FORAGING BEHAVIOR OF THE LESSER NODDY *ANOUS TENUIROSTRIS* FROM THE EASTERN INDIAN OCEAN: INSIGHTS FROM MICRO-GEOLOGGING

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Received 14 January 2017, accepted 11 March 2017

ABSTRACT

SURMAN, C.A., NICHOLSON, L.W. & AYLING, S. 2017. Foraging behaviour of the Lesser Noddy *Anous tenuirostris melanops* from the eastern Indian Ocean: insights from micro-geologging. *Marine Ornithology* 45: 123–128.

We present the first tracking data of the foraging behaviour of a small tern, the 100 g Lesser Noddy *Anous tenuirostris* from the eastern Indian Ocean. Using small geologging devices (hereafter GPS), the 17 individuals tracked foraged 4.8–112 km from Pelsaert Island, Houtman Abrolhos, Western Australia. All tracking devices were recovered, and all the tracked individuals continued to breed normally. The mean trip distance was 79.5 km (standard error [SE] 9.8 km), with a mean trip length of 5 h 39 min (SE 39 min), at a mean travel speed of 12.6 km/h (SE 0.6 km/h). In the summer, breeding Lesser Noddies foraged diurnally from 04h00 to 20h40, returning to their colony at night. Individuals tracked in November spent significantly more time foraging and commuted further afield than those tracked in December. Lesser Noddies foraged in the west-southwest sector from the main colonies on Pelsaert Island. The Lesser Noddy at Pelsaert Island is the lightest seabird (104 g) tracked to date using GPS devices. Monitoring of noddies before and after tracking, in conjunction with rapid device attachment, deployment and recovery, indicated that these lightweight GPSs provided a successful tracking device for small seabirds.

Key words: geologging, GPS, Houtman Abrolhos, Lesser Noddy, tropical seabird, Indian Ocean

INTRODUCTION

Recent innovation in the development of lightweight tracking devices, such as global positioning system (GPS) and global location sensing (GLS) devices, has revolutionised the study of foraging behaviour in seabirds (Phillips *et al.* 2004, Soanes *et al.* 2015). A reduction in tracker size and weight has allowed much smaller seabirds, such as the Sooty Tern *Onychoprion fuscata* (~175 g), to be tracked at sea (Soanes *et al.* 2015). Previously, weight limitations of GPS and a universal standard of deploying only payloads that are <3% body mass (Phillips *et al*. 2003) had confined studies to birds that are at least ~330 g (e.g., Wedge-tailed Shearwaters *Ardenna pacifica*; Catry *et al*. 2009a, Carey *et al.* 2009, Cecere *et al*. 2013). The very small (~1.5 g) but low accuracy (~120 km) GLS devices provided the first insights into migratory movements on a large scale for smaller seabirds and migratory waterbirds that undertake extensive interbreeding migrations, e.g., Arctic Tern *Sterna paradisaea* (Fijn *et al*. 2013), Wedge-tailed Shearwater (Cecere *et al*. 2013), Short-tailed Shearwater *A. tenuirostris* (Carey *et al*. 2009), gadfly petrels (Raynor *et al*. 2016) and Bar-tailed Godwit *Limosa lapponica* (Conklin & Battley 2010).

The Lesser Noddy *Anous tenuirostris* is among the smallest of tropical terns, with a mean mass of 104 g (Surman & Wooller 1995). In the eastern Indian Ocean, approximately ~50 000 pairs of subspecies *A.t. melanops* nest on three small islands within the Houtman Abrolhos, of which 32 000 pairs nest on Pelsaert Island (Surman *et al.* 2016). At-sea observations and data from GLS have indicated that the Lesser Noddies at the Houtman Abrolhos have a limited foraging range during both breeding and non-breeding periods (Surman pers. obs.). In addition, their timing of breeding and reproductive performance exhibits high annual variability. This is linked to El Nino–Southern Oscillation influences upon the Leeuwin Current and delivery of their planktivorous fish prey (Surman & Wooller 2003, Surman *et al.* 2012, Surman & Nicholson 2009a).

