Albatross chicks reveal interactions of adults with artisanal longline fisheries within a short range

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Abstract

Incidental capture in fisheries ("bycatch") is a major threat to global marine biodiversity, especially to those species with low fecundity such as albatrosses. Efforts to reduce bycatch have been undertaken in industrial fisheries, however seabird interactions with artisanal, small-scale fleets remain largely unknown. Torishima (Japan) is an important breeding site for two albatross species (short-tailed *Phoebastria albatrus* and black-footed *P. nigripes*), and lies in the range of the artisanal longline fishery for the splendid alfonsino *Beryx splendens*. In February-March 2017, we GPS-tracked 23 foraging trips of *P. nigripes* feeding chicks, and monitored prevalence of fishing gear at the nests using a metal detector. Albatrosses foraged within 280 km from Torishima, and only 3.7% of the GPS locations occurred over the shallow habitats targeted by the alfonsino fishery (150–500 m), suggesting relatively low risks of interaction. However, 190 (54.3%) nests of *P. nigripes* contained fishing gear, among which 12 (3.4%) nests or chicks contained a hook or an unidentified metallic object. Six hooks were also collected from *P. albatrus* nests. All found hooks, except one, originated from the alfonsino fishery, indicating that both albatross species actually interacted with this fishery at sea. Both approaches provided data from returning birds, and do not reflect possible lethal cases at sea. Monitoring sub-lethal effects of bycatch, and inviting small-scale fisheries to report the gear lost at sea, is desirable to further help quantifying and reducing the impact of fisheries on seabirds.

Keywords

Artisanal fisheries; *Phoebastria* albatrosses; seabird-fisheries interactions; longline; bio-logging; Northwest Pacific

Introduction

Fisheries are a severe threat to marine biodiversity, impacting ecosystems from the open ocean to the coasts, and from the poles to the tropics (Jackson et al. 2001; Halpern et al. 2008). Commercial fishing has indeed resulted in widespread ecosystem disorders through over-harvesting, habitat degradation and the mortality of non-target species, also called bycatch (Hall et al. 2000). Marine megafauna, including sea turtles, sharks, marine mammals and seabirds, is particularly susceptible to bycatch because these species are attracted to fishery bait and discards, and have naturally low fecundity making their populations sensitive to additional mortality (Brothers 1991; Hall et al. 2000; Lewison et al. 2004).

Most species of albatrosses worldwide currently face extinction risk, mainly because of fisheries (Anderson et al. 2011; Phillips et al. 2016). Severe declines in albatross populations have notably been caused by unsustainable mortality levels in the longline fisheries (e.g., Weimerskirch et al. 1997), although effective mitigation measures have reduced albatross bycatch in large-scale fisheries in recent years (e.g., Robertson et al. 2014). Insufficient data remain however to assess seabird bycatch in many longline fisheries, and this is the case for artisanal, small-scale fleets. Indeed, despite their importance to global catches, small-scale fisheries are often largely unstudied compared to industrial fleets (Lewison et al. 2004; Pauly 2006). In the Mediterranean for example, artisanal longliners can locally have severe impacts on threatened seabirds, as they may implement less or no bycatch mitigation measures compared to semi-industrial pelagic longliners (Belda and Sánchez 2001; Cortés et al. 2017, 2018). Today, major data gaps concern artisanal fleets in West Africa and Northwest Pacific (Anderson et al. 2011).

The splendid alfonsino *Beryx splendens* is a commercially important resource in the Pacific side of Japan (Adachi et al. 2000), with annual catches up to 11,000 t. It is exploited year-round with small-scale longliners operating notably along the Izu islands (Takeuchi 2014). In this study we intend to provide a first assessment of at-sea interactions between this small-scale fishery and local albatross populations. In the southern Izu archipelago, Torishima holds about 85% of the global population of the Vulnerable short-tailed albatross *Phoebastria albatrus*, and regionally important numbers of the Near-Threatened black-footed albatross *P. nigripes* (BirdLife International 2018). Both short-tailed and black-footed albatrosses are already known to be at risk of bycatch in industrial fisheries operating in the northern Pacific (Hyrenbach and Dotson 2003; Lewison and Crowder 2003; Suryan et al. 2007; Fischer et al. 2009), but local interactions with artisanal fisheries remain unaddressed. We GPS-tracked black-footed albatrosses breeding at Torishima to quantify the overlap between their at-sea habitat and that targeted by the alfonsino longliners. Concomitantly, we monitored nests of *P. nigripes* and *P. albatrus* for the occurrence of fishing gear to reveal actual bird-fishery contacts at sea, and propose options to help reducing these interactions.

