



Nonbreeding distribution of flesh-footed shearwaters and the potential for overlap with north Pacific fisheries



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ABSTRACT

Populations of flesh-footed shearwaters on Lord Howe Island, Tasman Sea, have declined recently, with mortality in longline fisheries likely to be one of the major causes. It is therefore imperative to increase our understanding of their distribution at sea, especially during winter. Although they are known to migrate to the north Pacific Ocean, until this study there was very little information available on timing of movements, distribution and habitat use of individuals. Ten to 16 flesh-footed shearwaters (37 in total) were tracked from Lord Howe Island in each of three winter seasons (2005, 2007 and 2008). All birds migrated to the north-west Pacific Ocean, with approximately 70% wintering to the east of Japan in the Kurashio and Oyashio currents, around the Bonin Islands in the north Philippine Sea, or in the eastern Sea of Japan. Others spent a varying amount of time in the Yellow and East China seas, or in the western Sea of Japan. These waters already support intensive fisheries and demand for seafood is likely to rise in tandem with the increasing human populations of East Asia. Consequently, results presented here show that members of the largest population of flesh-footed shearwaters winter exclusively in the north-west Pacific Ocean around Japan and East Asia, in areas they are likely to overlap extensively with a number of fisheries; it is therefore imperative to obtain more information on current and projected levels of bird bycatch and effort in these fisheries in order to developing management strategies for the conservation of the east Australian and New Zealand populations of the flesh-footed shearwater.

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1. Introduction

Seabirds are among the most threatened groups of birds in the world; 28% of species are listed as Vulnerable, Endangered or Critically Endangered by the World Conservation Union (IUCN) (Croxall et al., 2012). They are at risk from a range of processes, both on land, such as destruction of breeding habitat or predation by introduced animals, and at sea, including incidental mortality in fisheries or reduction in prey abundance resulting from overfishing (Croxall et al., 2012). Marine threats are particularly difficult to quantify; in addition to the difficulties of observing seabirds at sea, many species migrate long distances. As they traverse multiple national and administrative boundaries, they move great distances from Exclusive Economic Zones where local breeders may be afforded legislative protection, into waters under different national jurisdictions or the High Seas, where they may be at much greater

risk from fisheries, oil and gas extraction, other sources of pollution, and hunting, etc. (Moors and Atkinson, 1984; Tuck et al., 2003; Zydels et al., 2009; Finkelstein et al., 2010; Montevecchi et al., 2012). Effective protection therefore requires information on their movements and distribution at sea, year-round. Procellariiformes (albatrosses and petrels) are especially wide-ranging, with individual albatrosses ranging throughout the Southern Ocean and a number of species of shearwater migrating between the northern and southern hemispheres (Marchant and Higgins, 1990; Klomp and Schultz, 2000; Shaffer et al., 2006; Rayner et al., 2011b). Hence, they are particularly susceptible to threats over wide areas.

All albatrosses, both giant petrel *Macronectes* spp., the five *Procellaria* petrels and Balearic shearwater *Puffinus mauretanicus* are listed under the Agreement for the Conservation of Albatross and Petrels (ACAP) (ACAP, 2012). However, several other species of migratory shearwater have also been identified as potentially deserving inclusion under ACAP (Cooper and Baker, 2008). This includes the flesh-footed shearwater *Puffinus carneipes*, which is a medium-sized shearwater that migrates to the northern hemisphere for the austral winter (Tuck and Wilcox, 2010; Rayner et al., 2011b). This species is currently listed as Least Concern by

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IUCN, which primarily reflects the lack of evidence for a decline in Western Australia, where the majority of birds breed but there is no long-term monitoring program (Birdlife International, 2012). Information on population status is better at Lord Howe Island, off eastern Australia, which holds 5–14% of the Australian, and 8% of the world population (Priddel et al., 2006; Brooke, 2004; Reid et al., 2013). Here, habitat destruction led to a 36% reduction in nesting habitat, and a decline of up to 50% in breeding numbers over the period 1978–2002 (Priddel et al., 2006).

Ship-board observations indicated that the flesh-footed shearwater was one of the most commonly-killed seabirds in longline fisheries off the east coast of Australia (Gales et al., 1998; Baker and Wise, 2005). During 1998–2002, an estimated 8972–18,490 were killed in the Eastern Tuna and Billfish Fishery (ETBF) (Baker and Wise, 2005), leading to the conclusion that by-catch was the principal factor driving the local population decline (Tuck and Wilcox, 2010). In recent years, there has been a reduction in the observed by-catch rates, from 0.38 birds/1000 hooks between 1998 and 2002, to less than 0.07 birds/1000 hooks between 2002 and 2007 (Baker and Wise, 2005; Trebilco et al., 2010). Nevertheless, there is evidence the Lord Howe population may be continuing to decline (Reid et al., 2013).

