Notornis, 2007, *Vol. 54: 180-188*
0029-4470

Satellite tracking of sooty shearwaters (*Puffinus griseus*) during their pre-laying "exodus" and incubation

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Abstract Platform terminal transmitters (PTTs) using the CLS:Argos System were attached to adult sooty shearwaters (*Puffinus griseus*) at Taiaroa Head, South I, New Zealand. Three PTTs were attached to adults during the pre-breeding period, and 2 were attached to adults during the incubation period. During the pre-laying excursion, 1 male flew a minimum distance of 7700 km over 34 days while another male flew 4200 km during 28 days. The minimum distance flown by a female was 3700 km during 16 days. Pre-breeding birds mainly frequented waters < 1000 m deep. During the mid-breeding period a male sooty shearwater flew a minimum of 18000 km in 36 days, while the female flew 4100 km in 13 days. There were comparatively fewer flight locations close to the Otago and the Canterbury coasts for mid-breeding deployments compared to pre-breeding deployments, and most were in waters >1000 m deep.

Söhle, I.S.; Robertson, C.J.R.; Nicholls, D.G.; Mouritsen, H.; Frost, B.; Moller, H. Satellite tracking of sooty shearwaters (*Puffinus griseus*) during their pre-laying "exodus" and incubation. *Notornis 54(3)*: 180-188.

Keywords sooty shearwater; *Puffinus griseus*; satellite tracking; breeding; New Zealand

INTRODUCTION

Platform terminal transmitters (PTTs) can help researchers understand migration routes, stopover sites, ranges, and the way birds use meteorological and oceanographic conditions to ease their flight to and from feeding grounds and breeding colonies. Telemetry has also helped assess human-induced threats to seabirds (Jouventin & Weimerskirch 1990; Alexander *et al.* 1997), and the provision of extra food by fishing discards and offal (Garthe *et al.* 1996; Freeman *et al.* 1997). The information obtained can assist conservation biologists to set priorities for management and research (Taylor 2000a, b).

The early use of PTTs on seabirds concentrated on the largest birds (Prince *et al.* 1992; Weimerskirch *et al.* 1993; Nicholls *et al.* 1995). As lighter PTTs have been developed, they have been deployed on smaller seabirds, including the Westland petrel *Procellaria westlandica* (Freeman *et al.* 1997), the short-tailed shearwater *Puffinus tenuirostris* (Nicholls *et al.* 1998), and Cory's shearwater *Calonectris diomedea* (Ristow *et al.* 2000).

The sooty shearwater *Puffinus griseus* is a medium-sized petrel that migrates to the Northern Hemisphere in the non-breeding season.. Adults breed at a few, small, relict mainland sites in New Zealand, and in large colonies on offshore islands, in New Zealand (Richdale 1944; Warham 1982; Hamilton & Moller 1995; Hamilton 1998) and South America (Everett & Pittman 1993; Warham 1996). They nest in burrows upon their return in late Sep to early Oct from the trans-equatorial migration. A single egg is laid in the period from mid-Nov to early Dec (Richdale 1944), and incubated for *c.*53 days; hatching occurs in mid- to late-Jan.

Received 2 August 2006; accepted 31 March 2007
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Table 1 Summary of attachments, performance,and fates of satellite transmitters and sooty shearwaters (*Puffinus griseus*) tracked from the colony at Taiaroa Head, South I, New Zealand, in 1999-2000.

PTT no.	Sex	Date of deployment	Date of last transmission	Expected battery life (days)	Total time of transmission (days)
TX-21805	♂	7 Oct 1999	4 Nov 1999	60	28
TX-23738	♂	7 Oct 1999	10 Nov 1999	90	34
TX-06750	♀	13 Oct 1999	29 Oct 1999	32	16
TX-21289	♀	18 Jan 2000	31 Oct 2000	32	13
TX-21290	♂	18 Jan 2000	23 Feb 2000	32	36

PTT no.	Maximum range from Taiaroa Head (km)	Possible reason for tracking termination	Adult recaptured	Chick fledged
TX-21805	500	Attachment failure	Yes	Yes
TX-23738	1800	Attachment failure or adult died	No	?
TX-06750	1300	Attachment failure	Yes	Yes
TX-21289	2300	Attachment failure or adult died	No	No
TX-21290	8600	Battery failure	Yes	Yes

Non-breeding birds leave the colony in Mar and early Apr while the frequency of feeding visits by breeding adults decreases significantly from mid-Apr. The last adults are seen at the colony in the 1st days of May. Fledglings start to emerge from their burrows to exercise their wings in mid-Apr. Fledging flights begin shortly afterwards and by mid-May most chicks have left the colony; a few may remain until the last week of May (Falla 1934; Richdale 1963; Warham & Wilson 1982).