Materials and methods

Fieldwork was conducted on the western slope of Torishima (Tokyo, Japan; 30.49° N, 140.29° E; Fig. 1), from 16 February to 5 March 2017. Black-footed albatrosses arrive at the colonies in mid- to late October, lay an egg between mid-November and mid-December, that hatches from mid-January to mid-February; chicks fledge during June through mid-July, and adults leave the colonies in mid- to late July (ACAP 2010). Short-tailed albatrosses are about 2-3 weeks more precocious (ACAP 2009). GPS loggers (GiPSy5 with 600 mAh battery, TechnoSmart, Italy; dimensions: 45 × 22 × 18 mm; mass: 17 g) were programmed to record location every 20 sec, sealed into waterproof heat-shrink tubing, and attached with Tesa ® tape to the back feathers of 18 adult individuals in late chick-brooding (17–26 February). A VHF transmitter (Sakura transmitter LT-04-2, Circuit Design, Inc., Japan; 30 × 11 × 9 mm, 5 g) was also attached on each tracked bird. The signal (150 MHz) was received from > 500 m on a fixed antenna and allowed to increase chances of recapturing the birds on their arrival and to avoid disturbing the study nests with frequent visits for surveying the birds' return. Loggers were retrieved after 3.3 ± 1.1 d on average (range: 1.9–5.2 d), capturing one to several foraging trips at sea. Birds were measured upon recapture to assign sex (Fernández et al. 2001). Three birds could not be recaptured during our stay on the island.

From 23 February to 1 March, a total of 350 black-footed albatross nests across seven sub-colonies were examined for the presence of fishing gear (e.g. lines, snoods, hooks). They contained a live chick (n=268, brooded or not), an egg (n=6; incubated or abandoned), and 76 others were occupied by a non-breeding adult or were recently deserted (i.e., not covered with vegetation). Each nest was first visually inspected; a high sensitivity metal detector (Beruf Handy EMD-28, Japan) was then used on the nest surface and the chick's abdomen to reveal metallic objects. It took about one minute to monitor one nest. Nests of short-tailed albatrosses were also monitored at their neighbouring colony, but to avoid disturbing this fragile population nest checks were made by eye only, while visiting the colony for other purposes (e.g., when ringing all 207 chicks on 3 March). Whenever possible without excessively disturbing the birds, fishing gear was removed from the monitored nests. Gear found opportunistically at non-monitored nests was noted separately.

GPS datasets were downloaded from the loggers and analysed in R 3.4.2 (R Core Team; www.R-project.org), following the framework and scripts provided in Lascelles et al. (2016) with R packages 'sp', 'maptools', 'rgdal', 'adehabitatHR', 'geosphere', 'fields', 'spatstat', 'maps', 'rgeos', and 'mapdata'. All data points at the nest were removed. Kernel density estimations were computed from linearly re-interpolated data (every 10 sec). The search radius *h* for the kernel estimations was based on the scale of the birds' area-restricted search behaviour (45.5 km), calculated from a first-passage time analysis. To examine whether multiple trips made by single birds caused pseudo-replication in the dataset, an iterative measure of the proximity of the trips' core utilisation areas was conducted. This analysis showed that core areas from one individual's multiple trips were not closer than that of trips from different individuals (Mann–Whitney U-tests, $P = 0.43$). Finally, the sample's representativeness was examined by measuring how the population's utilisation core area changed with increased inclusion of data. This asymptotic metric indicated a suitable (88.53%) representativeness of the tracking data for the population's space use. Interpolated locations were mapped over a 1-min bathymetry grid (ETOPO1, Amante and Eakins 2009) to examine the albatrosses' marine habitat use, with the R package 'marmap' (Pante and Simon-Bouhet 2013). Differences in trip metrics between sexes were tested using Wilcoxon rank sum test with continuity correction or Welch two sample t-test, depending on whether the variable distribution was significantly different from a normal distribution or not, respectively (assessed from a Shapiro-Wilk normality test). Fisher's exact test for count data was used to compare proportions between groups of birds, nest contents or gear type. For all statistics, differences were considered significant when $P < 0.05$. Values indicated are mean ± SD.

