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**TITLE First evidence of migration across the South Pacific in endangered Amsterdam albatross and conservation implications**

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## 1 **Introduction**

2 Many seabirds undergo long-distance migrations between their breeding and wintering areas. This is  
3 particularly the case to reach upwelling systems: across North Pacific [1,2], across South Pacific from  
4 Australia to the Humboldt Current region [3] or across South Atlantic to the Benguela/Agulhas Current  
5 region [4]. As oceanic migrants albatrosses are amongst the most globally-threatened species and have  
6 direct interaction with fishing vessels, fisheries bycatch is one of the major conservation issue worldwide  
7 [5–7].

8 Albatrosses are long-lived species (i.e. high adult survival rates, delayed sexual maturity and low  
9 fecundity) and large-sized species (i.e. *Diomedea spp.*) breed biennially if successful in fledging a chick  
10 [8]. Given these extreme life-history traits, population trajectories are highly sensitive to changes in  
11 adult mortality. Albatrosses have a wide at sea distribution and are therefore potentially threatened by  
12 a multitude of fisheries in national and international waters [4,9–12]. Naïve juvenile albatrosses disperse  
13 widely and may have distinct routes and use different areas compared to adults [13–15].

14 Among the albatrosses the Amsterdam albatross (*Diomedea amsterdamensis*) is listed among the most  
15 endangered species due to a very small population (~ 300-350 individuals; Barbraud et al. unpublished  
16 data) and being endemic to a single isolated island in the southern Indian Ocean, Amsterdam Island. It is  
17 one of the world's rarest birds. Very sensitive to additional mortality [16,17], the Amsterdam albatross is  
18 identified as a priority species to protect, especially at risk due to bycatch [18], and has benefited from  
19 two successive National Plans of Actions since 2011 (NPOA 1<sup>st</sup>: 2011- 2015, 2<sup>nd</sup>: 2018-2027). The  
20 Amsterdam albatross is a dispersive migrant known to undertake long-distance movements from  
21 eastern to western South Indian Ocean, occasionally reaching South Atlantic and therefore, crossing  
22 many fishing areas [14,19]. To our knowledge no observation of incidental catch has been reported for  
23 this species. Yet this does not imply that it is not happening especially i) in fisheries without onboard  
24 observers dedicated to bycatch or not required to report bycatch or ring recoveries, or in Illegal,

25 Unreported and Unregulated (IUU) fisheries, ii) when low percentage of hauled hooks (<5%) are being  
26 surveyed by bycatch-dedicated observers onboard vessels [20], and iii) due to identification issues.  
27 During last decades, bycatch estimates of hundreds of albatrosses were reported in the South Indian  
28 Ocean [21] and included several species at risk across the Southern Hemisphere [18].  
29 As part of a multi-year survey evaluating juvenile dispersal and immature at-sea distribution linked to  
30 the current NPOA framework for the Amsterdam albatross, the present study reports the first evidence  
31 from a single individual that Amsterdam albatross can wander for extensive periods outside the Indian  
32 Ocean, in the Pacific Ocean. This unprecedented, unexpected and novel finding is discussed in terms of  
33 overlap risk with fisheries and conservation issues.

34

## 35 **Materials and methods**

### 36 **Study species and data loggers**

37 Amsterdam Island (37° 50' S; 77° 33' E) is located in the subtropical part of the southern Indian Ocean.  
38 In this oceanic area, the southern subtropical front (SSTF) delimits the warmer subtropical from the  
39 colder sub-Antarctic waters [22]. The Amsterdam albatross, like other great albatrosses, is a biennial  
40 breeder [23,24], with high survival during juvenile, immature and adult phase [17]. Juvenile birds fledge  
41 and migrate independently from the adults in January. Immature birds may visit the colony when they  
42 are 4–7 yrs old, but generally only start breeding at 9 yrs old [16].

43 Previous study during the first months at sea of juveniles Amsterdam albatross showed an initial rapid  
44 movement taking all individuals away from the vicinity of their native colony. Then, they dispersed at  
45 large-scale in the entire southern Indian Ocean (15° to 135° E, ~ 4 500 km from the colony), through a  
46 large range of latitudinal gradient (27° to 47° S) similarly to the adults during their sabbatical period  
47 [14,19].