The broad pelagic range of the sooty shearwater has been detected by surveys from planes and ships, from dead birds washed ashore, and through recovery of banded birds in the North Pacific Ocean, North Atlantic Ocean (Phillips 1963; Ogi *et al.* 1981; Gutzman & Myers 1983; Chu 1984; Bourne *et al.* 1988; Brown 1988; Spear & Ainley 1999), South African waters (Phillips 1963; Stanford, 1953), Chilean waters (Jehl 1973), and around New Zealand (Richdale 1963; Warham *et al*. 1982; Lyver *et al.* 2000; Scofield & Christie 2002). These data suggest where sooty shearwaters generally occur, but are of little assistance in determining the activity of birds at sea, pinpointing feeding zones, or tracking trans-equatorial migration routes.

The aim of this study was to investigate the movements of sooty shearwaters during the periods after return from migration and before egg-laying, and during incubation and early chick-rearing.

METHODS

PTTs were attached to sooty shearwaters breeding at Taiaroa Head (45°45´S, 170°44´E), Otago Peninsula, 35 km northeast of Dunedin, New Zealand. Söhle *et al.* (2000) describe the development of attachment techniques using imitation satellite transmitters (ISTs), before the deployment of PTTs.

Pre-laying "exodus" deployment

Sooty shearwaters normally return to the same breeding burrow in successive years (Richdale 1963), so adults chosen for the pre-breeding trial were caught at burrows known to be inhabited by an established breeding pair from the previous breeding season (Söhle *et al.* 2000). We targeted experienced breeders from previously-occupied burrows to minimise the chance of equipment loss, and also assumed that established breeders were less likely to desert.

Toothpick barricades were erected (Hamilton 1998) across 18 burrow entrances on 7 Oct 1999 to determine which burrows were occupied. If the barricade was found to have been knocked down during the night, 'exit-nets' were placed over the entrance to catch adults leaving the burrow just before dawn. Three adults were captured, individually identified from previous banding, weighed, and a PTT was attached to each. A feather sample from each PTT-carrying adults was taken for later sex determination, using DNA analysis. Birds were returned to their burrow after handling. The exit net was then removed, allowing the bird to leave.

The 3 birds captured during the pre-breeding period were each fitted with a Microwave Telemetry PTT-100® transmitter (65 × 20 × 10 mm). A low, flat, package configuration, with the battery (26 × 17 × 7 mm) protruding from the left side was chosen to minimise the effects on the birds when moving within their burrows (Freeman *et al.* 1997). Each PTT and battery was enclosed in an epoxy coating to protect against water and pressure while diving. PTTs were equipped with a 230 mm-long coated antenna (1.2 mm dia.) protruding at an angle of 45°, and an internal battery voltage sensor to monitor battery life. Before attachment, PTTs were attached