The splendid alfonsino mainly uses 200–800 m depth zones with strong bathymetric gradients (Takeuchi 2014; Iwamoto et al. 2015). Demersal longlining targeting alfonsino is operated from small boats off the coasts nearby Tokyo and the northern Izu chain (typically < 5 t with 1–3 men, but up to 5–19 t with 3–7 men; setting lines of 50 hooks), and from larger boats in offshore areas including southern Izu chain (50–99 t, 10 men; 20 hooks per branch with 60 branches per line; only two boats currently in activity, Takeuchi 2014). Hooks are set mostly between 150 and 500 m. Fishers of the longliner Housei Maru (targeting alfonsino from Hachijojima, central Izu) helped identifying fishing gear collected at the nests.

Results

A total of 27 at-sea trips were collected from 15 black-footed albatrosses (9 females, 6 males). Four trips lasting < 6 h were discarded, as those may reflect unusual activity following logger deployment or recapture attempts. The 23 retained tracks lasted 38.8 ± 17.4 h on average (Table 1). The furthest location was in the northern sector (within 45° on each side of the North) of the colony for 14 trips, and in the western, southern, and eastern sectors for 4, 3, and 2 trips, respectively. Birds reached a maximum range of 279.3 ± 162.5 km from their nest, covering a total minimum path of 1070.4 ± 635.1 km. Differences between sexes were not significant regarding trip duration ($t_{20.4} = 2.05$, $P = 0.053$), maximum range ($W = 91$, $N = 23$, $P = 0.12$), total distance ($W = 96$, $N = 23$, $P = 0.057$) or proportion of birds heading northward (Fisher's exact test, $P = 0.10$).

Kernel density estimations concentrated mainly along the Izu chain (Fig 1). The birds exploited marine habitats characterized by relatively shallow depths, compared to the available environment: most GPS locations (55.9%) occurred over areas ≤ 2000 m, and frequency of locations was the highest for areas 1000–1200 m deep (Fig 2). Only 3.7% of the locations occurred in habitats targeted by the alfonsino fisheries (depths 150–500 m).

Fishing gear or metallic objects were seen or detected on 190 (54.3%) of the monitored nests of black-footed albatrosses, and at all of the surveyed sub-colonies (20.8–79.3% of the nests in each sub-colony, Table 2). At 188 nests (53.7%), multi- or mono-filament lines were found, that were not characteristic of any specific fishery (Fig 3). In eight of these nests, a hook was also detected: six of these hooks were identified as from the alfonsino longline fishery; the two others were broken and could not be identified. Moreover, metallic objects were detected inside four chicks (1.5% of the chicks; see online video) from three different sub-colonies. Two of these chicks also had fishing lines on their nest. There was no case with both a hook detected on the nest and metal inside the chick. Overall, 3.4% of our survey plot (12 nests, all with a chick, i.e. 4.5% of the nests with a chick) contained a hook or a metallic object, and only 45.7% (160 nests) had no visible fishing gear or detected metal whatsoever. The occurrence of fishing lines on a nest was associated with a significantly greater probability of metal detection at this nest (Fisher's exact test, $P = 0.033$). Nests with a chick were also significantly more likely to contain a hook/metallic object, but not a line or either object (Fisher's exact tests, $P = 0.038$, $P = 0.97$, $P = 0.96$, respectively).

Four other hooks were found opportunistically at black-footed albatross nests, all of which originated from the alfonsino longline fishery. One chick was also observed with a hook and line in its bill, which came from this fishery.

Six hooks were found on short-tailed albatross nests. Five of them were again identified as from the alfonsino longline fishery; one was larger and probably used in pelagic fisheries. Fishing lines were also seen on the nests, but their occurrence was not quantified.

Discussion

GPS tracking of black-footed albatrosses showed that the adults' foraging habitat marginally overlaps with the shallow areas exploited by the artisanal longline fishery for alfonsino: this would suggest a small risk of bird-fisheries interaction. However, nest-based monitoring showed that both black-footed and short-tailed albatrosses do interact at least with this specific fishery at sea, and can transfer fishing gear to their chick. Numerous studies (e.g., Fischer et al. 2009) rely on the rationale that overlap between the at-sea distribution of fisheries and seabirds can translate into bycatch risks: yet here we show that an expected overlap as small as < 4% was sufficient for adult *P. nigripes* to actually and repeatedly contact fishing gear at sea, although our observations did not account for gear accumulation at the nest over time.

