THE FORAGING AND MIGRATION OF MANX SHEARWATERS ON LUNDY

by

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INTRODUCTION

The complex foraging and migratory movements of many species have largely remained mysterious outside of ringing records and at-sea surveys. Gathering high-resolution behavioural information for individual animals has, until recently, been expensive and required large devices. The continuing miniaturisation of tracking technology is now enabling researchers to record the year round movements of individual animals in the wild and to record in high detail their dynamic foraging behaviour. The richness of information these technologies provides is starting to provide new insights into the magnitude of migratory journeys (Egevang *et al.* 2010), important foraging areas (Freeman *et al.* 2010a), individual movement consistency (Phillips *et al.* 2005; Guilford *et al.* 2011) and the dynamical interaction of animals and their environment (Phillips *et al.* 2006; Shaffer *et al.* 2006; Felicisimo *et al.* 2008; Weimerskirch *et al.* 2012).

We have recently examined the foraging and migratory movements of the Manx Shearwater (*Puffinus puffinus*) breeding on Skomer Island (Guilford *et al.* 2008; Guilford *et al.* 2009) using both miniature global positioning system (GPS) devices and geolocation devices. The Manx Shearwater is a small (c.400g), nocturnal, migratory seabird which is of special importance in the UK as the majority of individuals (93%) breed in the UK and Ireland (Mitchell *et al.* 2004).

Lundy is an isolated island in the Bristol Channel, approximately 20 km off the northern coast of Devon. Lundy hosts a number of seabird species, and has recently successfully eradicated an invasive rat population resulting in an encouraging increase in the number of breeding individuals of many species (Brown *et al.* 2011). Manx Shearwaters in particular have shown a dramatic increase on Lundy over the last decade (~250%) likely due to the eradication programme.

In this context, we here report on the successful tracking of foraging and migratory movements of individual Manx Shearwaters breeding on Lundy. We have previously reported on the similarity of migratory routes of shearwaters breeding on the island to those on Skomer Island (Dean *et al.* 2011). In this paper, we report on a second year of migratory tracking and a third year of tracking during summer foraging.

METHODS

Study birds

This research is part of an ongoing study on Lundy initiated in 2009 (Freeman *et al.* 2010b; Dean *et al.* 2011). Over two previous years (2009, 2010) geolocation devices have been deployed on individuals breeding at an existing study colony near the Old Light on the west side of the island. In previous seasons, burrows with established breeding pairs were identified and marked. Twenty marked burrows were then pegged with small bamboo sticks which are displaced when birds enter or leave the burrow. Pegged burrows were netted with purse nets to capture departing or returning birds and monitored from dusk till dawn each night. All nets were inspected at regular 15-minute intervals. Unmarked birds found in nets that had not attempted to enter burrows were ringed with a metal BTO ring and released on the surface. If the bamboo pegs were disturbed by apparent entrance or exit, the bird was assumed to be resident and selected for deployment.

Over the period 26 July to 8 August 2011, study burrows were rediscovered and markers refreshed for ease of identification during nocturnal work. As previously, purse nets were deployed at each burrow entrance and monitored at regular intervals. Captured birds with existing geolocation devices either had the devices downloaded *in situ* or removed and replaced with a fresh device. Birds of sufficient mass were selected for GPS deployment, and further processed.

GPS Deployments

A total of 23 lightweight GPS devices (iGotU-120, Mobile Action) were deployed between 27 and 31 July 2011. Devices were attached above the centre of gravity to four or five small bunches of back feathers using 1-cm strips of waterproof Tesa tape (Guilford *et al.* 2008). The total weight of individual GPS devices and attachments was 14.5-15g. On recapture, devices were recovered by carefully peeling back the tape, removing the device and then removing remaining tape from feathers. Birds were weighed on deployment and recovery to assess mass changes during the tracking period.

GLS Deployments

GLS devices (2.5g Mk15 and Mk19; British Antarctic Survey, Cambridge) were attached to elliptical Darvic rings with miniature cable-ties and fitted to the birds' legs. Devices were recovered or downloaded *in situ* the following year.