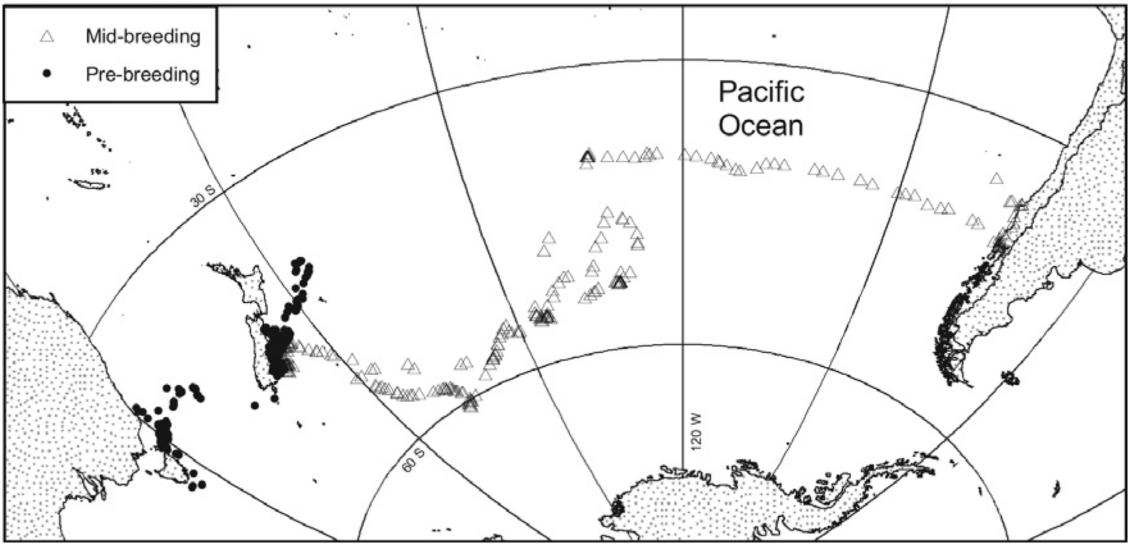

Fig. 1 Argos® tracking locations for 5 adult sooty shearwaters (*Puffinus griseus*) tracked from Taiaroa Head, South I, New Zealand, in 1999 and 2000. •, locations for 3 birds during the pre-breeding period, 1999; △, locations for flights of 2 birds tracked during the 2000 mid-breeding incubation period.

using Araldite® glue to a rectangular piece of linen fabric (64 × 49 mm) with trimmed edges. After attaching the fabric-based PTT with glue to the back feathers, birds were held for 3 minutes to allow the glue to set. With 2 people, the period of capture, handling of birds, PTT attachment, and glue setting, was up to 7 min.

The PTTs had a repetition transmission rate of 85 s. Each PTT had a different duty cycle regime until the battery expired: TX-6750 transmitted continuously throughout 24 h ('continuous mode'); TX-21805 transmitted for 10 h on and 9 h off ('10/9 mode'); and TX-23738 transmitted for 9 h on and 18 h off ('9/18 mode').

Incubation period deployment

A burrowscope (Lyver *et al.* 1998) was used to detect eggs in 24 burrows, 2 days before the PTT experiment began., toothpick barricades (Hamilton 1998) were placed across entrances of burrows containing eggs on 18 Jan 2000. If the barricade was found to have been knocked down during the night, 'exit-nets' were placed over the burrow entrance to catch adults leaving the burrows near dawn. Two adults from different burrows were caught, weighed and banded. Before the PTT was attached, their brood patch was inspected to confirm that they were breeding adults. After fitting the PTTs, the birds were returned to their burrows. The exit net was then removed allowing the birds to leave. Different birds were used for this experiment.

The 2 birds were each fitted with a Microwave Telemetry PTT-100® (65 mm × 16 mm × 16 mm) with 3 loops on the metal casing to assist attachment. PTTs were attached following a technique described by Prince *et al*. (1992) (illustrated by D. Anderson at *www.wfu.edu/albatross/PTTmount.jpg*), but modified to fit sooty shearwaters (Söhle 2001). Handling of birds and PTT attachment took 2 people up to 15 min. Both PTTs attached during the incubation period ran on continuous mode duty cycle, transmitting every 85 s.

Tracking system information and data analysis

Locations were received through the CLS:Argos System (Toulouse, France), each up-link location had been assigned a location class index (LC) which specified the accuracy of each Argos location. Seven location classes were provided by Argos. LC = 3, 2, and 1 had an accuracy of up to 1 km. Argos advised that the remaining 4 classes (LC = 0, A, B, Z) were to be used at the researchers' discretion, and Argos did not provide an accuracy rating for them (Anon 1999; CLS:Argos FAQ). However, Nicholls & Robertson (2007) have assessed the accuracy and precision of all LCs, which allows greater confidence in their use. The datasets from the 3 pre-breeding deployments were derived from a DIAG archive file that was filtered and selected by DGN and CJRR using the procedures developed to select data and describe movements of satellite-tracked seabirds (Nicholls & Robertson 2007). The incubation period deployment locations came from a concurrently-downloaded DIAG file (not an archive set), and were selected in a similar manner. The target speed in the selection process for closer examination of the records before final selection was set at 40 km h^{-1}.