During the summer breeding season, flesh-footed shearwaters from Lord Howe Island generally spend their time off the east coast of Australia between ~22–42°S and 150–165°E (Thalmann et al., 2009; Reid et al., 2012). Bird by-catch rates in this region are relatively well known (Trebilco et al., 2010). However, mortality during the non-breeding season was identified as a fundamental uncertainty in assessing the impact of fisheries (Tuck and Wilcox, 2010). Evidence from at-sea sightings and from band recoveries suggests that non-breeding flesh-footed shearwaters forage in waters of the north-western Pacific Ocean (in particular off Korea and Japan) with occasional sightings off the coast of Canada, and the USA (Shuntov, 1998; Tuck and Wilcox, 2010). However, the colony of origin cannot be ascribed from at-sea sightings and the proportion of each population that inhabits each of these areas is also unknown. Banding records (13,000 banded; 1234 recovered as of May 2010) from Lord Howe Island show that all of the flesh-footed shearwaters recovered away from the southern hemisphere were in the north-west Pacific, mostly in the Sea of Japan near Korea, and others near the Tsugaru Strait or south of Japan (Tuck and Wilcox, 2010).

To more fully diagnose the continuing decline of the flesh-footed shearwater at Lord Howe Island, we need to improve our understanding of their distribution during the non-breeding season (austral winter). The development of a range of devices since the 1990s has greatly improved our ability to track bird movements, and small, leg-mounted light-based geolocators (Global Location Sensors or GLS loggers) have proven particularly effective for use on small seabirds (Shaffer et al., 2009; Rayner et al., 2011a). We deployed GLS loggers on flesh-footed shearwaters from Lord Howe Island in three different years in order to determine annual variation in timing of migration and non-breeding distribution, use of different water masses and oceanographic features, and levels of overlap and potential interaction with particular fisheries.

2. Materials and methods

2.1. Logger deployments

Lord Howe Island (31°30'S 159°05'E) is a small oceanic island in the northern Tasman Sea, situated approximately 600 km east of the Australian mainland. We tracked post-breeding adults throughout their migrations to the northern hemisphere, in three years. Two types of archival tags were used: LTD 2400 (Lotek, St. Johns, Newfoundland) in 2005 and 2007, and Mk7 GLS loggers

(British Antarctic Survey, Cambridge, UK) in 2007 and 2008. Archival tags were fastened to the left leg of each shearwater using a 25 mm Velcro strip. Total weights, including attachment, of Mk7 GLS and LTD 2400 loggers were 5.1 g and 7.1 g, respectively (0.7–1.3% of adult body weight).

Tags were deployed on birds occupying burrows that were known to contain chicks during visits in April. As shearwaters breed annually (Marchant and Higgins, 1990), these birds were considered most likely to return to breed the subsequent year. We attached 20 loggers in April 2005, 22 in 2007 and 23 in 2008. Loggers were recovered during late October and early November of the following austral summer.

The LTD 2400 loggers recorded light levels, temperature and pressure (depth) every two seconds. The temperature sensor has a resolution of 0.05°C and accuracy of ±0.1°C. The Mk7 GLS loggers sampled light levels every minute and at the end of every ten minute period the maximum light level was recorded. Additionally, every three seconds the logger tested for saltwater immersion, and recorded the number of positive tests every ten minutes; hence, values range from 0 (fully dry) to 200 (fully wet). The temperature sensor of these loggers is internal and takes ten minutes to stabilize, so temperatures were recorded after 20 min of continuous immersion. To conserve memory, another record was only taken after a subsequent dry event, followed by a further 20 min of continuous immersion. Shearwaters rest on the water for a number of hours each night and hence most records of water temperature were taken in the hours of darkness. The temperature sensors of Mk7 loggers had a resolution of 0.625°C and an accuracy of ±0.5°C. All loggers were calibrated for 2–7 days at the study site before and after deployment on birds. Temperature sensors were calibrated by taking readings of known temperatures between 5–35°C in a salt water bath.

Several studies have examined the effects on foraging efficiency, trip duration or return rates of attaching devices such as GLS loggers or satellite-transmitters to wild animals (Phillips et al., 2003; Söhle, 2003; Igual et al., 2005; Vandenabeele et al., 2012). Past studies have not found major effects, and given its relatively large size, we did not expect to find significant effects of loggers on our study species. In order to determine if there was any effects of attaching tags, forty recently returned adult flesh-footed shearwaters (with devices, or randomly-selected controls) were weighed during October/November 2008. Birds were sexed using methods from Thalmann et al. (2007). The effects of sex and device deployment on body mass was tested using a model based on Equation 1 (using the R package r2winbugs);

$$Weight_i = \alpha + \beta_{j(i)} * Sex_i + \delta_{k(i)} * Attachment_i + \varepsilon_i \quad (1)$$

$$\varepsilon_i \sim Normal(0, \sigma^2)$$

where $Weight_i$ is the weight of bird i , α is the value for the base case (female with no attachment), β is the coefficient of the factor Sex , which could take three levels j (female, male and unknown) and δ is the coefficient of the factor $Attachment$, which can take two levels k (no and yes), with an error term ε . Importance of these variables is indicated by how far their mean and credible interval deviate from 0, with non-significant terms overlapping zero and those that had a significant effect not overlapping zero. In order to further compare the effects of these terms, we examined the Deviance Information Criterion (DIC) of four models using combinations of these terms (single term, both terms, interacting terms).