48 The main objective of the ongoing NPOA is to improve the conservation status of the species by  
49 removing or reducing the threats on breeding success and survival rates for the species. Planned actions  
50 concern specific objectives regarding threats on land (i.e. pathogen contamination, limitation or  
51 eradication of introduced invasive species) and at sea (i.e. at-sea distribution of different stages, habitat  
52 modelling and projection, overlap risk assessment with fisheries, implementation of the most efficient  
53 bycatch mitigation measures). Under this NPOA framework, a study was launched to gain additional  
54 knowledge on the at-sea distribution of the immature stage (between fledging and the first return on  
55 land), a period for which only very limited data exist [14, 19]. Hence, the study of juvenile birds at-sea  
56 movements was completed using Global Location Sensing (GLS; Mk15-British Antarctic Survey). GLSs  
57 record the ambient light level every 10 min, from which local sunrise and sunset hours can be inferred  
58 allowing estimating location every 12 h [25]. Locations based on light-based archival tags are associated  
59 with spatial error estimates (~200 km; [26]). Beside the accuracy of those loggers, broad-scale  
60 movements can be confidently identified and allowed us to track the birds for prolonged periods with a  
61 minimal disturbance [13]. The birds were tagged as chick ( $n = 21$ ) in 2011 before leaving the colony for  
62 the first time. To date, at year  $t+9$ , we have retrieved 12 of the 21 GLS loggers deployed (recovery rate  
63 ~57%) from which 10 individual tracks were estimated (2 loggers failed to record data), thereby allowing  
64 to extend the study of juvenile and immature stages over a period up to ~ 3.1 yrs after fledging. The  
65 present study focuses on one individual which travelled outside the Indian Ocean, revealing a new  
66 migratory pathway and bringing additional information about fisheries overlap.

67

## 68 **Data and processing**

69 Fishing data

70 To describe the overlap between the distributions of the tracked bird and fishing effort (i.e. longline and  
71 trawl), we collated the data available from the relevant regional fisheries management organisations

72 (RFMOs; Table 1, Fig. 1, Appendix A) and the Commission for the Conservation of Antarctic Marine Living  
73 Resources (CCAMLR). Note that some RFMO fishing effort datasets are very incomplete (particularly in  
74 the Indian Ocean) and can thus result in biased estimates of overlap, particularly when comparing across  
75 different RFMOs [27]. To assess the association of albatrosses with fishing vessels [28] we used Global  
76 Fishing Watch (GFW) available datasets for assessing fisheries interactions by estimating daily overlap  
77 between fishing activity (presence and intensity) and bird distribution (twice daily locations), i.e. a proxy  
78 of being at risk to incidental bycatch (Appendix A).

79

#### 80 Fishery observer data

81 The seabird observation data collected during fishing activities by the scientific onboard observers [29]  
82 were used to identify direct interactions through photo-identification of individuals ringed as part of an  
83 ongoing long-term monitoring capture-recapture study (CEBC dataset; see [17]). Observer data were  
84 collected under the French Southern Ocean Fishery Observer Program [30] and entered on board into  
85 an electronic logbook designed by the Muséum National d’Histoire Naturelle de Paris (MNHN) and then  
86 uploaded in an 11G Oracle database named “PECHEKER” hosted and managed by MNHN [29].

87

#### 88 Analysis of light data

89 We used the FLightR R package [31,32] to determine post-fledging migration movements and timing.  
90 FLightR uses the slope of the light curve around twilight to estimate locations. We defined twilights with  
91 the *preprocessLight* function followed by an additional automated screening using the *twilightEdit*  
92 function, in the TwGeos [33] R package (Appendix A).

93

#### 94 Overlap with fisheries

95 The number of GLS locations situated in High Seas, RFMOs and Exclusive Economic Zones (EEZs) areas  
96 were counted using R software (version 4.0.4) in order to assess the percentage of the entire movement  
97 in each area. Then, the GLS locations of the albatross were aggregated in visited cells, according to the  
98 spatial accuracy of the fishing data. This spatial overlap based on the common centroids of the cells was  
99 completed by a temporal join to assess the concomitant use of the same cell by the bird and the fishing  
100 vessels (e.g. proxy of being at risk to incidental bycatch, see Appendix A).

101

## 102 **Results**

103 Out of the ten juvenile individuals with recorded tracks, nine distributed entirely in the southern Indian  
104 Ocean during their first years at sea (not illustrated, see [19]). However, surprisingly, one travelled  
105 outside the Indian Ocean, providing the first evidence that Amsterdam albatross can wander in the  
106 Pacific Ocean (Fig. 1). Before its GLS tag stopped (1176 days after leaving the colony), this individual  
107 travelled a total distance of ~185 800 km and went as far as 12 915 km away from its colony. During its  
108 first three years at sea, this individual crossed two Ocean basins: the Indian Ocean and the Pacific  
109 Ocean. It distributed mainly in the southern Indian Ocean (~66% of locations), but in a totally  
110 unexpected way it also spent a large part of its time in the southern Pacific Ocean (~34%), the rest being  
111 distributed among the global Southern Ocean (<~1%). The bird spent its first 793 days (06/12/2011 to  
112 06/02/2014) in the Indian Ocean basin and the next 383 days in the Pacific Ocean basin (06/02/2014 to  
113 24/02/2015). The latitudinal range expanded between -22.8°S to -54.8°S. As the device stopped  
114 recording off the Chilean coast (10 696 km away from Amsterdam Island), the return journey to the  
115 colony was not completed (Fig. 1).

116 The bird distributed mainly in high seas (78% of the locations) and within 13 EEZs (22% of locations;  
117 Appendix Table S1 & S2). In high seas, its distribution overlapped with seven RFMOs (3 targeting tuna-  
118 like species and 3 targeting non-tuna-like species; Table 1, Appendix Table S3, Fig. 1 & 2). Overlaps



119 occurred in the southern Indian Ocean within IOTC (~62%) and SIOFA (~48%) areas, and in Pacific Ocean  
120 RFMOs (SPRFMO: 24%, WCPFC: 2% and IATTC: 28%) areas.