Black-footed albatrosses in late chick-brooding foraged within 300 km from Torishima, on average. This is remarkably consistent with conspecifics from the central Pacific Ocean (Fernández et al. 2001; Hyrenbach et al. 2002; Kappes et al. 2015), and with other subtropical albatross species (e.g. Thiebot et al. 2014) during chick-brooding. These previous studies indicated however that albatrosses were distributed mostly over oceanic waters > 3000 m deep, and infrequently over shallower continental shelves. In contrast, the black-footed albatrosses from Torishima and nearby Mukojima islands (Kawakami et al. 2006) selected relatively shallower areas within their foraging radius, putting them at higher risk of contact with small-scale longliners. Especially, birds from Torishima mostly moved northward, *i.e.* to the Tokyo region where the alfonsino small-scale fisheries are primarily based (Takeuchi 2014). Since seabirds' foraging range varies dramatically across life-cycle stages (e.g. Thiebot et al. 2014), the risk of bird-fisheries interaction may equally depend on the stage. For instance, stage-dependent analyses have shown that the overlap score with pelagic longliners increased with seabirds' foraging range (Thiebot et al. 2016). However, in the case of the near-shore fishery for alfonsino, it is likely that the interaction risk is maximal when the albatrosses' foraging range is minimal (during chick-brooding), while this risk would be diluted when the birds spend more time in offshore waters away from Torishima, during larger-scale movement stages.

Large-scale patterns of seabird interactions with fisheries are known to vary by sex (Gianuca et al. 2017): more females are caught in subtropical regions (e.g., Weimerskirch et al. 2018), but male albatrosses are more likely to ingest marine debris from human activities, including fisheries, than females (Jiménez et al. 2015). During chick-brooding however, the relatively small foraging radius of albatrosses leads both sexes to temporarily exploit similar areas (e.g. Hyrenbach et al. 2002; Thiebot et al. 2014), suggesting similar risks of contact with the alfonsino fisheries by male and female *P. nigripes* from Torishima.

Albatrosses are able to swallow the baited hooks, or to attack the fish hauled up on the lines; however they cannot break up the line when they are caught, and may thus drown, unless they are cut free by the fishers or have ingested hooks from lost snoods (Phillips et al. 2010; Thiebot et al. 2015). Hence, the number of interactions indirectly witnessed from nest-based monitoring only reflects the non-lethal cases, after which the birds were able to come back to the nest. Lethal cases possibly occurring at sea could thus not be investigated through our study design. Previous nest-based surveys carried out on several species in the Southern Ocean (Phillips et al. 2010) show much lower figures than at Torishima. For albatrosses of the genus *Thalassarche*, comparable to *P. nigripes* in their foraging behaviour, fishing gear was found in 0.08% of black-browed *T. melanophris* and 0.13% of grey-headed *T. chrysostoma* albatrosses' nests. The considerably higher rate observed at Torishima (54.3%) likely reflects that our rates are un-corrected for inter-annual gear accumulation at the nest (see below). Yet, fishing material occurred in 0.7% of stomach samples from *Thalassarche spp.*

chicks, while at Torishima twice this proportion of *P. nigripes* chicks had ingested a metallic object. Hence, the adults from Torishima have an apparent higher rate of interaction with human activities, than southern albatrosses.

Metal detected in chicks most likely indicated hooks: other metallic objects at sea would quickly sink out of reach of the birds, while baited hooks or hauled fish can be targeted by the birds near the surface (Brothers 1991). Such detections uncontestably indicate that the chicks acquired these items after they hatched, while fishing gear at the nest may be accumulated over time and over-estimate bird-fisheries interaction rates. Hence, minimum number of interactions may be estimated, assuming that metal detections (4 over 350 nests) also reflect hooks from the alfonsino fishery, as supported by the chick found among the non-monitored nests with this type of hook. From the 2060 pairs of *P. nigripes* breeding at Torishima in 2013 (reviewed in BirdLife International 2018), at least 24 of them would be in contact with the alfonsino fishery alone, during the 2–3 weeks of one chick-brooding season (Kappes et al. 2015). This is a conservative estimate: each chick detected with metal may actually contain several hooks, while other chicks may have regurgitated, or even digested the hooks (suggested in Phillips et al. 2010).

