# FORAGING MOVEMENTS AND THE MIGRATION TRAJECTORY OF FLESH-FOOTED SHEARWATERS *PUFFINUS CARNEIPES* FROM THE SOUTH COAST OF WESTERN AUSTRALIA

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**SUMMARY**

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Five adult Flesh-footed Shearwaters *Puffinus carneipes* captured in King George Sound, Western Australia, during the 2008 chick-rearing season, were tracked using satellite telemetry. Transmitters were deployed on three birds in early March during the first half of the nestling period and on two birds toward the end of April, shortly before their annual departure from the south coast. During the earlier period, the birds demonstrated erratic foraging flight, in which they frequented neritic waters within approximately 300 km of the release location. By contrast, significantly faster, direct flight over pelagic waters, away from the south coast later in the season, was interpreted as the beginning of the shearwaters' migration. For the time that locations were received via satellite, these latter movements conformed with predictions made 56 years ago regarding the migration trajectory of Flesh-footed Shearwaters from Western Australian colonies.

Key words: Flesh-footed Shearwater, *Puffinus carneipes*, satellite telemetry, foraging, migration, Western Australia

## INTRODUCTION

Of the several *Puffinus* shearwater species that breed around Australia's southern coast, the Flesh-footed Shearwater *P. carneipes* is probably the least studied. Despite its abundance and known association with fishing vessels (Gales *et al.* 1998), only the east Australian population, breeding on Lord Howe Island, has received consistent scientific investigation during the last decade (Dyer 2001, Baker & Wise 2005, Priddel *et al.* 2006). By contrast, almost 50 years have elapsed since biologic data were published concerning colonies on the many islands off the southern coast of Western Australia (Warham 1958, Powell *et al.* 2007). Moreover, because of the difficulties associated with studying pelagic seabirds generally, most knowledge was, until recently, derived from data collected at the colony when they returned to breed. Before the advent of remote tracking devices that now permit global monitoring of wide-ranging animals, the foraging movements and destinations of shearwaters were largely unknown and often subject to inference.

Chaurand & Weimerskirch (1994) described a bimodal foraging strategy in which pelagic seabird parents alternated short and long trips when provisioning young (see also Weimerskirch *et al.* 1994). Short-tailed Shearwater *P. tenuirostris* nestlings, for example, receive regular feeds for short intervals, before undergoing fasts of up to two weeks' duration (Hamer *et al.* 1997, Weimerskirch & Cherel 1998, Hamer *et al.* 2000). This situation was interpreted as a novel strategy in which parents dedicated their entire foraging effort to chick provisioning, before both departed on a long-distant, self-feeding foray to rich Antarctic waters (Nicholls *et al.* 1998; Klomp & Schultz 2000; Schultz & Klomp 2000a, 2000b). Weimerskirch & Cherel (1998) suggested that, during these Antarctic visits, Short-tailed Shearwaters foraged at least 1000 km south of Tasmania in the Polar Frontal Zone—a hypothesis that Schultz & Klomp (2000a) later confirmed using satellite telemetry. The latter authors found that a single extended foraging trip could involve a total distance of more than 15 000 km. Einoder & Goldsworthy (2005) have since used the same technology to examine the behaviour of individuals during chick-provisioning trips of short duration.

Booth *et al.* (2000) described a different strategy of long and short foraging trips in the Little Shearwater *P. assimilis,* in which parents cooperatively alternated seven-day extended trips with nightly chick provisioning before exchanging roles. In this way, nestlings were fed nightly while their parents avoided an energy debt to the demands of frequently provisioning a single large young. Given that Flesh-footed Shearwater nestlings receive, on average, slightly less than one meal per night (C. Powell, unpub. data), it is likely that parent Flesh-footed Shearwaters forage close to the breeding colony or undertake a cooperative provisioning strategy similar to that of the Little Shearwater.

Gibson-Hill (1953) suggested that, upon leaving their breeding grounds, Flesh-footed Shearwaters from Western Australia move westward around Cape Leeuwin, making for the waters south of the Houtman Abrolhos Islands.