121 The French EEZs was the most overlapping country with 5 EEZs representing up to 41% of the bird's  
122 distribution (Fig. A2), followed by Chile (2 EEZs, ~38%), South Africa (2 EEZs, ~15%), and New Zealand  
123 (~1.8%).

124 While SIOFA was created only recently (agreement signed in 2006) and entered into force in 2012 the  
125 overlap between fishing effort and bird location could not be estimated due to data inaccessibility.

126

127 Overlap with fishing effort

128 This Amsterdam albatross movement encompassed 143 cells on the RFMOs grid (3 340 661 km<sup>2</sup>) and  
129 451 cells on the GFW grid (1 383 682 km<sup>2</sup>). These cells were spatially overlapping with fishery areas for  
130 82% and 66% respectively.

131 The spatio-temporal overlap with the monthly RFMO fishing data showed no concomitant use of the  
132 same cell with trawling (data available only for SPRFMO and CCAMLR). However, it happened with  
133 longlining for 120 cells visits (36%, Fig. 3a). These potential interactions happened primarily in IOTC (95  
134 cells visits, 79%) and to a lesser extent in IATTC (12 cells visits, 10%), CCAMLR (9 cells visits, 7.5%) and  
135 WCPFC (4 cells visits, 3.6%). In time, this overlap spanned almost all the trip duration, occurring on 27  
136 months out of the 39 recorded. It also included all the months of the year. The corresponding fishing  
137 effort was 7 655 856, 920 785, 2 068 290 and 7 041 deployed hooks respectively in IOTC, IATTC, CCAMLR  
138 and WCPFC.

139 The spatio-temporal overlap with the daily GFW data showed concomitant use of the same cell with  
140 fishing vessels detected during the same day for 11 cells visits (0.7%, Fig. 3b) in 2012. These potential  
141 interactions happened primarily in IOTC / SIOFA (7 cells visits, 63.6%) in May, June, November and

142 December with maximum fishing effort estimated at 24 hours. CCAMLR was also concerned to a lesser  
143 extent with 4 cells visits (36.3%) in April, with maximum fishing effort estimated at 22 hours.

144

145 Fishery observer data

146 Sixteen observations of Amsterdam albatrosses were reported for fifteen different individuals, during  
147 2018-2021 (28 Feb - 6 Apr) and from the stern of a pot fishery vessel targeting the Saint Paul rock  
148 lobster (*Jasus paulensis*). All the observed individuals were immature birds (aged between 2 and 11 yrs)  
149 that never attempted to breed, except one breeding adult (aged 15 yrs). They were all observed within  
150 the Amsterdam and Saint Paul EEZ. Observations from on-board observers provide evidence of direct  
151 interactions with fishing vessels and instances of prey consumption (offals) related to fishing activity  
152 (Appendix Fig. A1).

153

## 154 **Discussion**

155 This is the first evidence that Amsterdam albatross wander for extended periods outside the Indian  
156 Ocean, in the Pacific Ocean (except short visits in the southeastern part of the Atlantic Ocean; [19]). This  
157 novel finding changes the scope of coverage (e.g. spatial and temporal extent) and conservation strategy  
158 for the species. Unexpectedly the South Pacific RFMOs were largely at risk of overlap. Multi-year  
159 tracking datasets of immature birds of this extremely rare species is an important input to fisheries  
160 management processes, highlighting new fisheries that were not considered to pose risk to this species  
161 until now. Furthermore, our results clearly evidenced for the first-time direct interactions with fishing  
162 vessels during the immature stage.

163 Even if the way back to Amsterdam Island was not recorded, it is likely that this bird went back to its  
164 birth colony following the prevailing winds of the Antarctic circumpolar current belt, as wandering  
165 albatrosses *D. exulans* from the South Indian do [13]. Therefore, we strongly suspect that Amsterdam

166 albatrosses may also cross the South Atlantic to complete a circumpolar navigation, and potentially use  
167 all the RFMOs of the Southern Ocean (ICCAT, SEAFO or more of the CCCAMLR areas).

168 This unique migratory behaviour is unprecedented for the Amsterdam albatross either because it may  
169 be very rare, or alternatively, because only few juvenile individuals ( $n = 10$ ) have been successfully  
170 tracked over several years. This raises the possibility of the existence of an unrevealed or novel  
171 migratory pathway unknown for this species. Although this finding concerns a single bird to date, it  
172 represents 10% of the individuals tracked so far.

