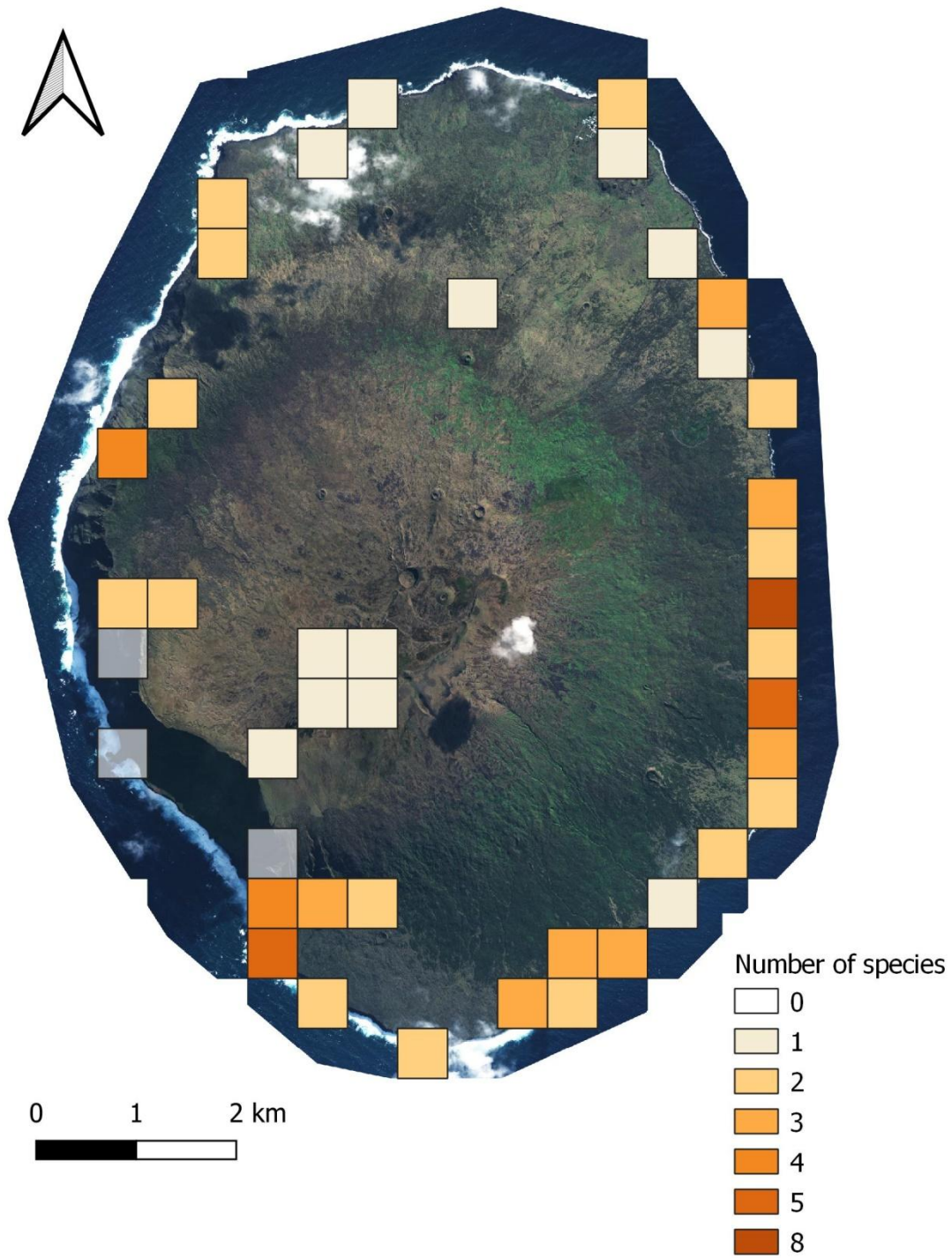
674 **Fig 1** Map of Amsterdam Island showing the localities and periods of deployment of song  
675 meters



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678 **Fig 2** Map of Amsterdam Island showing the number of burrow-nesting seabird species  
679 detected by acoustic method per 500 x 500 m grid cell



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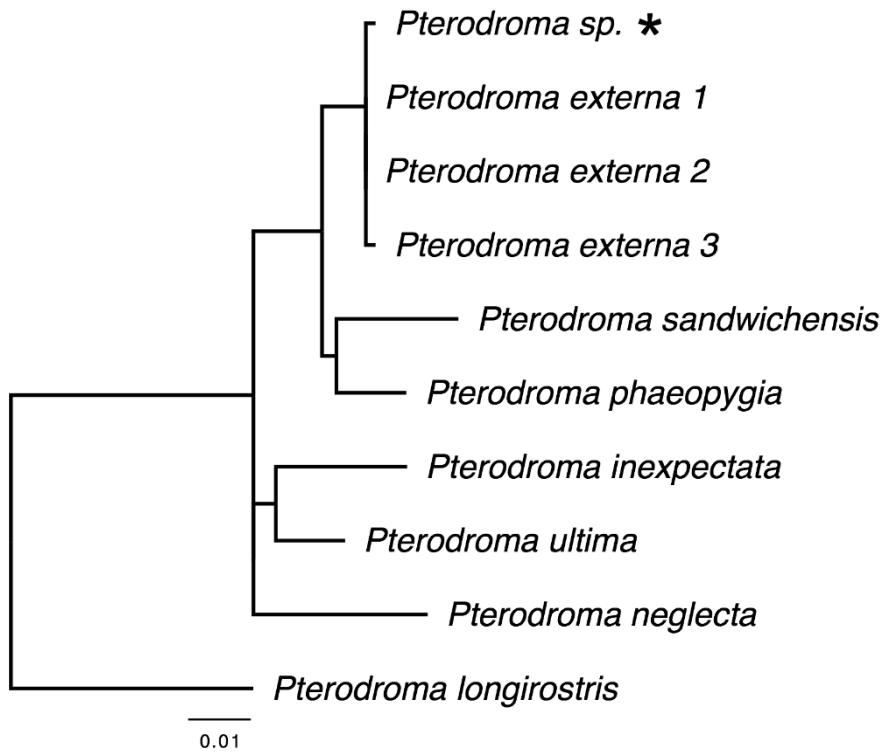
682 **Fig 3** Views of the Juan-Fernandez petrel captured on Amsterdam Island on 02 February 2022

683 (© d'Orchymont 2022)



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685 **Fig 4** A phylogenetic tree of *Pterodroma* species using the obtained cytochrome *b* sequence of  
686 the individual of interest (marked with an asterisk) and other species obtained from GenBank  
687 (Table S1)



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