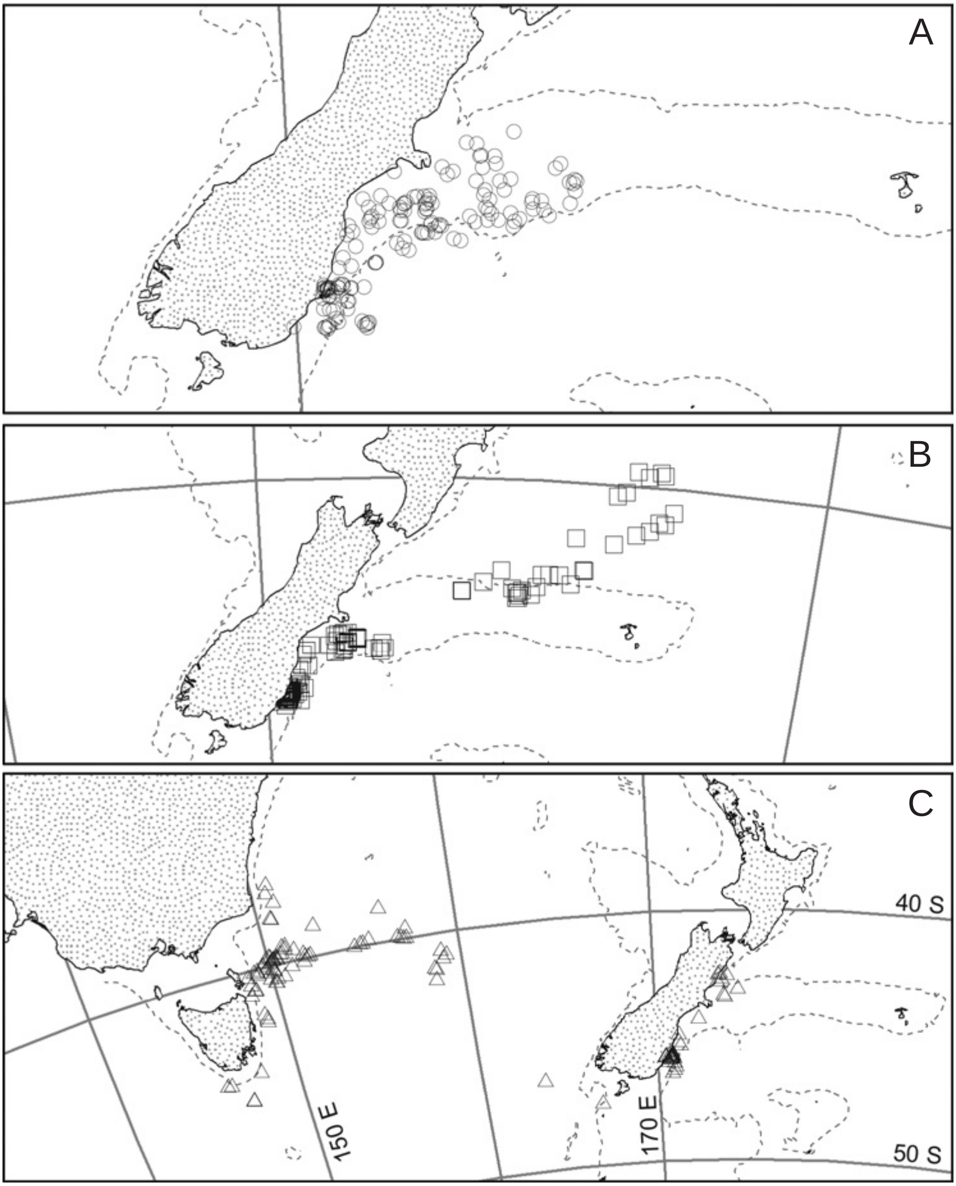

Fig. 2 Argos® tracking locations for sooty shearwaters (*Puffinus griseus*) from Taiaroa Head, South I, New Zealand: ○, TX-21805, ♂; □, TX-6750♀; △, TX-23738, ♂, during the 1999 pre-breeding period.