2.2. Estimation of at-sea movements

Positions derived from GLS loggers deployed on flying birds are known to be somewhat inaccurate, with mean errors of 186 km attributable to variation in sensor orientation, intermittent shading by plumage, time of year, and extensive, potentially non-linear

movements (Phillips et al., 2004). Estimates of Latitude derived from GLS loggers are less certain than those for Longitude (Phillips et al., 2004). To better integrate knowledge of tracks and to reflect the underlying uncertainty involved in geolocation, at-sea movements were estimated using a Bayesian approach with a Markov Chain Monte Carlo method to approximate the posterior distribution of the track using the tripEstimation software (version 0.0–24) package in R (R Development Core Team, 2009; Sumner et al., 2009). Initially, two positions per day were estimated from light intensities during twilight periods (Sumner et al., 2009). The track developed this way can be considered as part of a latent movement model (Sumner et al., 2009). Namely, starting from the incomplete observations (here the positions based on light data recorded by the loggers), improved estimates of the true positions were obtained by combining these initial positions with other sources of information, including prior data (that seabirds do not feed over land), data recorded by the logger, such as sea surface temperature (SST) and the distribution of likely flight speed (Reid, unpublished data) to find a posterior track (Sumner et al., 2009; Thiebot and Pinaud, 2010). Water temperature recorded at night by the logger was compared with weekly averaged $1 \times 1^\circ$ NCEP Reynolds Optimally Interpolated SST (Reynolds and Smith, 1994), and choosing locations that were no more than 2°C higher or 2°C lower, respectively, than the maximum and minimum temperatures recorded by the logger (Sumner et al., 2009). Temperatures were chosen to reflect the known temperature gradients likely to be encountered by the shearwaters. Chains for each track were run 20,000 times in order to derive two mean positions for each day after an initial burn-in of 10,000 (Sumner et al., 2009).

Dates of departure and return from migration were identified by examining the light, temperature and immersion data. As flesh-footed shearwaters only visit their burrows at night, the date of first return was assumed to be that preceding the first occasion that the logger was completely dry overnight. Departures are more difficult to identify, as birds only visit their burrows very briefly to feed older chicks. Approximate departure dates were identified as the last period of extended dryness recorded by the immersion data during the night (generally, at night, birds spent most of their time on the water) prior to their migrating northwards (as shown by positions from light data).

2.3. Kernel analysis

Two mean daily posterior positions were derived for each trip from tripEstimation for use in kernel density analysis (above). A two-dimensional binned kernel density estimate was used to identify core areas used each non-breeding season. After inspection of a range of band widths, a band width of ~ 75 km was chosen (Wand and Jones, 1995). This creates a grid with a matrix of density estimates, which are then plotted to give a visualisation of areas used. The analysis was based on a standard bi-variate normal density, and was performed using the KernSmooth package (version 2.23) in R (v. 2.9.0; R Development Core Team, 2009). Kernel analysis assumes that the positions are independent and identically distributed (Wand and Jones, 1995), whereas animal tracking data are highly auto-correlated. Therefore, kernel density plots should be viewed with some caution. An alternative method of showing areas used, and presenting all uncertainty, is to plot all chains derived from tripEstimation (Appendix A).

3. Results

3.1. Effect of loggers

Twenty-two birds with loggers, and 18 control birds without loggers were weighed on their return to the colony. This included

25 females, 9 males and 6 of unknown sex. Mean weights of returning females without loggers attached were 573.5 g (on-line Appendix Table A1). The mean mass of males, birds of unknown sex and birds that had a logger over the previous winter were higher than females without a logger (on-line Appendix Table A1). However, only the credible interval (Bayesian confidence interval) for males did not overlap with that of females, indicating that while sex was having a significant effect on the returning weights of weighed birds, the attachment of a logger was not. Similarly, variation in the weight of recently-returned birds was best explained by a model that only included sex (on-line Appendix Table A2).

3.2. Movements of non-breeding flesh-footed shearwaters

We retrieved 17, 19 and 19 loggers, in 2005, 2007 and 2008 respectively (85%, 86% and 83% of those deployed in each year). Some loggers failed to download or the data were corrupted (six, nine and three in 2005, 2007 and 2008, respectively), hence data on movements during the non-breeding period were available for 11, 10 and 16 flesh-footed shearwaters in 2005, 2007 and 2008, respectively.

Flesh-footed shearwaters departed their colonies in late April or early May; median departure date of 25 April in 2005 and 2008, and 30 April in 2007 (Table 1). There was one outlier (a bird that departed on 2 April), whose chick was weighed subsequently (on 8–11 April) and found to be below the 20th percentile of weights recorded at the time. Median return dates were in late September (the latest were in mid October) and varied by only 3 days between years (Table 1).