Knowledge of seabird distributions is needed to gain insight into environmental factors and potential threats away from breeding sites that may affect seabird reproductive success and survival. This information would greatly assist conservation efforts, permitting management of the seabirds' breeding and foraging habitat. For example, the Australian government recently tried to introduce a new system of Commonwealth marine reserves; however, there is little information on the proportion of the year-round distribution of Australian seabirds that are covered by these reserves. The more distribution data that can be obtained, the more effective this new system is likely to be, by ameliorating threats through zoning activities. In that regard, although breeding and non-breeding distributions of tropical seabirds have been tracked at several sites in the western Indian Ocean (Catry *et al.* 2009b, Catry *et al.* 2013, Cecere *et al.* 2013, Le Corre *et al.* 2012), much less is known about the distribution of these species at colonies in the eastern Indian Ocean, including those off the coast of Western Australia. Previous studies of seabird distribution in the eastern Indian Ocean have relied upon vessel-based observations, which have been constrained in their coverage both spatially and temporally (see Surman & Wooller 2000, Dunlop *et al*. 2001, Dunlop 2011).

Therefore, to augment our understanding of Lesser Noddy habitat use off Western Australia, we tracked individuals from a breeding location at the Houtman Abrolhos archipelago.

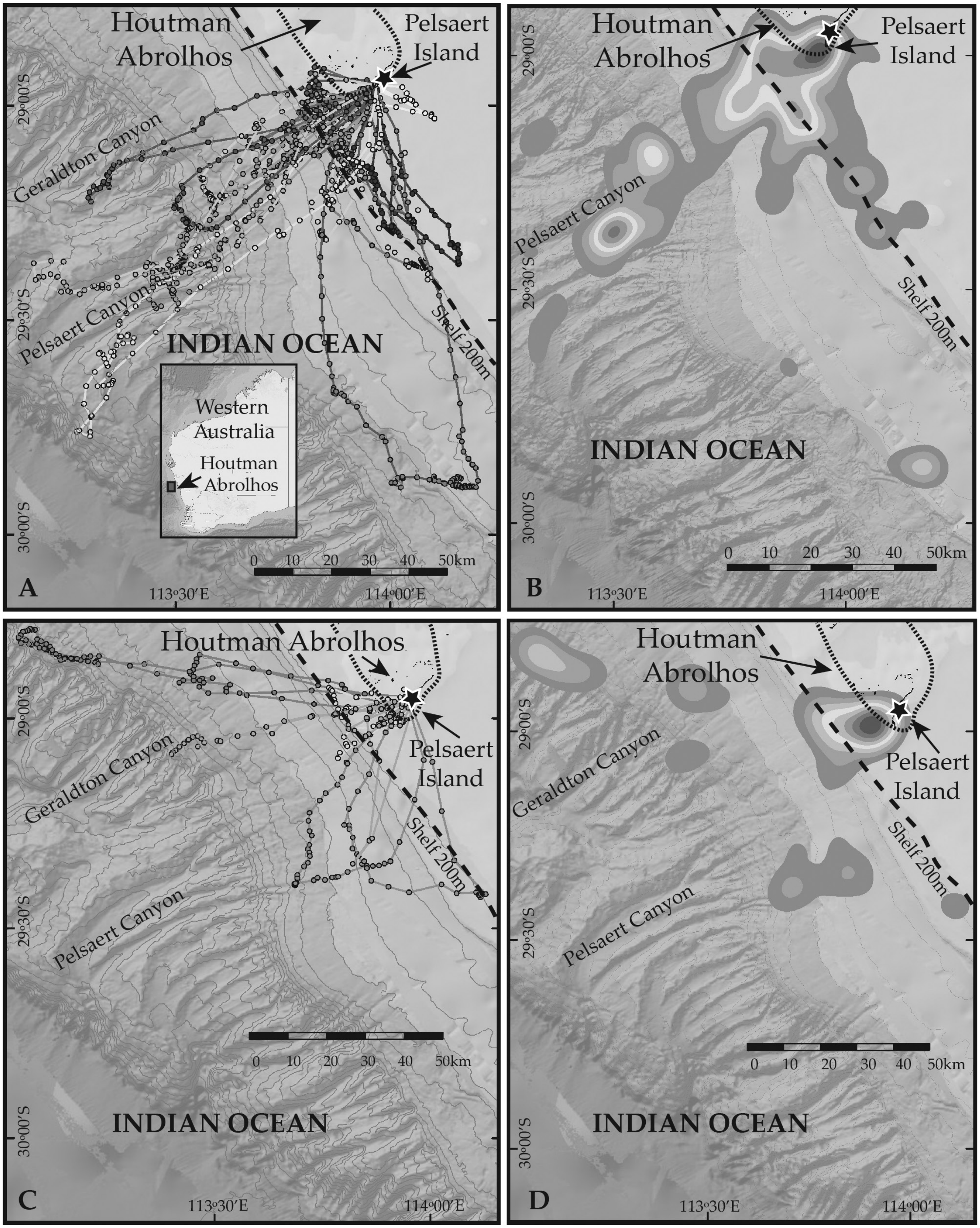

Fig. 1. The Pelsaert Island deployment site (black star), within the Houtman Abrolhos archipelago (dotted line): (A) tracks of 14 breeding Lesser Noddies (38 foraging trips) recorded during November 2014; (B) kernel density plot of all noddy positions recorded outside of the reef lagoon during November 2014; (C) tracks of three breeding noddies (13 foraging trips) recorded in December 2014 and (D) kernel density plot of all noddy positions recorded outside of the reef lagoon during December 2014.

STUDY AREA AND METHODS

The study was conducted at Pelsaert Island (28°56′S, 113°58′E), Houtman Abrolhos, Western Australia. Pelsaert Island (120 ha) is the southernmost and third largest of an archipelago of 192 islands, islets and rocks (the Houtman Abrolhos), 60 km off the mid-western coast of Australia (Surman & Nicholson 2009b; Fig. 1a).

On Pelsaert Island, noddies were selected from extensive colonies (*ca.* 35 000 breeding pairs; Surman *et al*. 2016). At this location, the Lesser Noddy nests only in white mangrove *Avicennia marina* trees (Surman & Wooller 1995).

Lesser Noddies were tracked during two 14-d field surveys undertaken in November and December 2014. Micro-GPS loggers (nano-Fix-GEO, Pathtrack Ltd., UK) weighing 2.0 g (<1.9% body weight) were attached to the two innermost retrices of breeding individuals (mean weight, 104 g, $n = 16$) using Tesa tape (Wilson *et al*. 1997). Logger dimensions were 24 × 11 × 7 mm with a 50 mm whip antenna. Loggers were deployed over several 3-d periods while birds were attending nests to brood eggs or care for chicks. They were not redeployed on birds previously tracked. Since this species builds large nests on branches of the mangrove, birds were selected based on ease of access, in order to reduce disturbance to neighbours.