RESULTS

Pre-breeding "exodus" movements

The PTTs (including packaging) weighed an average of 31.9 g, corresponding to 3.7% of the mean mass of birds caught on 7 Oct 1999, before the pre-laying "exodus". Signals for these transmitters were received for 16, 28, and 34 days after attachment (Table 1). Fig. 1 gives a summary of the distribution of the satellite-locations for these 3 birds, and for the 2 birds tracked during the later, incubation period, flights.

The maximum range for 2 adult males in the pre-breeding period was 1800 km, to the coast of Tasmania and 500 km northeast of the Taiaroa Head colony. One male travelled throughout the Canterbury Bight north to the southern edge of the Mernoo Bank on its 1st trip and to the edge of the Chatham Rise on its 2nd trip (Fig. 2, O). The 2nd male flew to Kaikoura (north-eastern South I), and then moved back to the Taiaroa Head breeding colony (or passed it during the night) and went around the

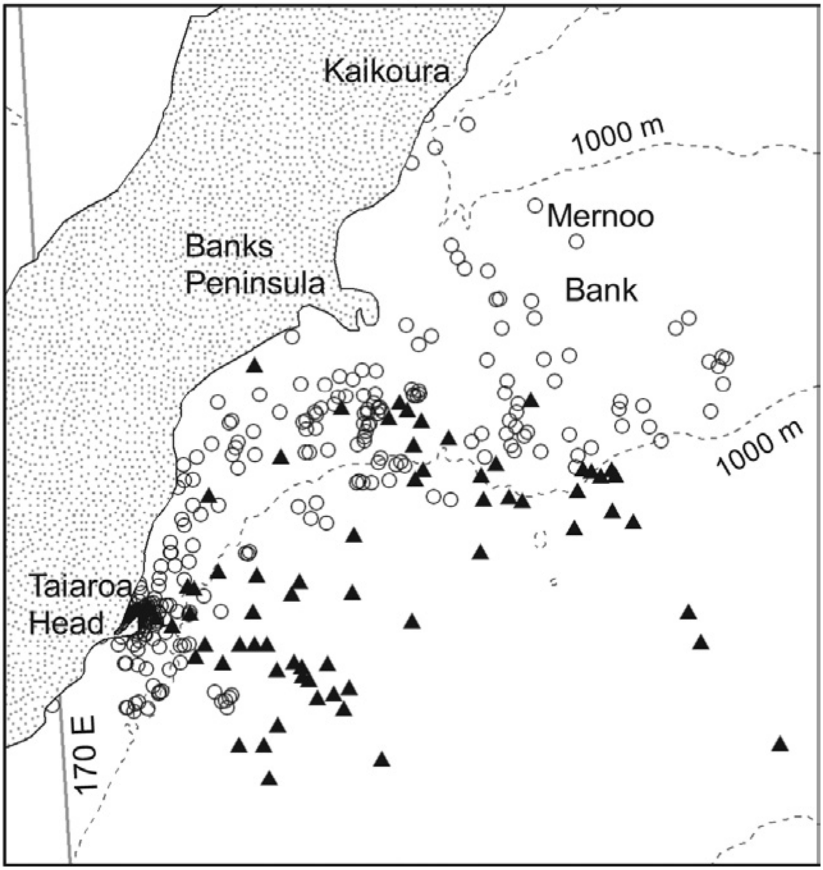

Fig. 3 Argos® locations for breeding adult sooty shearwaters (*Puffinus griseus*) tracked in waters off the eastern South Island, New Zealand. ○, locations of 3 birds tracked during the pre-breeding period; ▲, locations of 2 birds tracked during the incubation period.

southern end of New Zealand across the Tasman Sea, and then west to the coast of Tasmania and southeast New South Wales, Australia (Fig. 2, △). This bird took 3.4 days to return from the Kaikoura coast to the area of Taiaroa Head, and then 8.1 days to reach the Australian coast from there.