Data analysis

Raw geolocation light data were processed using TransEdit2 and Locator (British Antarctic Survey, see Geolocator manual v8, available at: **ftp://ftp.nerc-bas.ac.uk/pub/addg/Geolocator_manual_v8.pdf**), with a light-dark threshold value of 5, sun elevation angle of -3.5° and minimum dark period of four hours. Trajectories were then calculated from transition data using Locator (British Antarctic Survey), with a sun elevation angle of -3.5° and retarding sunsets by nine minutes. Locations recorded within seven days of the seasonal equinoxes were removed as the uniform day-length makes location estimates inaccurate. Any locations with an apparent speed of more than 50 kmh^{-1} were also removed. As resulting locations have a mean error of 85 km ± 47 km (Phillips *et al.* 2004), they may appear over land.

Estimated locations for both GPS and geolocation data were further processed and mapped using ArcMap (ESRI Inc. 1999-2012), and the Geospatial Modelling Environment (Spatial Ecology LLC). Kernel density estimates (for occupancy contours) were produced with a bandwidth of 0.1 and a cell size of 1 for migration data, and a bandwidth of 0.005 and cell size of 0.01 for foraging data.

RESULTS

Foraging trips

Of 23 deployments, a total of 19 individuals carrying GPS devices were recaptured (Table 1), resulting in 16 recorded foraging trips (with three devices waterlogged). Foraging trips lasted from two to eight days, with a roughly bimodal distribution of trip lengths. Most individuals showed a net gain in mass over the tracking period.

Table 1. GPS Deployment summaries for each bird. Dates of deployment and recovery of devices and mass changes are shown. Starred records indicate unsuccessful deployments, due either to waterlogging or lack of recapture within the study period.							
Ring number	**Burrow**	**Deployment**	**Recovery**	**Duration**	**Mass at deployment**	**Mass at recovery**	**Change in mass**
FB32225	5	27/07/2011	30/07/2011	3	420	411	-9
EW87540	6	27/07/2011	01/08/2011	5	400	420	20
EW87954	9	27/07/2011	03/08/2011	7	420	–	–
FB32229	7	27/07/2011	02/08/2011	6	363	375	12
EW87613*	1	27/07/2011	04/08/2011	8	440	413	-27
FB32227*	14	27/07/2011	–	–	405	–	–
EW87548	13	27/07/2011	01/08/2011	5	375	392	17
EF98338	3	28/07/2011	04/08/2011	7	415	419	4
EW87541	7	28/07/2011	30/07/2011	2	443	545	102
FB32224	2	28/07/2011	30/07/2011	2	425	426	1
EF98348	8	28/07/2011	31/07/2011	3	432	400	-32
EW87558	14	28/07/2011	31/07/2011	3	390	367	-23
FB32230	1	28/07/2011	01/08/2011	4	393	457	64
EW87547*	11	28/07/2011	–	–	380	–	–
FB32226	5	28/07/2011	31/07/2011	3	382	428	46
FB32223*	6	30/07/2011	–	–	385	–	–
FC27339*	2	30/07/2011	02/08/2011	3	468	460	-8
EW87543*	9	30/07/2011	–	–	413	–	–
EX62015	3	30/07/2011	01/08/2011	2	416	401	-15
EW87555	13	31/07/2011	05/08/2011	5	372	333	-39
FB32225*	5	31/07/2011	05/08/2011	5	411	420	9
EF98338	3	31/07/2011	04/08/2011	4	419	452	33
EW87541	12/7	30/07/2011	04/08/2011	5	545	–	–

As in previous years, the distribution of foraging locations remains largely local, but unlike previous years, we see a number of trips south to the northern coast of Cornwall between St Ives and St Just (Figure 1 – see colour plate 12), and no northern trips. There also appears to be a slightly increased level of activity between Lundy and St Ives around Padstow, where the river Camel issues into the sea. Individual routes highlight these patterns (Figure 2 – colour plate 13) with a large mass of local foraging and rafting around Lundy and some direct routes down to the northern coast of Cornwall.

Migration

Sixteen geolocation devices were recovered and two devices showed failures, resulting in 14 tracked migrations covering 2010-2011. Figure 3 (colour plate 14) shows the estimated locations of each individual's migratory route. In general, the pattern of migratory routes is largely consistent with previous years and other colonies (Guilford *et al.* 2009; Freeman *et al.* 2010), with individuals travelling south along the western coast of Africa, across to Brazil then down the eastern coast of South America. Northward movements are also consistent with previous years, with individuals moving into the Caribbean before tracking across the North Atlantic to return to Lundy.