All tracked birds spent the austral winter in the north-west Pacific Ocean (Fig. 1). Most birds (87%) either migrated to the Sea of Japan, waters to the east of Japan, or both, and 13% went to the Yellow Sea or East China Sea between Korea and Taiwan. Within the Sea of Japan, birds concentrated in the area of the Sub-Arctic Convergence, either off the coast of Korea (40% of all locations in the Sea of Japan), or off the west coast of Japan (60%). Those birds that spent the non-breeding period to the east of Japan were found in the convergence zone of the warm Kuroshio and cold Oyashio currents (Fig. 1; Tomczak and Godfrey, 2003). There was little difference between years in the areas used (Fig. 2). Tracked birds spent their time predominantly in waters with a median SST of $15\text{--}25^\circ\text{C}$ (Table 2).

Once in the non-breeding region, birds moved gradually further north (and those in the Sea of Japan moved northeast) as time progressed, with the centre of the kernel distribution at $\sim 35^\circ\text{N}$ during May–June and $\sim 40^\circ\text{N}$ during July–September (Fig. 2). During May some staged in the Philippine Sea west of the Northern Marianas Islands at about 20°N 140°E , though this was more apparent in 2005 and 2008, than in 2007. Birds were present in the Sea of Okhotsk and the Tatar Strait only in the latter part of the non-breeding season (July–September).

When migrating northwards at the start of the non-breeding period, the tracked birds followed a fairly direct route on a north-westerly bearing (Figs. 2 and 3). When returning south towards the colony, there was some indication that birds passed further east than on the northward migration (Figs. 2 and 3).

One bird tagged in April 2005 was not recaptured until November 2007, providing data for three successive years (Fig. 4). During all three winters it spent the majority of time in the western Sea of Japan (west of 135°E). Arrival dates in this area each year were very consistent (15 May 2005, 5 May 2006 and 15 May 2007). Later easterly movements were less consistent; the bird departed for the Sea of Okhotsk and the Tatar Strait on 1 August 2005, 10 July 2006 and 27 July 2007, where it remained until its eventual migration south to the breeding colony. First return to the colony

Table 1

Timing of migration and period away from colony of flesh-footed shearwaters tracked from Lord Howe Island using GLS loggers.

Year	Number of birds tracked	Departure dates		Return dates		Migration duration	
		Median	Range	Median	Range	Median	Range
2005	11	25 April	20 April–4 May	30 September	22 September–18 October	149	149–167
2007	10	30 April	29 April–5 May	27 September	25 September–21 October	150	146–169
2008	16	25 April	2 April–4 May	29 September	20 September–6 October	160	141–180

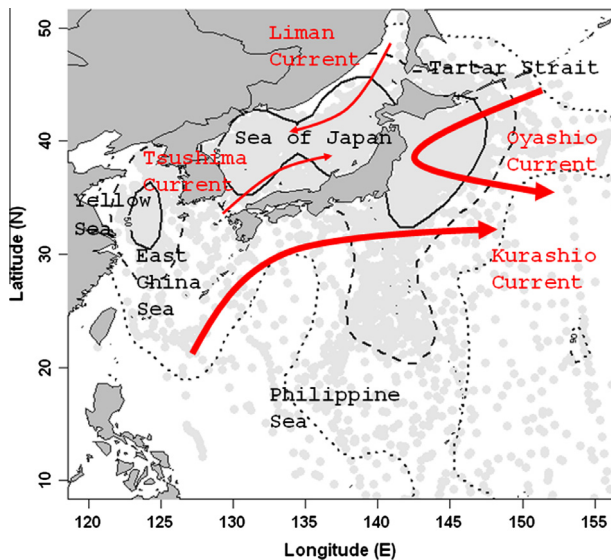


Fig. 1. Density distribution of flesh-footed shearwaters tracked from Lord Howe Island using geolocators in winter 2005, 2007 and 2008. Isopleths represent 90% (dotted), 75% (dashed) and 50% (continuous) kernel isopleths using the pooled dataset. Approximate route of the major currents in the region adapted from Tomczak and Godfrey (2003).

occurred in late September or early October (27 September 2005, 21 September 2006 and 6 October 2007).

4. Discussion

During three winters, all flesh-footed shearwaters tracked from Lord Howe Island migrated to the north-west Pacific Ocean, confirming the pattern of band recoveries from this colony (Tuck and Wilcox, 2010; ABBBS data, unpublished). Only a small number of flesh-footed shearwaters from other locations have been tracked during the non-breeding period. This includes three from Kaua-haia Island off the North Island of New Zealand, which travelled to similar areas to those visited by the birds from Lord Howe Island (Rayner et al., 2011b). In contrast, birds from Western Australia fitted with satellite-transmitters in 2008 were tracked towards the central Indian Ocean when transmission ceased in early May (Powell, 2009). These results tend to confirm previous suggestions of a migratory divide, with birds from Western Australia migrating to the western Indian Ocean, and those from Lord Howe Island and New Zealand to the North Pacific (Bourne, 1960; Bailey, 1966; Brooke, 2004). The wintering area of the small population on Smith Island in South Australia is unknown.