The female made 3 trips during the pre-breeding period including a stay south of the Mernoo Bank before travelling to the north of the Chatham Rise (Fig. 2, ☐). Her maximum range from Taiaroa Head was 1300 km and she returned to the colony twice while transmitting.

Tracking locations when close to the Otago and Canterbury coasts showed that these pre-laying period birds frequented waters principally <1000 m deep (Fig. 3). Clusters of points at similar locations suggested that birds could have been resting on the water or feeding.

Tracking of pre-breeding birds distances on successive days (Fig. 4) show that 1 male (TX-23738, on 9/18 mode) flew a minimum cumulative point-to-point distance of 7700 km in 34 days; another male (TX-21805, on 10/9 mode) 4200 km during 28 days; and the female (TX-6750, continuous mode) went 3700 km in 16 days. Male TX-23738 flew steadily without any significant bursts or reductions in travel speed. TX-21805 showed a similar steady flight speed except it accelerated when flying west towards Tasmania in days 22-24 post-attachment. However, the cumulative-distance curve for female TX-6750 started with a slow and steady increase in cumulative distance similar to that of TX-23738, but its distance travelled then increased from day 12 to day 15. Nicholls & Robertson (2007) demonstrated the inherent pitfalls in this type of representation, resulting from the influences of the duty-cycle on the intervals between the selected locations.

Incubation period movements

The PTTs deployed during the incubation period averaged 25.2 g, corresponding to 3.3% of the body mass of the adults captured on 18 Jan 2000. Signals were received from these transmitters for 13 and 36 days after deployment (Table 1).

A flight of 8600 km eastwards across the Southern Ocean to the coast of Chile was recorded in continuous transmission mode for the male carrying transmitter TX-21290. Female TX-21289 flew 2300 km east of the Otago Peninsula (Fig. 1). There were comparatively fewer flight locations close to the