Figure 4 (colour plate 15) shows occupancy contours of overwintering locations, showing those wintering areas where individuals are estimated to have spent 50% of their time. Two distinct zones are evident within the wintering distribution, with individuals moving further south from November to February. In addition, the distribution of individual high-occupancy contours (Figure 5 – colour plate 16) is very variable, with a few individuals making consistent use of the northern areas.

DISCUSSION

The foraging behaviour of Manx Shearwaters on Lundy appears highly dynamic. While a consistent majority of birds appear to forage within local waters, the location of more remote foraging locations appears to differ compared to previous work (Freeman *et al.* 2010; Dean *et al.* 2011). In particular, we recorded no birds foraging more than around 30 km north of the island. However, this may be due to the 'snapshot' nature of most tracking studies, the brief duration of studies masking possibly consistent patterns of foraging behaviour over the season. The advent of devices able to track the foraging movements of individuals throughout the breeding season will likely reveal whether this is the case. The consistent importance of the areas local to Lundy should not, however, be underestimated.

A number of interesting behaviours are highlighted in the individual foraging trajectories. Those individuals who choose to forage further from Lundy sometimes engage in apparent coast-following behaviour, with some trajectories running parallel to the coastline for many kilometres. Other individuals, however, return from the southern area across much more open water, returning to the west-facing colony from the west. Many of the individuals who visited the area of the Cornish coast near St Ives also overnighted there, possibly to exploit nocturnal resources or in anticipation of impending resource shifts.

The migratory movements of shearwaters from Lundy appear consistent with previous work (Dean *et al.* 2011). Individuals migrate to a specific location off the Patagonian shelf. Those areas of high occupancy over winter appear to shift consistently, perhaps in response to shifting sea-surface temperatures, productivity-shifts or seasonal upwelling. However, the contribution to this temporal shift may vary amongst individuals (Figure 5 – colour plate 16), with some individuals remaining in the northern zones of the overwintering areas and others moving to the south. Such individual specialisation may be an important aspect of the overwintering behaviour of the shearwaters and can perhaps be better assessed by exploring the behaviour states of individuals during winter (Guilford *et al.* 2009).

The dynamic, individual nature of the movement ecology of Manx Shearwaters is gradually becoming apparent. As we continue to gather a greater volume of tracking data, we are just starting to uncover the nuances and details that may be missed by traditional tracking programmes. This rounded view of their behaviour is fundamental. The flexibility in foraging movements and the individuality of migratory routes will have important implications for assessing the robustness or fragility of this important species to habitat loss, environmental change and management strategies.