Flesh-footed shearwaters tagged in this study migrated to three principal regions in the north-west Pacific Ocean, (i) south-east Japan, (ii) the Sea of Japan and (iii) the East China Sea. Each of these regions has particular oceanographic features and fisheries that might attract the birds and potentially lead to fatal interactions.

4.1. South Eastern Japan

The distribution of shearwaters from New Zealand and Lord Howe Island overlapped off southeast Japan at the confluence of the Kurashio and Oyashio currents (Rayner et al., 2011b, this study). The Kuroshio current is a warm current that flows north-east from the Philippines past the east coast of Japan, with the Tsushima current branching off toward the Sea of Japan (Tomczak and Godfrey, 2003). Off Hokkaido it meets the cold, southward flowing Oyashio current. The resultant high productivity where these currents converge attracts predatory fish and squid, and hence many fisheries (Tian et al., 2004). Good fishing grounds for pole and line fisheries occur in warm waters where the mixing layer between the fronts is shallow, forcing prey and predatory fish nearer the surface.

The waters to the south east of Japan are also an important area for longline fishing for tunas and billfish, exploited by Japanese distant-water and domestic coastal vessels (<20 Gross Registered Tonnage [GRT]) (Rayner et al., 2011b). The Korean, Taiwanese and Japanese distant-water longline fleets mainly operate in equatorial regions when targeting tropical tunas (Anon, 2011a; Kim et al., 2011; Uosaki et al., 2011). The Japanese and Taiwanese fleets also operate in northern hemisphere temperate waters targeting albacore. The Taiwanese temperate water fleet is largely to the east of 155°E suggesting that overlap with the main concentrations of flesh-footed shearwaters off the east coast of Japan is likely to be minimal. The Japanese distant-water fishery also operates to the east of Japan targeting swordfish *Xiphias gladius* and albacore *Thunnus alalunga* in areas that overlap with non-breeding flesh-footed shearwaters tracked from both Lord Howe Island and New Zealand (Rayner et al., 2011b; Uosaki et al., 2011, this study). Landings and effort from this fishery have declined markedly since the early 1980s, and in 2010 only 171 vessels were operating, compared with 1520 in 1980 (on-line Appendix Fig. A2; Anon, 2011b).

The distribution of effort in the Japanese domestic coastal longline fishery suggests it is likely to overlap with non-breeding flesh-footed shearwaters to the south east of Japan where albacore are targeted (Tuck and Wilcox, 2010; Uosaki et al., 2011; Fig. 5). An historical time-series of fishing effort for this fishery was not available, however annual catch (which is not necessarily a good proxy for fishing effort), increased until the mid-1990s, and has since remained stable at around 35–40,000 tonnes of tunas and billfish. The coastal fishery currently deploys more hooks in waters surrounding southeast Japan than the offshore and distant-water longline fleet (Uosaki et al., 2011), and catch more tunas and billfish than the entire distant-water fleet reporting to the Western and Central Pacific Fisheries Commission (Fig. 5). Member nations of the Western and Central Pacific Fisheries Commission (WCPFC) currently must use at least two of ten suggested mitigation measures when fishing north of 23°N (WCPFC, 2007) and Japan's National Plan of Action for seabirds (Anon, 2009) states that coastal and near-shore longline vessels shall adopt similar mitigation measures. Given the large scale overlap between birds and vessels (in particular with domestic longline fisheries), and the magnitude of the fishing effort, the longline fisheries off eastern Japan potentially pose a very serious threat to flesh-footed shearwaters.