Lines were the most prevalent anthropogenic item found at the nests. However, they could not be assigned to any particular fishery. Other fisheries than that targeting alfonsino may operate in the area (such as near-shore or coastal tuna longline fisheries, as supported by the bigger hook found on a short-tailed albatross nest; Fisheries Agency, Government of Japan 2009), as well as yet other maritime activities, from which mono- and multi-filament lines, respectively, could also originate.

Guidelines on fishing practices to abate albatross bycatch in industrial fisheries have been described for years (e.g., Brothers et al. 1999; Gilman et al. 2008; Løkkeborg 2011). Recent approaches to protect both wildlife and fisheries productivity against bycatch, have also been developed that are applicable to small-scale fisheries (Cortés and González-Solís 2018). These include automatic photo-monitoring to overcome some deficiencies in observer reports (Bartholomew et al. 2018), and the use of devices such as the 'Hookpod' which can be employed conveniently without impairing longline fishing efficiency (Sullivan et al. 2017). In Japan, the small-scale longline fisheries are currently requested to release the seabirds alive when caught, if possible after removing the hooks, and to avoid disposal of offal from the vessel during line setting (Fisheries Agency, Government of Japan 2009). Also, within 20 nautical miles (about 37 km) from Torishima and from October to May, these fisheries have to utilise streaming devices (tori-pole/tori-line) and at least one other mitigation measure (e.g., night-time setting, weighted branch lines). These measures certainly can limit bird-fisheries interactions, nevertheless our study shows that it does not prevent birds breeding at Torishima from ingesting fishing gear. Further approaches should thus be evaluated to tackle this issue. In Japan, *c.* 98% of fishers are artisanal, and fisheries are co-managed in a decentralized system involving fishers and the government (Matsuda et al. 2010). Under the current Fishery Law, resource conservation is an integral part of resource use, and local resource users are thus the principal decision makers in fishery resource management (Makino and Matsuda 2005), especially among coastal fisheries (Matsuda et al. 2010; Tsurita et al. 2018). Hence, this study is central to provide a scientific basis to pursue consultations between fishers, local government and environmental agencies. The alfonsino longline fishers may then need to evaluate which approaches could be best applicable to this fishery. Besides, the relatively small radius of the specially-regulated area around Torishima is one point that may deserve discussion, because our data show that the birds' foraging range exceeds by far this threshold, even during a stage when this range is presumably minimal in albatrosses (Thiebot et al. 2014). Finally, the option for small-scale fisheries operating near Torishima to report the number of hooks/snoods lost at sea, particularly those due to seabirds, could be debated as well in order to better evaluate the impact of bird-fisheries interactions both on wildlife and fisheries.

Artisanal, small-scale fisheries may severely threaten seabirds (Anderson et al. 2011; Cortés et al. 2017, 2018). In the Northwest Pacific, our study showed that albatrosses contact fishing gear from at least one artisanal fleet during the breeding period, when their foraging range is relatively short. Longer-term monitoring is nevertheless needed to better assess the local environmental risks posed by artisanal fisheries. Notably, removing all hooks and fishing lines/gear found from one visit to the next would allow to quantify (1) the annual rate of bird-fishery interactions; (2) the influence of breeding stage, and hence foraging range, on the fisheries contacted by the birds; and (3) the effectiveness of new regulations or fishing practices (Phillips et al. 2010; Løkkeborg 2011). Simultaneous tracking of the birds at sea, using the innovative approach from Weimerskirch et al. (2018), in which GPS loggers with radar-detection system enable to quantify bird-vessel interactions at sea, would be particularly helpful to refine risk assessments. Future studies at the nest may further aim at quantifying sub-lethal effects on the birds interacting with this small-scale fishery. Sub-lethal effects of bycatch may be considerable (Wilson et al. 2014), and encompass alteration of reproduction, feeding, and/or growth (*i.e.*, fitness) for animals that survived a fisheries interaction. For albatrosses, ingesting bait and hooks may cause such effects. It is thus desirable to measure growth in chicks; breeding success, frequency and mass of meals fed in adults; and stress response and immune defences in both, as a function of fishing gear prevalence. All these effects can indeed occur undetected following escape or release from fishing gear, while having significant consequences at the population or ecosystem-level on the longer-term (Wilson et al. 2014).