Adults incubating eggs or with small or medium-sized chicks were caught at the nest by hand. All nests were located under the mangrove canopy, protecting nest contents from predation by Silver Gulls *Chroicocephalus novaehollandiae*, a known predator of noddy eggs and chicks on Pelsaert Island.

GPS loggers were programmed to take positions at 10-min intervals between 03h00 and 21h00, with loggers in "off" mode between 21h00 and 03h00. Data recovered from GPS devices indicated that all birds were back at the nest site by 20h30. Since Lesser Noddies nest under tree canopies, the length of time that the GPS was on was changed to reduce power loss. Attachment of GPS loggers to the bird took 5 min and retrieval took 3 min. Foraging tracks were plotted in ArcMap.10 (ESRI).

Foraging trip duration, total trip distance, maximum foraging distance, travel speed, and maximum distance from the colony were calculated using the R software package *trip* and *tripdistance* (R Version 3.01).

Kernel density maps were generated in ArcGIS in the GDA94 MGA Zone 49 Projection. The kernels were produced using the QGIS heatmap plugin with a search radius of 10 000 m, cell size 50 × 50 m and kernel shape Quartic (biweight). The symbolization of the heatmap was classified in ArcGIS over five classes using the natural breaks (Jenks) method.

RESULTS

All 17 GPS loggers deployed were successfully recovered. All eggs/chicks were present in the nests of tracked adults 6 d after GPS logger retrieval. Thirteen of these 17 nests (76.5%) still contained

TABLE 1
Breeding status, deployment and recovery dates and timing and mass gain or loss of Lesser Noddies tracked on Pelsaert Island, Houtman Abrolhos, Western Australia

Individual	Breeding status	Deployment date	Recovery date	Deployment time (min:s)	Recovery time (min:s)	Mass difference (g)
19201	Egg	17 October 2014	19 October 2014	4:17	3:45	-4
01365	Chick	19 November 2014	22 November 2014	8:00	3:00	-2
19201	Chick	19 November 2014	22 November 2014	4:40	3:00	2
01366	Chick	19 November 2014	22 November 2014	4:00	2:00	-3
01367	Chick	19 November 2014	22 November 2014	7:30	3:30	0
01368	Chick	19 November 2014	22 November 2014	7:40	3:00	0
01442	Chick	19 November 2014	23 November 2014	3:00	4:00	-2
01369	Chick	19 November 2014	25 November 2014	4:41	3:00	13
01370	Chick	19 November 2014	22 November 2014	5:00	3:30	12
01371	Chick	22 November 2014	27 November 2014	4:40	2:50	11
01355	Chick	22 November 2014	25 November 2014	3:20	3:00	–
01373	Chick	22 November 2014	18 December 2014	5:30	4:30	7
01372	Chick	23 November 2014	25 November 2014	6:00	3:30	-6
01374	Chick	23 November 2014	25 November 2014	5:45	2:20	2
01375	Chick	17 December 2014	18 December 2014	4:45	2:30	22
01376	Chick	17 December 2014	18 December 2014	4:41	3:00	24
01377	Chick	17 December 2014	19 December 2014	6:19	4:00	7