> "Thence they strike out diagonally across the southern part of the Indian Ocean, finishing up somewhere in the broad patch of open sea north of the Mascarene Islands. Here, they pick up the monsoon in June and are carried round with it in a broad sweep. First northwards, past the Seychelles, then eastwards between the Maldives

> and Laccadives, past the south-west coast of Ceylon, and so down again towards Australia, skirting the Fremantle coast, southward bound in September" (Gibson-Hill 1953).

Bailey (1966) reported considerable numbers of Flesh-footed Shearwaters congregating in the Arabian Sea and the Gulf of Oman during the southwest monsoon. This timing coincides with the austral winter, and Warham (1990) proposed that these were Western Australian shearwaters, because numerous recoveries of birds banded on Lord Howe Island suggest that, from there, they migrate into the northwest Pacific (Hutton 1990, Marchant & Higgins 1990). Similarly, birds from New Zealand colonies follow a route through the central Pacific to Korean and Japanese waters, concentrating off the west coast of North America whilst in transit (Imber 1985, Warham 1996).

Bailey's (1966) Arabian Sea observations of birds arriving in mid- to late May; numbers peaking in late June to mid-August, and then declining through August–September concur with the chronology of Flesh-footed Shearwaters breeding in Western Australia, as observed by Powell *et al.* (2007) at one small colony in the Archipelago of the Recherche.

In the present study, satellite transmitters were attached to adult Flesh-footed Shearwaters at a breeding colony some 500 km west of the Archipelago, during the peak of chick provisioning, and to adults captured in the vicinity of that colony late in the chick-rearing season before their departure. The aim was to examine the foraging movements of Flesh-footed Shearwaters from the colony and, if possible, to examine their post-breeding migratory movements once they left the colony.

## STUDY AREA AND METHODS

In total, five KiwiSat 202 lightweight Platform Transmitter Terminals [PTTs (Sirtrack, Havelock North, New Zealand)] were deployed on adult Flesh-footed Shearwaters. Before having PTTs attached, each bird was weighed, measured and banded (Powell *et al.* 2007). Each PTT incorporated a single AA battery and weighed approximately 32 g, representing about 5% of the average body mass of an adult Flesh-footed Shearwater [625 g ± 3 g (standard error), Powell *et al.* 2007]. Moreover, similar units have been used successfully with smaller-bodied congeners (Nicholls *et al.* 1998, Klomp & Schultz 2000, Schultz & Klomp 2000a, Einoder & Goldsworthy 2005), and so no payload handicap was foreseen. Transmissions were received through the Argos satellite system, and data were accessed online (CLS 2008). Three PTTs, with a 60 s repetition rate and a 6 h on, 6 h off duty cycle [one transmission every 60 s for six hours, followed by a six-hour period of no transmission (CLS 2008)], were attached to adult shearwaters captured on Breaksea Island during the night of 6 March 2008. Attachment was made directly to the feathers between the scapulae, using a strip of mastic adhesive compound and then binding with Tesa tape (Tesa SE, Hamburg, Germany) (Wilson *et al.* 1997, Preston *et al.* 2008).

Breaksea Island is situated within King George Sound, about 12 km southeast of the town of Albany, off the south coast of Western Australia at around 35°04′S, 118°03′E (Fig. 1). Before the night of capture, burrows were visually examined with a burrowscope (Powell *et al.* 2007), and those that contained a chick (n = 12) were marked and monitored later, once dusk fell. Although the intention was to attach the PTTs to birds captured as they exited marked burrows, none of these was entered during the main influx of shearwaters shortly after nightfall, or during four hours immediately thereafter. Because of the limited time available on the island, it was necessary to deploy the PTTs immediately; and so it was resolved to attach them to birds captured at random near the marked burrows, with the assumption that each was provisioning a chick therein.