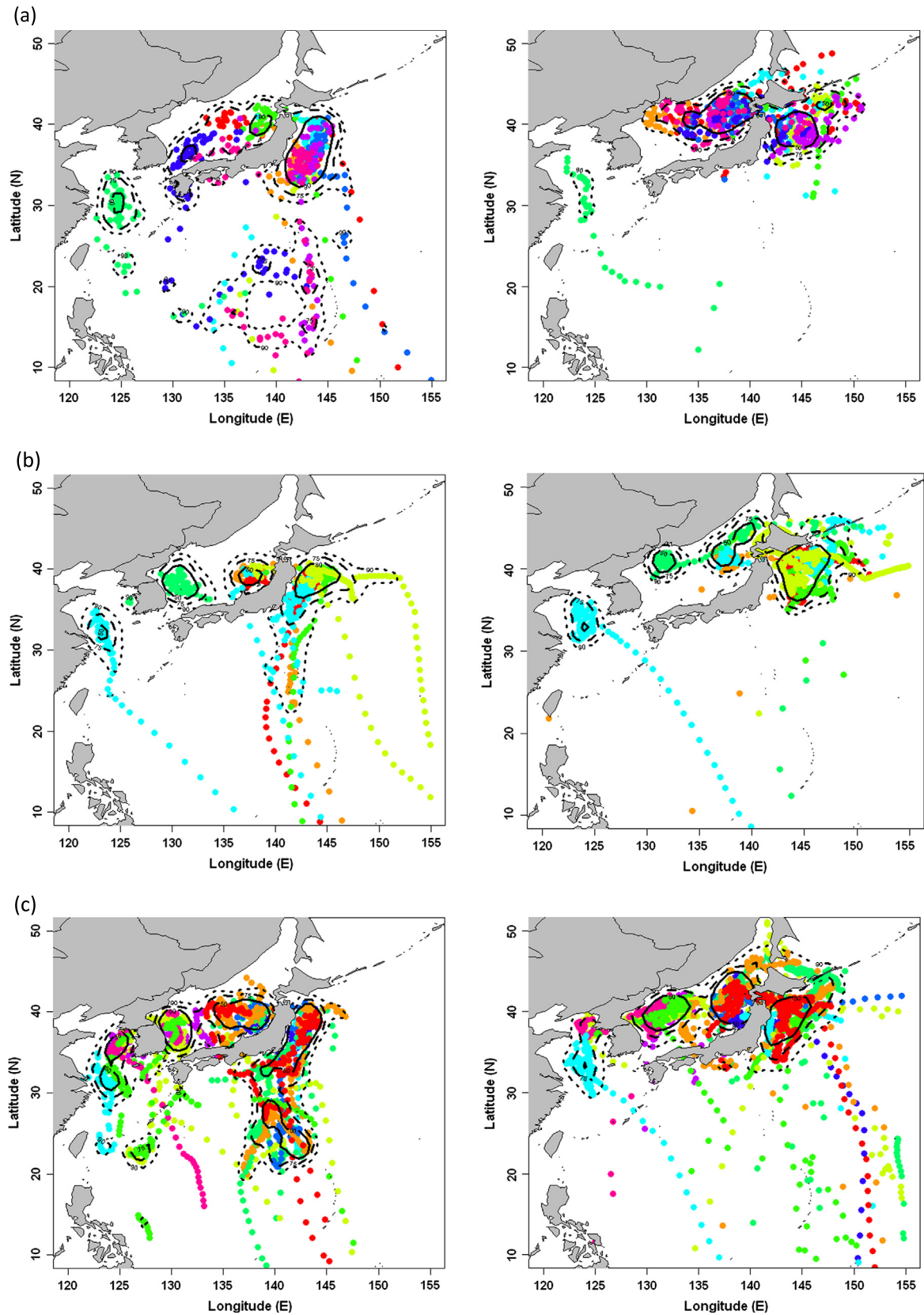


Fig. 2. Nonbreeding distribution (Isopleths represent 90% (dotted), 75% (dashed) and 50% (continuous) kernel isopleths) of flesh-footed shearwaters tracked from Lord Howe Island using GLS loggers in 2005, 2007 and 2008. Different colours represent individual birds. Left plots are early season (May–June), right plots late season (July–September). (a) 2005 nonbreeding season ($n = 10$ birds). (b) 2007 nonbreeding season ($n = 9$ birds). (c) 2008 nonbreeding season ($n = 16$ birds).

Table 2

Median \pm sd temperatures in waters used by flesh-footed shearwaters during the nonbreeding season (north of 20°N, i.e. excludes the outward and return migration).

Month	2005	2007	2008
May	17.4 \pm 4.2	15.2 \pm 2.8	15.5 \pm 3.6
June	17.5 \pm 3.3	17.4 \pm 2.2	16.8 \pm 2.6
July	20.2 \pm 3.4	19.0 \pm 3.1	19.9 \pm 2.8
August	21.4 \pm 3.4	19.8 \pm 3.7	20.3 \pm 2.9
September	26.3 \pm 4.7	21.8 \pm 3.7	24.4 \pm 4.4

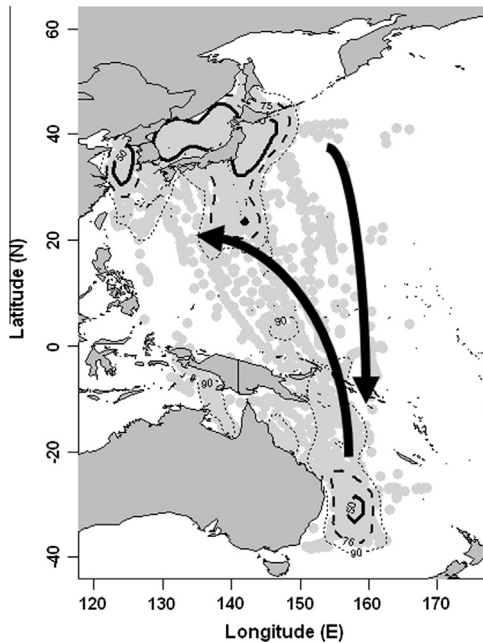


Fig. 3. Migration routes of flesh-footed shearwaters. Grey dots for each record (isopleths represent 90% (dotted), 75% (dashed) and 50% (continuous) kernel isopleths). Black arrows show approximate migration routes.