Acknowledgements We thank Satoshi and Miwa Konno for their invaluable help on the field, and the crew of the fishing boat Housei Maru from Hachijojima for kindly transporting us to/from Torishima. The authors also thank Akinori Takahashi for his involvement in the fieldtrip organization.

Compliance with ethical standards

Funding Provided by the Japan Society for the Promotion of Science (KAKENHI Grant-in-Aid #26304029 and #15K14439, to Y. Watanuki) and the Japan Ministry of the Environment (to the Yamashina Institute for Ornithology).

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval All applicable international, national, and institutional guidelines for the care and use of animals were followed. Permits to capture and tag birds on Torishima were obtained through the Japan Ministry of the Environment and Agency for Cultural Affairs, and Tokyo Metropolitan Government. Animal Ethics approvals were obtained through Hokkaido University.

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Figure Legends

Fig. 1 Kernel density estimations (95% and 50% contours: yellow thin and thick lines, respectively) of black-footed albatrosses GPS-tracked from Torishima (white triangle), southern Izu islands. Background shows bathymetry from dark grey (deep areas) to white (emerged areas) and the maximum isobath where the alfonsino fisheries operate (thin black line: 500 m) (colour figure online)

Fig. 2 Frequency distribution of the seafloor depth within: the birds' average foraging range (upper panel); the birds' exploited habitat (lower panel). Red dashed lines indicate lower (-500 m) and upper (-150 m) depths at which the alfonsino fisheries operate (colour figure online)

Fig. 3 Illustration of the nest survey steps: (a) visual search: in this case, fishing lines can be seen on the nest; then a metal detector is used to search (b) from the nest perimeter to its centre, and (c) on the chick's abdomen; (d) example of a hook from the alfonsino fishery (scale in cm). Pictures taken by JB Thiebot (colour figure online)

Table 1 Trip metrics (angles: 0 or 360° correspond to North). The four trips marked with asterisks were excluded from all analyses, due to their very short duration (< 6 h). Sex inferred from biometry is indicated for each individual (F: female; M: male)

Bird ID (Sex)	Trip ID	Duration (h)	Maximum Range (km)	Mean Speed (m s^{-1})	Total Distance (km)	Direction of the furthest point (°)
31 (F)	1	43.7	239.5	7.18	1067.6	344.01
32 (M)	2	27.7	262.5	7.08	684.9	329.68
32 (M)	3	17.8	49.6	4.11	181.2	184.43
32 (M)	4	42.3	283.5	7.67	777.0	339.12
32 (M)	5	22.9	225.4	7.52	583.6	261.00
33 (F)	6***	2.1	6.5	5.92	33.4	349.60
33 (F)	7	38.6	416.8	9.77	1351.9	341.27
33 (F)	8***	0.6	5.5	8.45	19.6	287.96
33 (F)	9	57.7	505.2	9.90	1962.5	2.03
34 (M)	10	44.2	303.8	5.76	879.6	319.53
35 (F)	11	26.4	173.4	9.88	484.3	333.12
35 (F)	12	24.1	176.8	10.57	576.2	338.83
36 (F)	13	41.1	282.3	6.89	895.2	35.40
36 (F)	14	17.5	171.3	6.01	394.9	336.15
39 (F)	15	43.3	424.5	10.32	1560.5	334.95
41 (M)	16	21.2	98.7	8.13	611.4	267.27
42 (F)	17	24.7	293.4	9.70	859.3	75.69
42 (F)	18	73.5	465.2	8.77	2294.3	339.05
42 (F)	19***	4.8	39.4	7.98	138.7	72.40
43 (M)	20***	5.9	26.6	9.35	198.9	290.25
43 (M)	21	41.3	223.4	6.99	1024.7	248.79
44 (F)	22	63.3	797.2	12.06	2740.8	19.48
46 (M)	23	27.6	362.2	12.42	1206.5	340.17
46 (M)	24	17.6	152.4	8.66	539.3	191.44
48 (F)	25	50.1	174.4	7.12	1277.7	78.93
49 (F)	26	76.3	201.9	6.48	1755.6	248.64
50 (M)	27	50.3	140.0	5.11	910.3	172.14
MEAN		38.8	279.3	8.2	1070.4	NA
S.D.		17.4	162.5	2.1	635.1	NA