173 As previously described for juveniles Amsterdam albatross in their first year, this bird distributed mainly  
174 within the South Indian during its first years at sea after fledging [19]. French, South African and  
175 Australian EEZs were previously identified as important foraging areas for this species [19], but new  
176 concerned EEZs have arisen from this study: Chilean and New Zealand EEZs. The finding of this  
177 unrevealed migratory pathway highlights that the conservation of this species goes far beyond France,  
178 which already provides a high level of protection within its EEZs particularly for the French Southern and  
179 Antarctic Lands [34], and the South Indian. This individual distributed largely over the high seas  
180 overlapping mainly with two RFMOs areas (i.e. IOTC and SIOFA, and overlaying marginally with the  
181 Indian part of the SEAFO). Nonetheless, in a completely unexpected way the South Pacific RFMOs were  
182 also largely overlaid (i.e. SPRFMO, IATTC and WCPFC). This reinforces the need for the application of  
183 best practices for bycatch mitigation measures and fisheries observer coverage to be mandated and  
184 enforced at a global scale to ensure no negative effects on this endangered population.

185 Despite the contrasted results of overlap analysis between RFMOs and GFW data, both approaches  
186 conducted on a partial migration of a single individual confirmed the potential for interactions with  
187 fisheries in different RFMOs. Nonetheless, some RFMO fishing effort datasets are known to be very  
188 incomplete (namely in the Indian Ocean) resulting in a biased estimate of overlap. The approach using

189 GFW data should be important to consider in order to complement and refine the overlap estimations,  
190 especially concerning specific fisheries (i.e. South Pacific trawl activity occurs in EEZS while SPRFMO  
191 covers trawling data only in the high seas).

192 The Amsterdam albatross is identified as a priority species to protect, especially at risk due to bycatch  
193 [18] with breeding adults foraging in a dense boat seascape (i.e. including density of fishing vessels [35]).  
194 Even if fine scale analysis between breeding adults tracked with GPS and AIS data seemed to reveal low  
195 interactions with fishing vessels [35], and especially for juvenile Amsterdam albatrosses [36], our results  
196 show clear evidence of direct interactions with fishing vessels during the immature stage. This suggests  
197 that interactions are likely underestimated, given the opportunistic aspect of these data, the elusiveness  
198 of this species and its identification difficulty. Further study on the juveniles' dispersal at sea with GLS  
199 loggers are needed to improve the knowledge on their spatial distribution and exposition to fisheries  
200 interactions. Additional deployments are planned during the ongoing NPOA.

201

202 We reported the first evidence of an immature of the Amsterdam albatross crossing the Pacific Ocean  
203 and estimated the relative importance of national jurisdictions and high seas areas for this individual.  
204 This bird made extensive use of the high seas, reinforcing the stake each country has in the  
205 management of biodiversity in international waters. While in the high seas, this individual, in each ocean  
206 basin, spent the most time within the areas of competence of the five RFMOs targeting tuna and non-  
207 tuna species. By making explicit the relative responsibilities that each country and RFMO has for the  
208 management of shared biodiversity [37] and by providing new evidence for direct interactions with  
209 fishing vessels, this work provides novel and important information for the conservation and  
210 management of this endangered species at the appropriate scale in the marine realm.

211

212 Table 1 Summary of regional fisheries management organisations characteristics competent in the high seas overlapping with an Amsterdam  
 213 albatross tracked during its first 3 yrs at sea  
 214

Ocean basin	Organisation	Targeted species	Gear type	Fishing effort data availability
Indian Ocean	Indian Ocean Tuna Commission (IOTC)	Tunas	Longline	<a href="https://www.iotc.org/data/datasets/latest/CELongline">https://www.iotc.org/data/datasets/latest/CELongline</a>
Indian Ocean	Southern Indian Ocean Fisheries Agreement (SIOFA)	Non-tunas	Longline, trawl	Not considered (data not available)
Pacific Ocean	Western and Central Pacific Fisheries Commission (WCPFC)	Tunas	Longline	<a href="https://www.wcpfc.int/wcpfc-public-domain-aggregated-catcheffort-data-download-page">https://www.wcpfc.int/wcpfc-public-domain-aggregated-catcheffort-data-download-page</a>
Pacific Ocean	InterAmerican Tropical Tuna Commission (IATTC)	Tunas	Longline	<a href="https://www.iattc.org/PublicDomainData/IATTC-Catch-by-species1.htm">https://www.iattc.org/PublicDomainData/IATTC-Catch-by-species1.htm</a>
Pacific Ocean	South Pacific Regional Management Organisation (SPRFMO)	Non-tunas	Longline, trawl	<a href="https://www.sprfmo.int/data/catch-information/">https://www.sprfmo.int/data/catch-information/</a>
Atlantic Ocean	International Commission for the Conservation of Atlantic Tuna (ICCAT)	Tunas	Longline	Not considered (no overlap)
Atlantic Ocean	South East Atlantic Fisheries Organisation (SEAFO)	Non-tunas	Longline, trawl	Not considered (weak overlap)

Global – Southern Commission for the Non-tunas Longline, trawl <https://www.ccamlr.org/en/data/access-and-use-ccamlr-data>  
Ocean Conservation of Antarctic Marine Living Resources (CCAMLR)