On 22 April 2008, two PTTS, this time with a 45 s repetition rate and 2 h on, 4 h off duty cycle, were attached in the same manner, except that Loctite 401 glue (Henkel Corporation. Rocky Hill, CT, U.S.A.) was used (Einoder & Goldsworthy 2005) in place of mastic. These two attachments were made onboard a fishing vessel during fishery by-catch observations, to two birds entangled in a purse seine net in King George Sound approximately 6.0 km northwest of Breaksea Island. This method of capture was opportunistic, but necessary because of the late stage of the breeding cycle—most adult shearwaters depart their breeding colony by the first week of May (Powell *et al.* 2007), before which the two PTTs were not available—and weather conditions precluding further visits to Breaksea Island.

Transmissions were received through the Argos satellite system, which assigns locations to seven quality classes. Classes 3, 2 and 1 (four or more signals per satellite pass) are of known accuracy, with errors of <150 m, <350 m and <1.0 km respectively. Classes 0 (four or more signals), A (three signals), B (two signals) and Z (one signal) have no known accuracy, and the spatial errors require determination by the user (CLS 2008). From tests at known sites before deployment, Ristow et al. (2000) determined

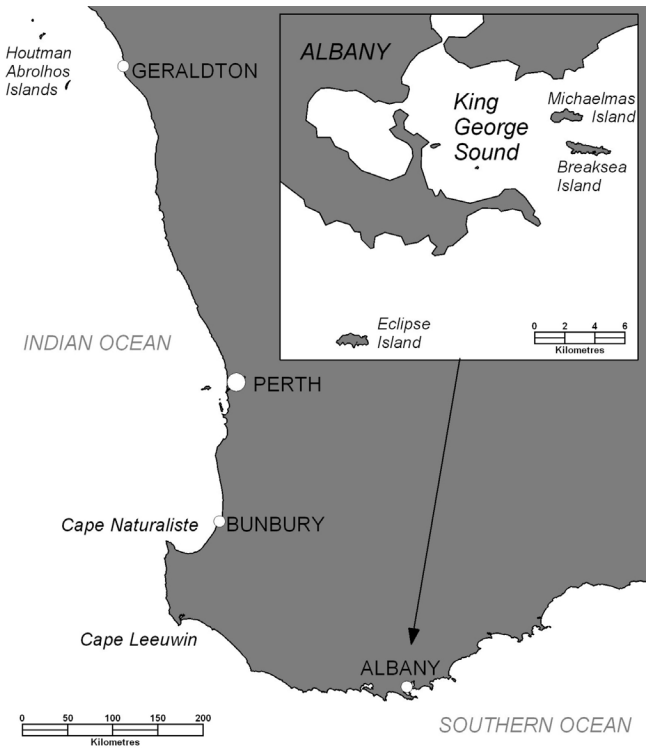


**Fig. 1.** The southwest portion of Western Australia and King George Sound (inset).

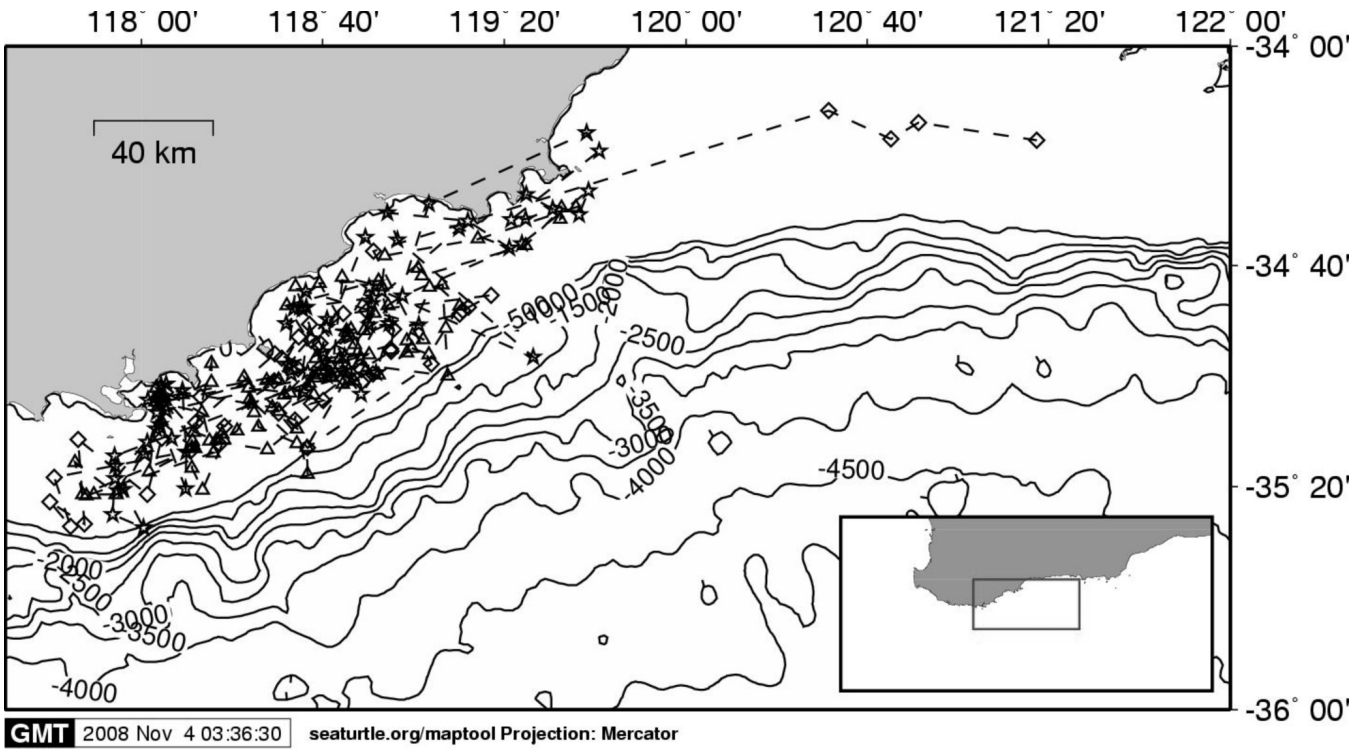


**Fig. 2.** The foraging movements of three Flesh-footed Shearwaters *Puffinus carneipes* during 6–19 March (73451, open stars), 6–22 March (73452, open triangles) and 6–14 March (73453, open diamonds) 2008. The points represent the filtered output of the STAT software package (Coyne & Godley 2005) that excludes locations resulting from signals received less than one hour apart. Tracks implying movement across land (for example, the open stars) are interpolations resulting from the "off" phase of the six-hour duty cycle.

**TABLE 1**
**Movements of five Flesh-footed Shearwaters *Puffinus carneipes* tracked by satellite during March–May 2008.**

| | Platform Transmitter Terminal ID | | | | |