chicks 27 d after retrieval compared with 28 of 35 (80.0%) control nests. In general, loggers operated for nearly two full days, with an average 152 fixes per deployment.

Affixing loggers was efficient: mean deployment time was 5:16 min (range 3:00–8:00 min) and recovery time 3:12 min (range 2:00–4:30 min; Table 1). Six nests were observed immediately after the bird with newly attached GPS logger was released, and it took an average of 1:21 min for birds to return to their nest site. All loggers attached to the central retrices were intact upon recovery, and all retrices remained undamaged after removal of the GPS and Tesa tape. On average, Lesser Noddy adults had increased their body mass by 5.2 g after the three-day logger deployment (Table 1).

The GPS tracks (Figs. 1a, c) and kernel density figures ((Figs. 1b, d) revealed that the Lesser Noddies foraged in a predominantly southwesterly direction, beyond the barrier reef edge and extending 93 km offshore in waters >1 km deep (Figs. 1a, b). The tracked birds returned in the late afternoon with the strong (46 km/h average) prevailing southwesterly sea breeze characteristic of the western Australian coast.

Of the 17 GPS loggers retrieved, all contained at least one complete return track, with an average 2.7 and 4.3 trips for birds tracked in November and December, respectively (Table 2). Mean foraging trips averaged 5:39 h (standard error [SE] 0:39 h; Fig. 2) and covered trip lengths from 9.4 to 258.1 km (mean 79.5 km, SE 9.8 km; Fig. 3). The maximum distance from the breeding colony on Pelsaert Island was 112 km and ranged from 4.8 to 112 km (mean 36.2 km, SE 4.1 km).

Both the mean maximum distance from the colony (Mann–Whitney $U = 315$, $P = 0.03$) and mean trip time ($U = 325.5$, $P = 0.01$) were significantly longer in birds tracked in November compared with birds tracked in December. There was no significant difference in the mean trip distance or the mean number of trips (Table 2).

Six individuals undertook relatively long foraging trips, ranging 13:00–15:30 h and covering total trip distances of 138–233 km, with maximum distances from the colony of 72.4–112 km (Figs. 1a, c). Differing foraging strategies were evident among individual birds. For example, two birds, both with medium-sized chicks, exhibited very different foraging behaviour over the two days of data collection. The first bird, 01368, undertook a relatively long foraging trip on each of the two days that the GPS collected data, with the first foraging trip lasting 7 h and extending 51 km west of Pelsaert Island. This bird returned from 92 km west of Pelsaert Island early the following day, spending over 13 h away before returning at 20h38. In contrast, the second bird, 19201, undertook 6 foraging trips over the same two days, each of short duration (<2.5 h) and all less than 20 km from Pelsaert Island.

Lesser Noddies are largely diurnal, with most foraging trips commencing before dawn (04h00–06h00; summer morning astronomical twilight is 04h20) in both November and December, with a second peak of departures during 10h00–12h00 (Fig. 4). Foraging trip return times peaked during both months between 18h00 and 20h00 (evening astronomical twilight is 20h48). However, there was a second minor peak in December during 12h00–14h00 (Fig. 5).

DISCUSSION

This study is the first to successfully deploy micro-GPS technology to track a small seabird of about 100 g. All GPS instruments deployed were successfully retrieved, all recorded foraging location data, and there was no observable impact upon the foraging adults or their breeding attempts.