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215

216

217

218 **FIGURES**

219 **Fig. 1** At sea track of a transoceanic immature Amsterdam albatross *Diomedea amsterdamensis* after  
220 fledging from Amsterdam Island, southern Indian Ocean, tracked up to age ~3 yrs. The first part of the  
221 journey was spent in the southern Indian Ocean (IO: 06/12/11 - 06/02/14) and the final part in the  
222 southern Pacific Ocean (PO: 07/02/14 – 24/02/15). The areas of competence of Regional Fisheries  
223 Management Organizations (RFMOs) in the high seas are reported: Southern Indian Ocean Fisheries  
224 Agreement (SIOFA), Indian Ocean Tuna Commission (IOTC), South Pacific Regional Management  
225 Organisation (SPRFMO), West Central Pacific Fisheries Commission (WCPFC), Inter American Tropical  
226 Tuna Commission (IATTC), International Commission for the Conservation of Atlantic Tunas (ICCAT),  
227 South East Atlantic Fisheries Organisation (SEAFO), Convention on the Conservation of Antarctic Living  
228 Marine Resources (CCAMLR). The different Exclusive Economic Zones (EEZs) are also presented (white  
229 areas). The breeding colony on the Amsterdam Island is denoted by a green dot, the red dot indicated  
230 the last available location.

231

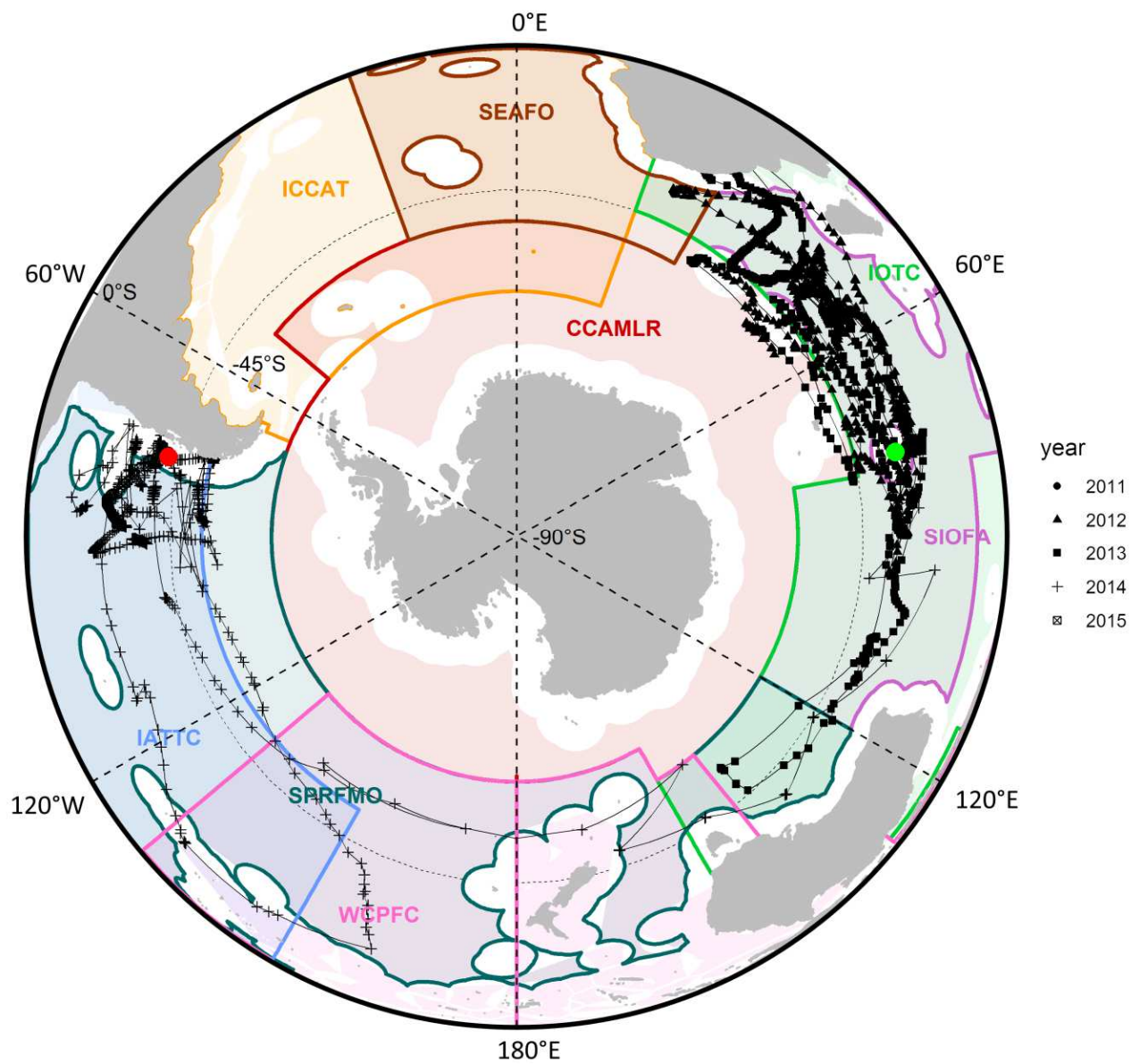
232 **Fig. 2** Distribution of the different levels of overlap between at sea distribution of one Amsterdam  
233 albatross *Diomedea amsterdamensis* after fledging up to age ~3 yrs and marine waters across Ocean  
234 basins. Percentages by a) the different Exclusive Economic Zones countries, and b) the different Regional  
235 Fisheries Management Organizations (RFMOs) in the high seas (inner pie-chart: Southern Indian Ocean  
236 Fisheries Agreement (SIOFA), Indian Ocean Tuna Commission (IOTC), South Pacific Regional  
237 Management Organisation (SPRFMO), West Central Pacific Fisheries Commission (WCPFC), Inter  
238 American Tropical Tuna Commission (IATTC), International Commission for the Conservation of Atlantic  
239 Tunas (ICCAT), South East Atlantic Fisheries Organisation (SEAFO), Convention on the Conservation of  
240 Antarctic Living Marine Resources (CCAMLR)), and Ocean Basins (outer pie-chart) are depicted.