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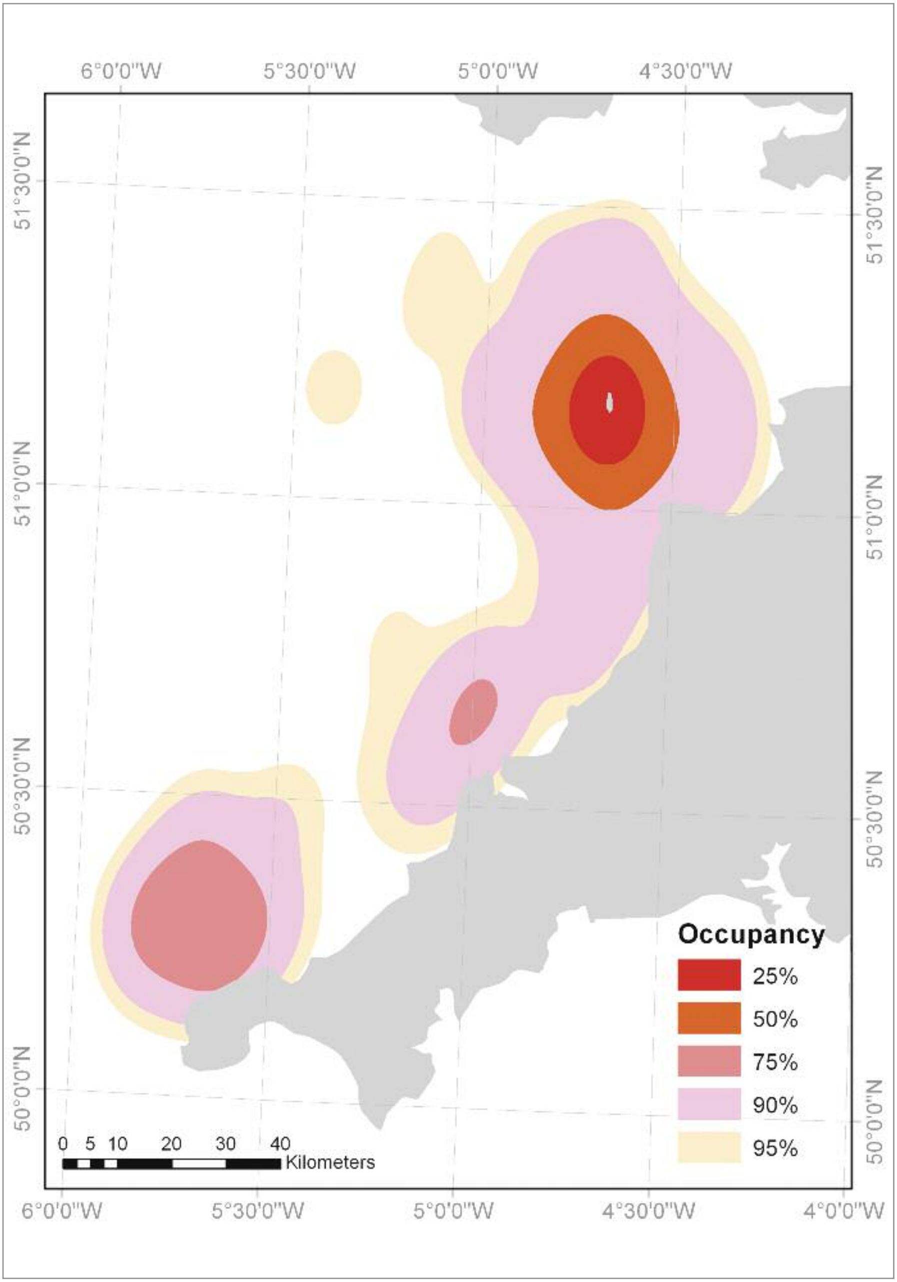