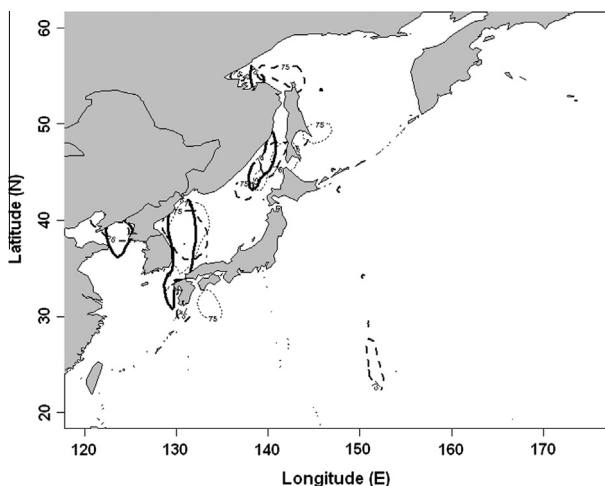


Fig. 4. Nonbreeding distribution of a single flesh-footed shearwater tracked in three consecutive years (2005, 2006 and 2007). The map shows the 75% kernel isopleths north of 20°N (continuous = 2005, dashed = 2006 and dotted = 2007).

4.2. The Sea of Japan

The Sea of Japan was an important foraging area for birds tracked in this study. Most birds were concentrated either off the

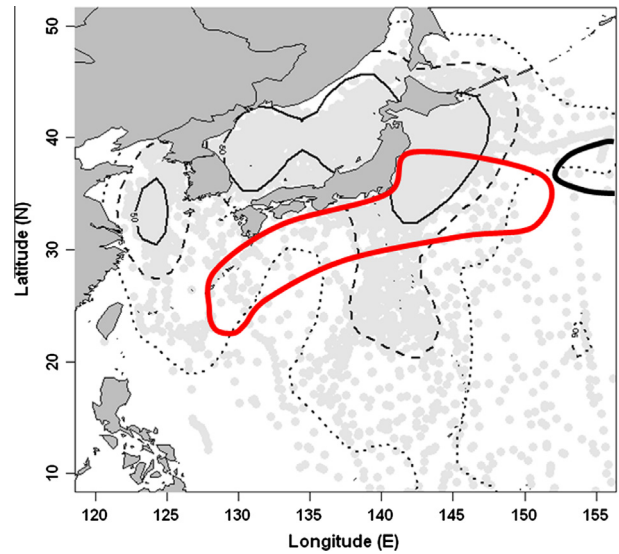


Fig. 5. A schematic representation of the principal areas of fishing effort for the Japanese domestic coastal longline (<20 GRT) fleet based upon data from Uosaki et al., 2011. Red circle is area used during Quarter 2 (April, May, June), Black for Quarter 3 (July, August, September). Isopleths represent 90% (dotted), 75% (dashed) and 50% (continuous) kernel isopleths using the pooled dataset (May–September). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

east coast of Korea, or off the Tsugaru Strait between Hokkaido and Honshu. Some were also distributed along the Sub-Arctic convergence between the Tsushima and Liman currents. Convergence zones such as this are generally highly productive and frequently favoured by seabirds (e.g. Pinaud and Weimerskirch, 2005). Flesh-footed shearwaters have previously been recorded following schools of mackerel within the Sea of Japan, and a large mackerel fishery exists in this area (Terazaki, 1999; Shuntov, 2000). Birds generally moved north-east when resident in the Sea of Japan, which corroborates shipboard observations that they were more common in the west in spring and summer, and in the northeast later in the season (Shuntov, 1998). At-sea observations suggest that the Sea of Japan is more important for flesh-footed than short-tailed *Puffinus tenuirostris* or sooty shearwaters *P. griseus*, although all three migrate to the north-west Pacific Ocean in large numbers (Shuntov, 2000). This may reflect somewhat differing habitat preferences, given that unlike flesh-footed shearwaters, short-tailed and sooty shearwaters frequently forage in Antarctic waters during the austral summer (Klomp and Schultz, 2000; Shaffer et al., 2009; Thalmann et al., 2009), and sooty and short-tailed shearwaters travel further north than flesh-footed shearwaters, to cold Bering Sea and Arctic waters, in the nonbreeding season (Marchant and Higgins, 1990; Klomp and Schultz, 2000; Shaffer et al., 2006, 2009). However, their preferences are clearly not exclusive, as tracked flesh-footed and sooty shearwaters overlap in waters east of Japan (Shaffer et al., 2006, this study).