241

242 **Fig. 3** Overlap between an immature of Amsterdam albatross *Diomedea amsterdamensis* tracked up to  
243 age ~3 yrs after fledging and fishing effort while this bird was at sea through different ocean basins  
244 visited using a) Regional Fisheries Management Organizations (RFMOs) dataset, with fishing effort  
245 expressed as the number of hooks set (longline fishing, aggregated monthly data, 5°x5° cell grid) and b)  
246 Global Fishing Watch dataset, with fishing effort expressed as hours (aggregated daily data, 200x200 km  
247 cell grid). The fishing effort is represented by the purple and the yellowish scales, corresponding  
248 respectively to the effort not matching and matching spatio-temporally the bird's movement. Fishing  
249 data were obtained from corresponding RFMOs in the high seas (see Materials and Methods Section).  
250 The areas of competence of RFMOs (coloured lines) and the different Exclusive Economic Zones (EEZs)  
251 are also presented (indigo blue areas). The 1<sup>st</sup> and last locations of the individual track are denoted (1<sup>st</sup>:  
252 green dot, last: red dot).

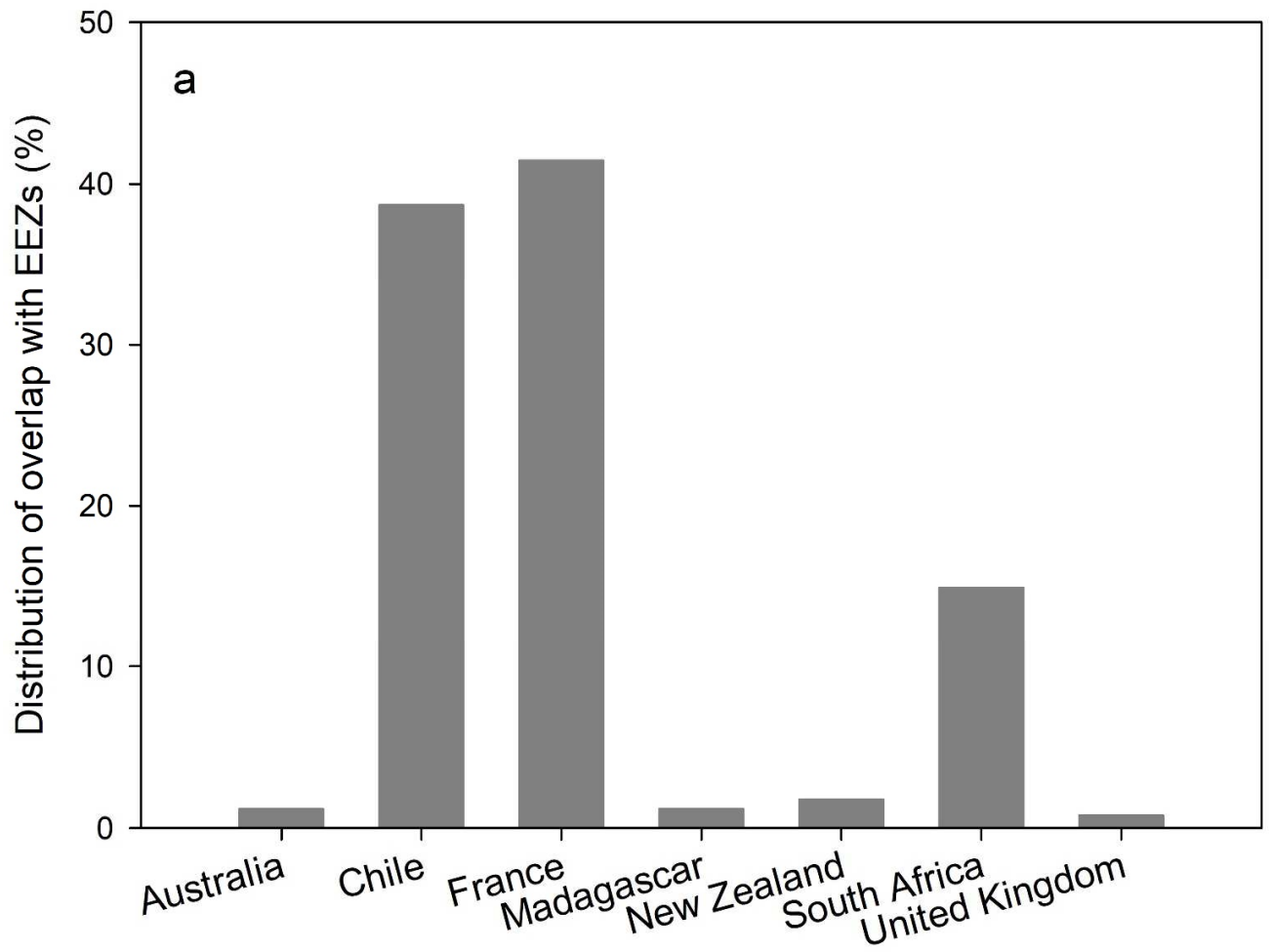
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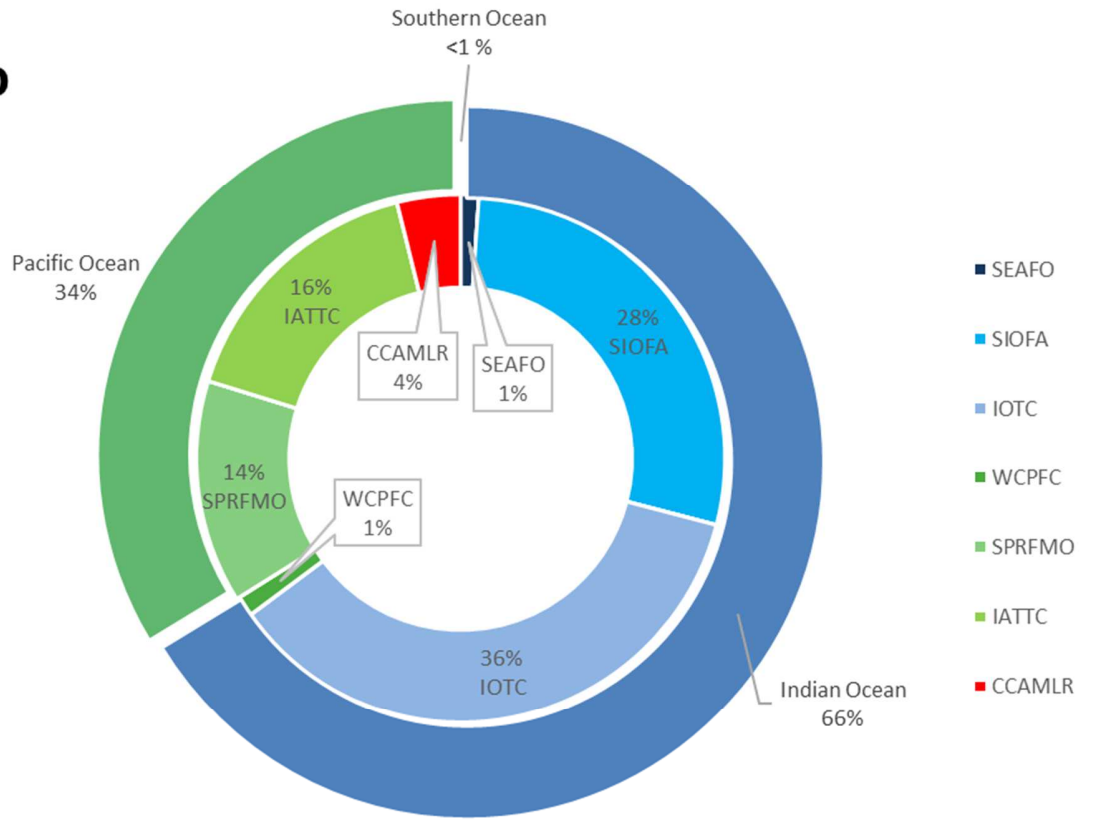