|---|---|---|---|---|---|
| | **73451** | **73452** | **73453** | **82159** | **82160** |
| Origin | | Breaksea Is | | King George Sound | |
| Total transmission period | 6–19 March | 6–22 March | 6–14 March | 22–26 April | 22–24 April |
| Days (n) | 13 | 16 | 8 | 4 | 2 |
| Made landfall at | — | Breaksea Is | — | — | Eclipse Is |
| Date | | 10 March | | | 22 April |
| Nights since last landfall (n) | | 4 | | | |
| Made landfall at | — | Breaksea Is | — | — | Eclipse Is |
| Date | — | 11 March | — | — | 23 April |
| Nights since last landfall (n) | | 1 | | | 1 |
| Made landfall at | — | Breaksea Is | — | — | — |
| Date | — | 20 March | — | — | — |
| Nights since last landfall (n) | | 9 | | | |
| Max straight-line distance from origin (km) | 183 | 157 | 309 | 80 | 21 |
| Transmission period during migration | — | 23–29 March | — | 27 April–12 May | 25 April–8 May |
| Days (n) | | 6 | | 15 | 13 |
| Total distance (km) | — | 2540 | — | 5273 | 4747 |
| Average daily distance (km) | — | 508 | — | 352 | 365 |

that 50% of class 0 and A locations are accurate within 10 km and are of sufficient resolution to examine movements at sea on a course temporal scale. Class 0 locations were likewise considered sufficient to satisfy the aims of the present study. Tracking data were analysed using the Satellite Tracking and Analysis Tool (STAT) software package (Coyne & Godley 2005), and graphics were generated using the Maptool program (www.seaturtle.org). Data were filtered to exclude locations resulting from

- fewer than four signals per satellite pass.
- travel speeds exceeding 60 km/h (Einoder & Goldsworthy 2005).
- signals obtained less than one hour apart (Limiñana *et al.* 2008).
- calculated distances greater than 1000 km from any previous location.