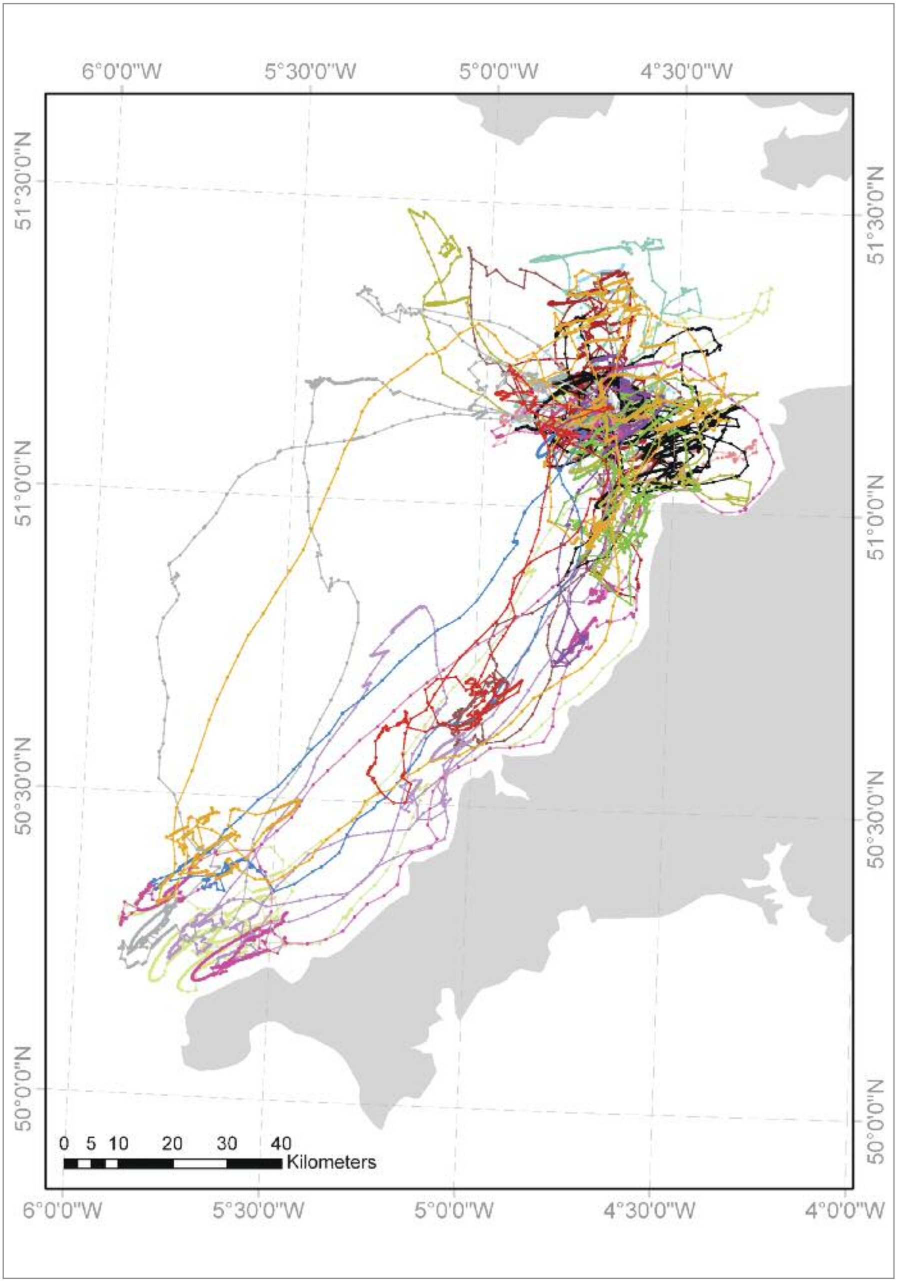
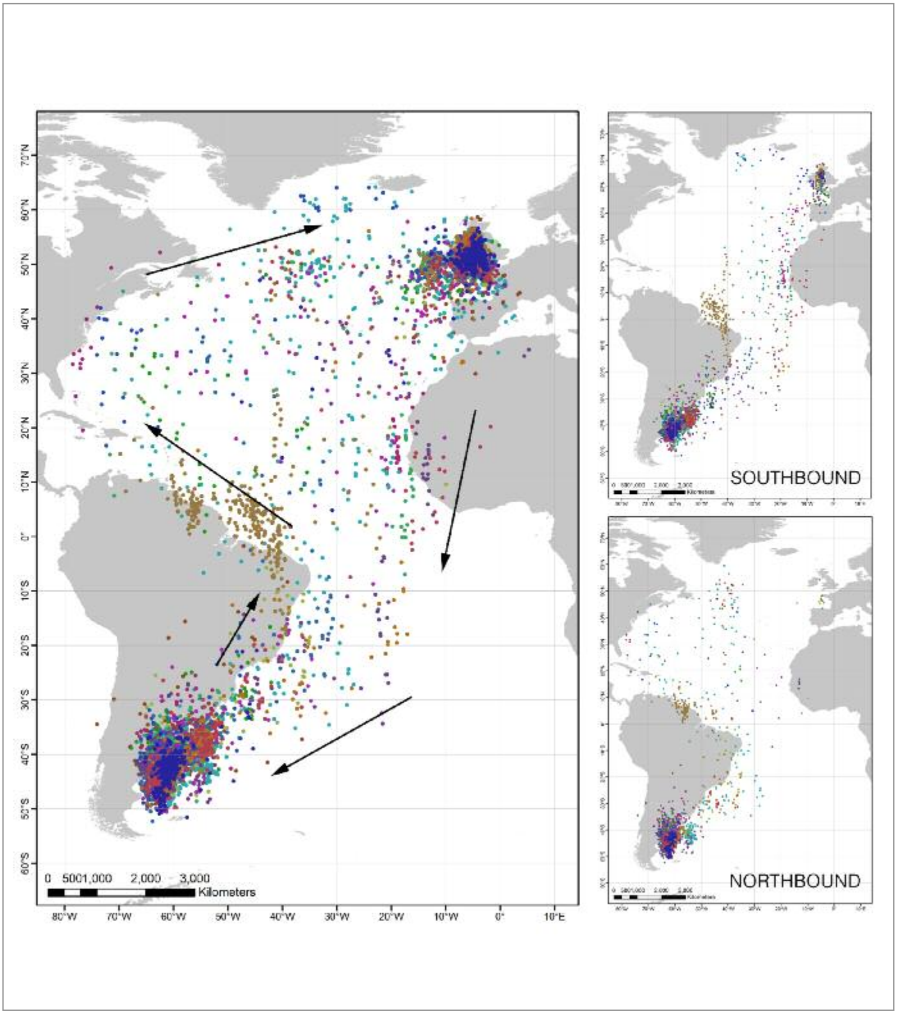
PLATE 12