TABLE 2
Foraging trip characteristics of Lesser Noddies tracked during November and December 2014 at Pelsaert Island, Houtman Abrolhos

Characteristic	Month and breeding status	
	November, eggs/chicks	December, large chicks
Number of GPS employed	14	3
Total number of trips	38	13
Mean number of trips	2.7	4.3
Trip time (hours)	6:09	4:14
Mean distance (km)	38.6	26.2
Maximum distance (km)	112	92

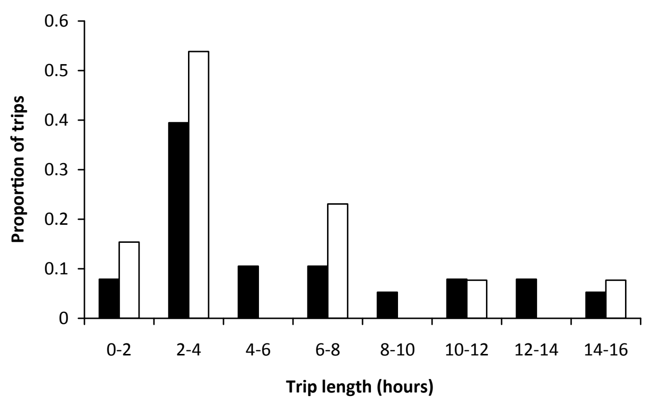

Fig. 2. Proportion of Lesser Noddy trips by trip duration. Black bars are November trips ($n = 38$), white bars December trips ($n = 13$).

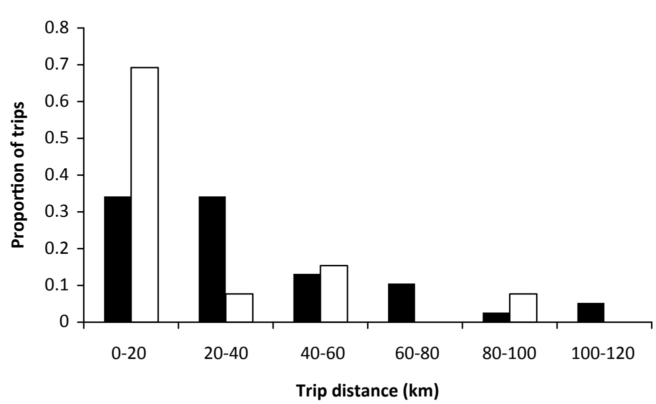

Fig. 3. Proportion of Lesser Noddy trips by trip distance. Black bars are November trips ($n = 38$), white bars December trips ($n = 13$).

Before this study, little was known of the foraging behaviour of breeding seabirds throughout the eastern Indian Ocean, with the exception of studies on the much larger sulids or shearwaters (Hennicke *et al.* 2015, Hennicke & Wiemerskirch 2014) on Christmas Island (12°S), and Wedge-tailed Shearwaters from the Seychelles foraging in the eastern Indian Ocean (Le Corre *et al.* 2012). Previous observations on the distribution of seabirds within this region had previously been based upon at-sea observations (Surman &Wooller 2000, 2003, Dunlop *et al*. 1996, 2001). Specifically, there were no data available on the foraging behaviour of the Lesser Noddy, a listed species restricted to three breeding islands at the Houtman Abrolhos. Previous studies had observed flight paths to/from breeding colonies (Storr *et al*. 1986, Surman & Wooller 1995), leading to conclusions that the species foraged to the southwest of the Houtman Abrolhos. Surman & Wooller (2003) had recorded at-sea observations of Lesser and Brown Noddies *A. stolidus* foraging approximately 60 km west-southwest of the Pelsaert Group.

Brown Noddies were observed at sea throughout the year around Reunion Island, where there are large colonies, suggesting that many birds do not make long-distance movements (Jaquemet *et al.* 2004). On Aride and Cousin Island (Seychelles), Brown Noddies breed only during the southeast monsoon, and little is known of their dispersal patterns (Catry *et al.* 2009b). However, Montecelli *et al.* 2014 presumed that the smaller Lesser Noddy foraged within 100 km of land over shallower plateau waters adjacent to breeding colonies. Similarly, Villard *et al*. 2015 suggested that the Black Noddy *A. minutus* foraged across inshore waters, within the confines of a New Caledonian lagoon. At St. Peter and St. Paul Rocks in the mid-Atlantic ridge, Black Noddies foraged over the oceanic waters surrounding the islands (Naves *et al.* 2002).

Surprisingly, Lesser Noddies tended to forage in waters well off the continental shelf (200 m isobar), usually to the west and southwest of the Pelsaert Island colony. As the breeding season progressed, the frequency of trips increased while the distance travelled decreased. This pattern would be expected with the increasing food demands on breeding adults from ever-growing nestlings.