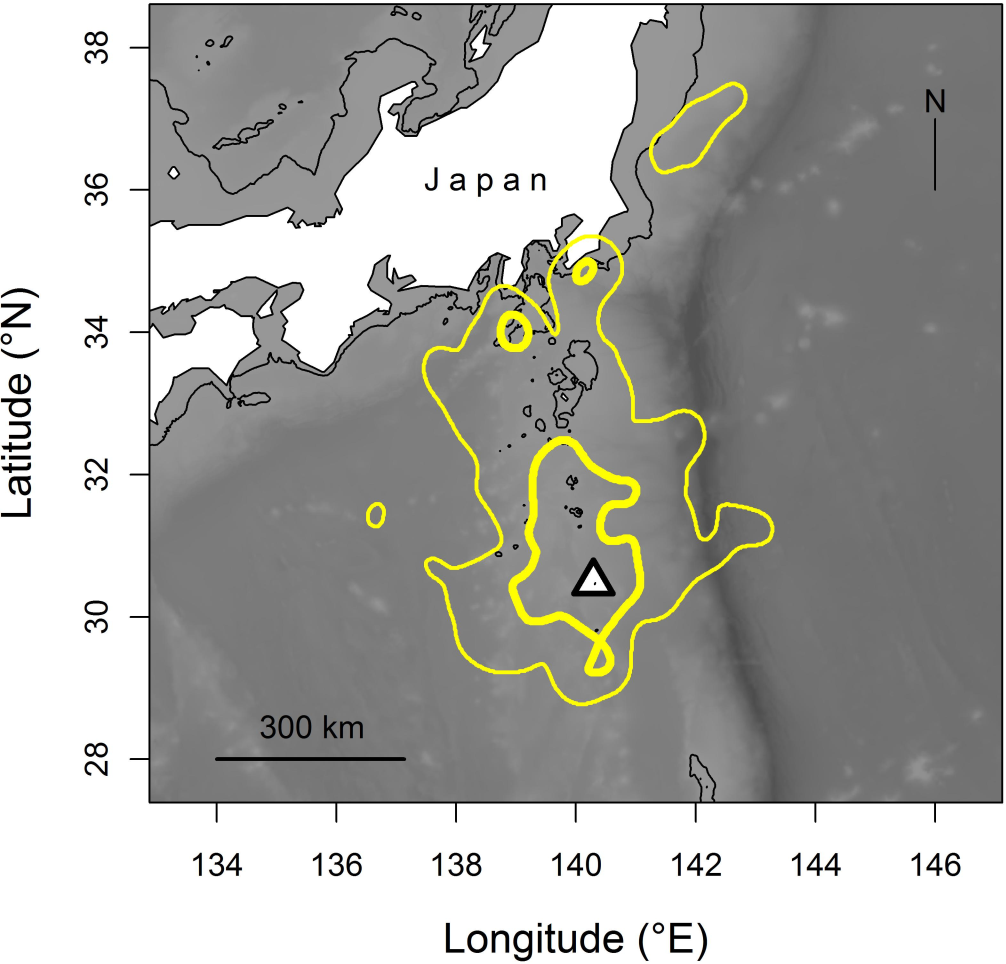
Table 2 Summary of nest monitoring per sub-colony plot of black-footed albatross on Torishima. Between brackets are detailed the numbers per nest content (chick/egg/inactive)

Sub-colony plot	Number of nests	Nests with lines	Nests with hook	Chicks with detected metal
Solar panel	6 (4/1/1)	2 (1/0/1)	1 (1/0/0)	0
Southernmost Ridge	24 (19/1/4)	5 (4/0/1)	1 (1/0/0)	0
Southernmost Ridge to Southern Ridge	40 (28/3/9)	21 (11/2/8)	1 (1/0/0)	1
North of counting viewpoint	29 (21/1/7)	23 (16/1/6)	0	0
South of counting viewpoint	110 (77/0/33)	59 (44/0/15)	1 (1/0/0)	1
Ōiwa	70 (59/0/11)	35 (27/0/8)	1 (1/0/0)	0
Matsu Ridge	71 (60/0/11)	43 (34/0/9)	3 (3/0/0)	2
Total	350 (268/6/76)	188 (137/3/48)	8 (8/0/0)	4