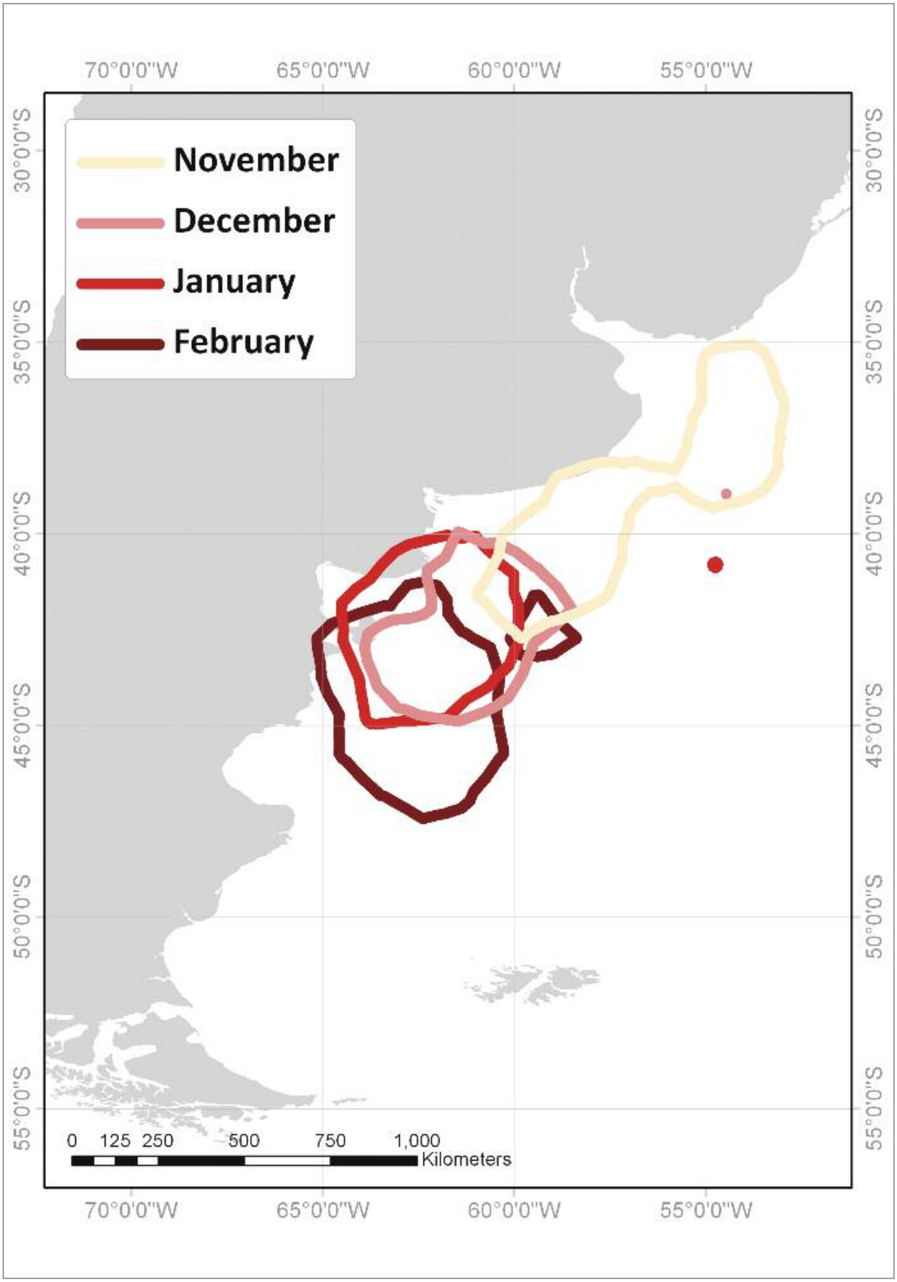
Manx Shearwaters – Figure 1 (p.106). Estimated occupancy polygons for foraging data. Each polygon shows the estimated area that contains a particular percentage of the recorded locations.