## RESULTS

Of 776 locations received in total, tracking data filtering removed 93 anomalous locations (12%). From deployment on the night of 6 March 2008 at Breaksea Island, the PTTs 73451, 73452 and 73453 transmitted locations for 13, 22 and 8 days respectively. Tracking by Argos revealed that, during these intervals, the birds carrying the transmitters (referred to hereafter by PTT number) frequented neritic waters up to approximately 300 km (straight-line distance) from Breaksea Island (Fig. 2). Two of the birds did not return to the island during the periods monitored, but the third made landfall on three subsequent occasions, at intervals of four, one and nine nights (Table 1). Two nights later, on the evening of 22 March, the same individual (73452) departed west and, by daybreak, was located 48 km west of the Australian mainland. It then followed the western-most portion of the southern coastline north, before changing course to the northwest.

The two PTTs deployed on 22 April transmitted for 19 and 15 days. One bird (82159) remained within the sound for five days until the early hours of 27 April, when it flew 72 km north-northeast before abruptly altering course to the southwest. Within 24 hours, it had travelled 388 km to below 36°S. The other bird (82160) was located at nearby Eclipse Island (Fig. 1) the night following capture and the subsequent night. Two days later, it headed west-southwest and, by the evening of 27 April, was almost 900 km away at 37°31′S, 108°45′E.

Following their departure west, 73452 and 82159 made their way north, passing close by capes Leeuwin and Naturaliste. Then, while 73452 struck out to the northwest, 82159 turned toward the mainland coast, approaching within five kilometres of Lancelin Island before assuming a similar course skirting the Houtman Abrolhos Islands (Fig. 1). Conversely, 82160 travelled deep to the southwest before turning north. Some 400 km off the westernmost point of the Australian mainland, its trajectory met that of 73452, which it paralleled north-westwards to a position about 1300 km west-northwest of North West Cape. Rather than maintain this north-westerly course, all three birds then deviated westwards. Transmission from 73452 ceased on 29 March. Extrapolation of its trajectory at that time would have intersected those of the other two birds, which later crossed approximately 2750 km west of Broome. From that position, 82160 ceased transmission on 8 May, 176 km further northwest; while 82159 flew northwest and then southwest to transmit its final location on 12 May at approximately 15ºS, 89ºE.

A regression identified a positive correlation between flight speed and distance from first transmission ($F_{1,432} = 14.005$, $R^2 = 0.031$, $P < 0.001$), and a two-sample *t*-test of significance (unequal variances assumed, $t_{238} = -6.31$, $P < 0.001$) determined that migratory flight [14.21 km/h ± 1.07 km/h (standard error); range: 0.19–52.41 km/h; n = 173] was significantly faster than foraging flight [6.87 km/h ± 0.46 km/h (standard error); range: 0.05–41.61 km/h; n = 261].

## DISCUSSION

From the data received from PTTs 73451, 73452 and 73453, it was evident that, during the period 6–22 March 2008 (16 days in total), the birds carrying these transmitters foraged in neritic waters, venturing outside the slope of the continental shelf only rarely. However, this finding does not necessarily preclude the possibility that Flesh-footed Shearwaters forage in pelagic waters while chick provisioning, given that it could not be confirmed that the birds carrying the transmitters were actually parents.

The possibility that the birds were actually non-breeding individuals seems unlikely, given that prospecting birds generally depart with the pre-laying exodus early in November and do not return (Warham 1990, Powell *et al.* 2007). A more probable explanation is that the birds captured were failed or widowed parents that had abandoned chick rearing for that year. Mate mortality is not unlikely, considering that Flesh-footed Shearwaters were suffering by-catch mortality in a local fishery (Dunlop 2008). In any case, similar work, focused specifically on adults confirmed to be parents, is required to determine the foraging strategy of this species when chick rearing.