Observations at the Houtman Abrolhos indicated that the majority of Lesser Noddies returned under the cover of darkness during their non-breeding period (between late April and early August), roosting in the mangrove nesting habitat (Surman 1997, Storr *et al.* 1986). However, storm-wrecked individuals have been found as far south as Busselton, Western Australia (34°S; Serventy *et al.* 1971). Recent records of Lesser Noddies roosting on Bernier Island (25°S, 113°E) at night suggest that, at least for a proportion of their non-breeding period, some foraged further afield (Colleen Sims, pers. comm.). However, at Reunion Island and the Seychelles, Lesser Noddies foraged over shelf waters and appeared not to disperse during their non-breeding period (Jaquemet *et al*. 2004, Catry *et al*. 2009b).

Activity patterns from the foraging data indicate that trip distance and duration reflected breeding stage, with birds tending to undertake more frequent shorter trips while feeding chicks. However, in some cases long trips were followed by short trips, with provisioning for the adult required a greater distance and longer duration, while trips of shorter distance and duration were presumably for chick provisioning. While there are some limitations in these data (i.e., sample size), there was a clear and expected difference in the maximum distance travelled and trip time for those birds tracked earlier in the breeding season. Birds tracked in November tended to forage for longer and travel further afield. We believe that this is a function of provisioning larger chicks in December, requiring more frequent meals.

The successful deployment of micro-GPS loggers on the threatened Lesser Noddy has provided insight into the foraging behaviour and location of this species at the Houtman Abrolhos islands. The geolocator data revealed that this non-migratory species foraged during the breeding season within a limited range of ~500 km north and south of the colony. Understanding key foraging locations of the Lesser Noddy may assist in the effective assignment of marine conservation areas in this region.

ACKNOWLEDGEMENTS

We thank Shae Surman, Anthony Docherty, and Alan Cottingham for their assistance in the field. Logistical support was kindly provided by the crew of the fisheries patrol vessels PV Chalmers and PV Houtman. We are particularly indebted to Greg Finlay of the Department of Fisheries and Murray Davidson, Pia Boschetti, Justin Peretina, and James MacFarlane of the Pelsaert Group for their support. This research was conducted with the permission of Western Australia's Department of Parks and Wildlife Regulation 23 (BB003684) and Regulation 17 (SF010903) the Australian Bird and Bat Banding Scheme (Authority No. 1803) and the Department of Fisheries. The Norman Wettenhall Foundation kindly provided funds for PathTrack GPS units. The comments of Nic Dunlop and an anonymous reviewer greatly improved the paper.

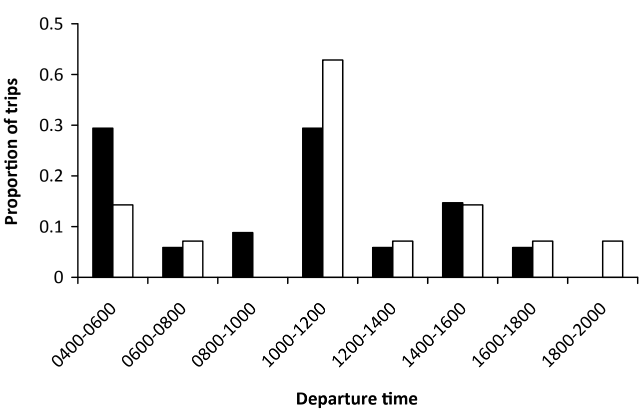

Fig. 4. Proportion of Lesser Noddy foraging trip departure times for birds tracked in November (solid) and December (open).

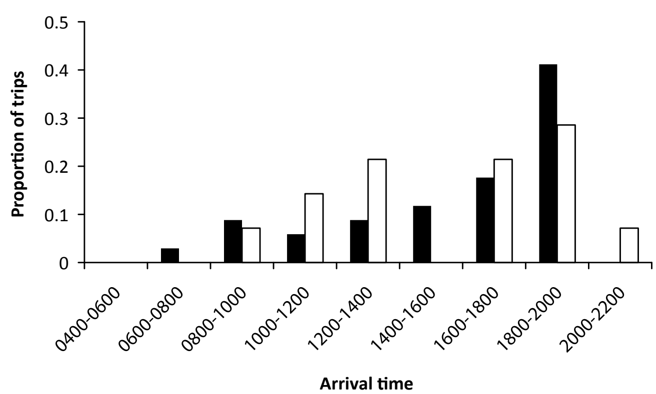

Fig. 5. Proportion of Lesser Noddy foraging trip return times for birds tracked in November (solid) and December (open).

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