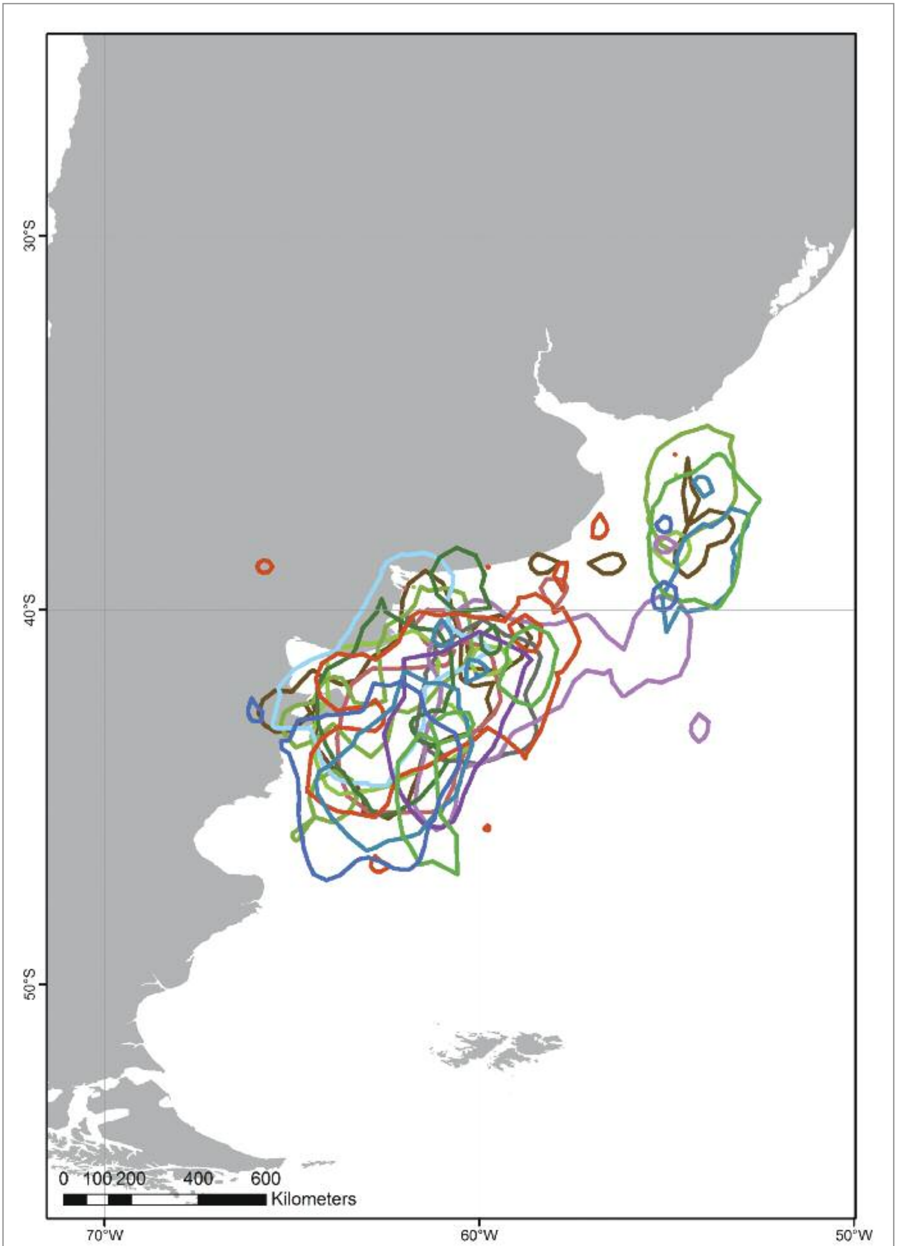
Manx Shearwaters – Figure 2 (p.106). Individual GPS tracks from Lundy 2011, with each individual shown in a different colour.



Manx Shearwaters – Figure 3 (p.106). Migratory routes. Inset panels show those locations for the southbound journey and winter (from September to December) and the northbound journey (from January to April).



Manx Shearwaters – Figure 4 (p.107). Temporal occupancy contours for November, December, January, February for the combined locations of 14 individuals. Each contour shows the estimated areas that contains 50% of the locations for that month.



Manx Shearwaters – Figure 5 (p.107). Overwintering areas. Occupancy contours for each individual showing the core overwintering areas that contain 50% of all overwinter locations.