Gibson-Hill (1953) predicted that once Flesh-footed Shearwaters departed their breeding colony, they travelled west, following the coast north past Cape Leeuwin and Cape Naturaliste towards the Houtman Abrolhos Islands. This, as it happened, was a very

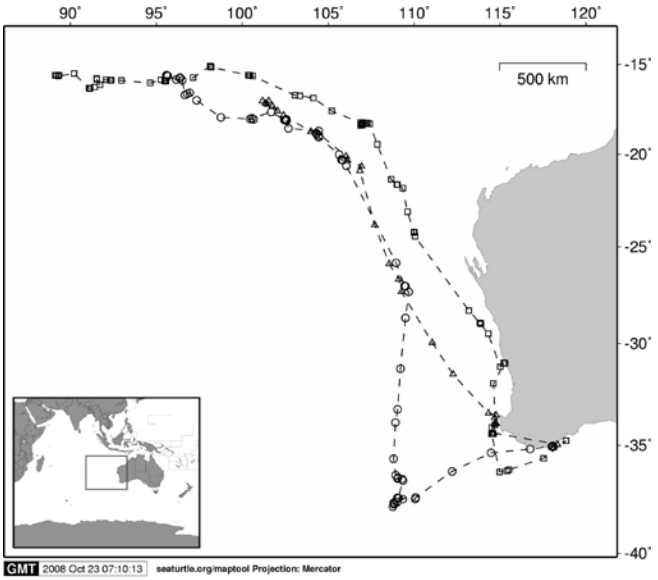


**Fig. 3.** The post-breeding migration trajectory of three Flesh-footed Shearwaters *Puffinus carneipes* 73452 (open triangles), 82159 (open squares) and 82160 (open circles) from the south coast of Western Australia north-westward into the Indian Ocean. The tracks represent 6-, 15- and 13-day intervals respectively; incorporating 23–29 March, 27 April–12 May and 25 April–8 May 2008.

accurate prediction—particularly in the case of 82159, which skirted the barrier reef of Pelseart Island, in the Abrolhos, after approaching close to the mainland near Lancelin. Gibson-Hill was perhaps even more accurate in his assumption that, from there, they strike out diagonally across the southern Indian Ocean. All three tracked birds demonstrated this behaviour (one from the Houtman Abrolhos, one from north of there, and one south of there from Cape Naturaliste), but all along the same north-northwest trajectory. Extrapolation of the gradual westerly deviation subsequently being made by each individual at their final transmission places them at the correct latitude and on course for a destination north of the Mascarene Islands, ready to pick up the southwest monsoon in June and to travel northwards with it past the Seychelles (Gibson-Hill 1953). Improved methods of transmitter attachment and use of newer devices with a greater duration of transmission will be necessary to confirm these movements in future studies.

Einoder & Goldsworthy (2005), who investigated the near-shore chick-provisioning phase of the Short-tailed Shearwater's foraging, described two modes of travel: rapid, direct flight to a specific, perhaps known, foraging area, and slower, "searching" flight associated with general foraging activity. Although differences in foraging flight could not be identified during the present study, the average flight speed of Flesh-footed Shearwaters was significantly greater once they ceased their erratic flight over neritic waters and were clearly embarking on offshore movements signalling the commencement of their migration. To reiterate the concerns of Einoder & Goldsworthy (2005) concerning the Short-tailed Shearwater in South Australian waters, the Flesh-footed Shearwater is a highly abundant seabird during the summer months in Western Australia. Likewise, a primary concern is the interaction with the harvest of pilchards by commercial fishers. Because the fishing effort during summer is concentrated within King George Sound, in the waters surrounding Breaksea Island, interaction with the commercial fishery is intense (Dunlop 2007, 2008), and further knowledge of the foraging and diet of the Flesh-footed Shearwater is pivotal to mitigating the seabird mortality associated with it.

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