Flesh-footed shearwaters overlap with a number of fisheries for smaller bait fish in the Sea of Japan and the East China Sea. Although their diet in nonbreeding grounds is unknown, these bait fish are potentially important prey (Marchant and Higgins, 1990). Fisheries in these regions are among the most heavily exploited in the world, and indeed those in the Sea of Japan are considered to be overexploited (FAO, 1999; Sherman et al., 2009). There are numerous examples of the impact of overfishing on seabirds in areas such as the North Sea and the Benguela upwelling system (Monaghan, 1992; Griffiths et al., 2004); thus, if overfishing is occurring in the bait fisheries off East Asia, it may well be having

a detrimental effect on shearwaters in their nonbreeding grounds, through both direct bycatch and indirect depletion of prey resources.

4.3. The East China Sea

Approximately 10% of flesh-footed shearwaters wintered in the Yellow or East China seas. Use of this region was apparent in all three years. There are very large fisheries for pelagic species, including chub mackerel (*Pneumatophorus japonicus*), black scraper (*Navodon modestus*), and anchovy (*Engraulis* spp.) in this region, which provide a large proportion of the catch for the domestic Chinese market (NOAA, 2000). As far as we are aware, there are no bird bycatch observers on board vessels, or published bird bycatch data from this area, and therefore the threats posed by these very extensive fisheries to flesh-footed shearwaters are entirely unknown.

4.4. Site fidelity and nonbreeding range

One shearwater was tracked for three successive years (2005–2007), and in each year remained in the western Sea of Japan from mid-May to late July. There are few previous studies of site fidelity in successive years in migratory seabirds. Individuals of another annual breeder, the black-browed albatross *Thalassarche melanophris*, travelled to the same region during the nonbreeding period in two successive years, and showed very similar centres of distribution; in contrast, fidelity to staging areas used when migrating to and from the breeding grounds was less strict (Phillips et al., 2005). Thus, their behaviour was similar to the flesh-footed shearwater detailed here. However, five out of 14 Cory's shearwaters *Calonectris diomedea* from the North Atlantic were found to winter in different areas in successive years (Dias et al., 2011). Grey-headed albatrosses *T. chrysostoma*, which are biennial breeders when successful, also showed fidelity to nonbreeding grounds, but variation in use of staging areas and in timing of movements in successive years (Croxall et al., 2005). The western Sea of Japan supports an annual mackerel fishery, and given the presence of the subarctic convergence, is likely to support a consistently high level of marine productivity (Terazaki, 1999). For this reason, it would be advantageous for seabirds to return there in successive years, rather than attempt to find alternative feeding grounds where that would entail an unnecessary risk. However, retaining flexibility in the timing of visits to migratory staging areas in different years is also important.

While our study highlights the importance of the north-west Pacific Ocean as a preferred region of migration, flesh-footed shearwaters are also recorded regularly in small numbers as far as c. 50°N in the north Pacific Ocean (Tuck and Wilcox, 2010) and off the west coast of North America between March and October (Wahl and Tweit, 2000; Tuck and Wilcox, 2010). None of the birds tracked from Lord Howe Island were recorded east of 170°E. However, birds from Lord Howe Island, and those from New Zealand, first travelled east from Japan before the migration south (Rayner et al., 2011b, this study). Given the relatively small number of birds that have been tracked, it is conceivable that others move as far east as the North American coast at this time. Alternatively, as some of the sightings are from the northern winter/austral summer, it is also possible that the records are of juveniles or pre-breeders, which disperse more widely than adults (Tuck and Wilcox, 2010).

5. Conclusion

It appears that the population of flesh-footed shearwaters at Lord Howe Island continues to decline despite evidence that some

of their threats have ameliorated in recent years. There are also indications that the New Zealand and Western Australian populations are smaller than previously estimated (Priddel et al., 2006; Baker et al., 2010; Reid et al., 2013, J. Lavers pers.comm.). As such, there is an urgent need to confirm the supposed migratory divide between the western and eastern Australian populations, and to improve our knowledge of the marine and terrestrial threats that each population may be facing.

This paper has illustrated the large potential for interactions between wintering flesh-footed shearwaters and northern hemisphere longline fisheries. The lack of available data on bird bycatch rates from these fisheries is a cause for concern. While the Australian domestic longline fishery overlaps substantially with breeding flesh-footed shearwaters, assessments of bird bycatch rates in this fishery conclude that there was a marked decline in recent years (Gales et al., 1998; Baker and Wise, 2005; Tuck and Wilcox, 2010). In fact, on-board observations from the domestic Australian fishery indicate that no flesh-footed shearwaters have been observed caught since 2006 (AFMA, unpublished data). The results presented here suggest that most or all birds breeding in eastern Australia spend the nonbreeding period in the northwest Pacific Ocean. Collection of data on bycatch rates, fishing effort and overlap in distribution of fisheries and birds in this region is clearly imperative for their conservation and management.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.biocon.2013.06.006>.

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