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**b**



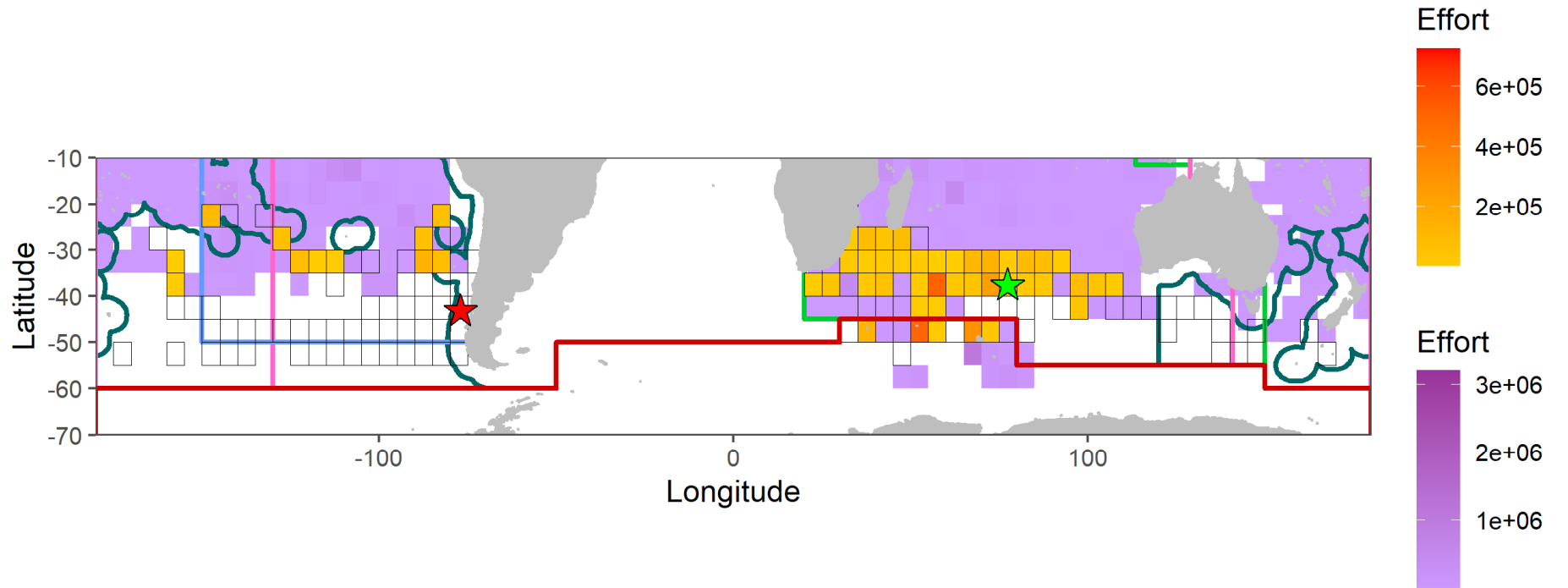
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262 Fig 3a



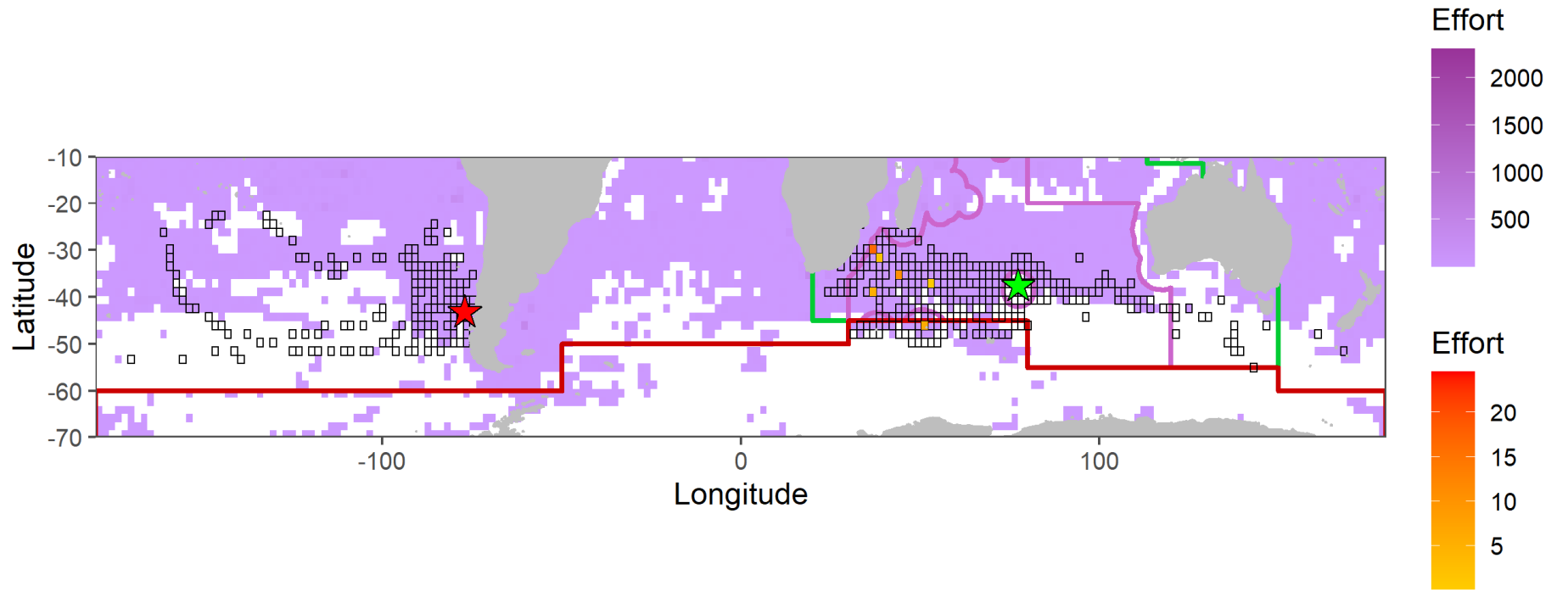
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