Electronic supplementary material

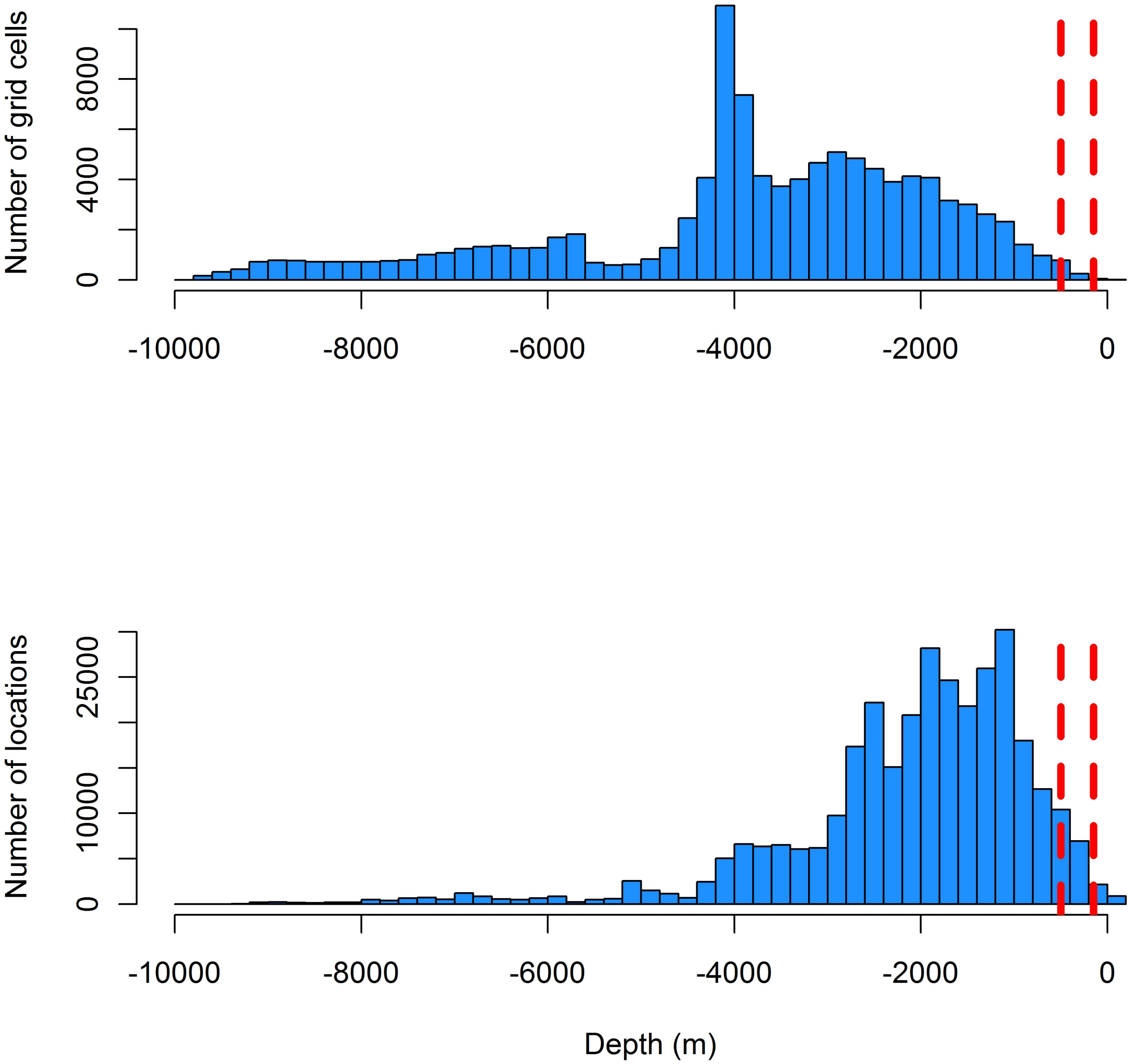
(Video) A case of detected metal inside a chick. The observer (B Nishizawa) first tests the sensitivity of the metal detector on his wristwatch, then checks the area around and inside the nest, and finally passes the detector against the chick’s belly. Video taken by JB Thiebot

Fig. 1



Japan
N
300 km
38
36
34
32
30
28
134
136
138
140
142
144
146
Latitude (°N)
Longitude (°E)

Fig. 2



Number of grid cells
0
4000
8000
-10000
-8000
-6000
-4000
-2000
0
Number of locations
0
10000
25000
-10000
-8000
-6000
-4000
-2000
0
Depth (m)

Fig. 3