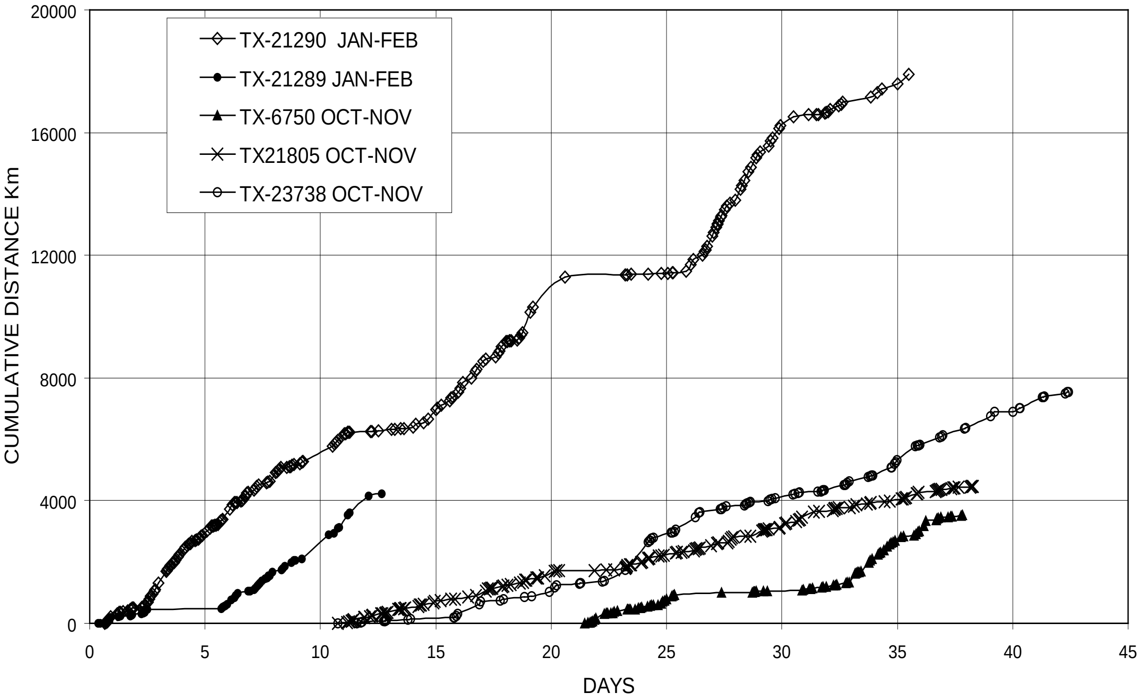

Fig. 4 Graphic presentation of minimum cumulative distances from 5 deployments of PTT the satellite tracking of sooty shearwaters (*Puffinus griseus*) from Taiaroa Head, South I, New Zealand. The individual curves are separated arbitrarily on the *x*-axis for easier comparison, e.g., day 1 of tracking for PTT T-06750 is day 21 on the *x*-axis. Between days 20 and 25 for TX-21290, there were several poor records that gave no valid locations, but there is a demonstrated lack of movement for a period of *c*.5 days.

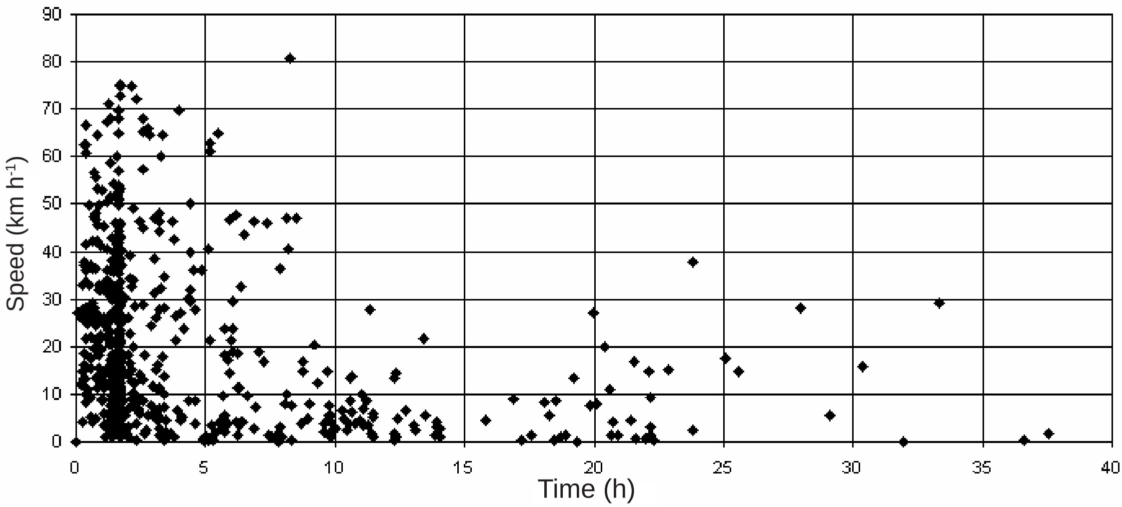

Fig. 5 Calculated point-to-point speeds according to the time interval between successive selected Argos® locations for 5 adult sooty shearwaters (*Puffinus griseus*) tracked from Taiaroa Head, South I, New Zealand, during the pre-breeding and incubation periods of the 1999/2000 breeding season.

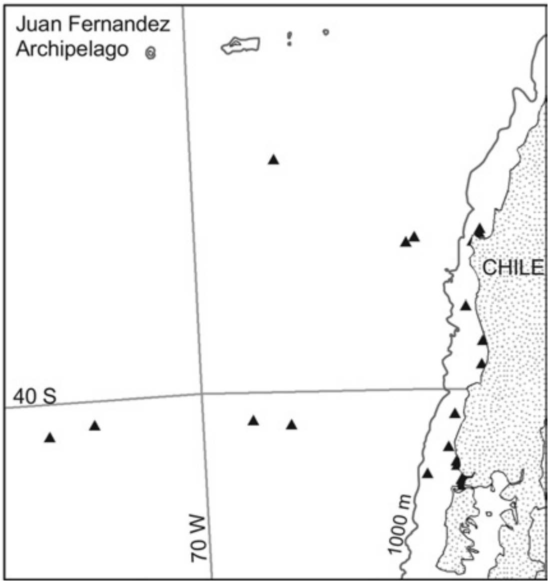

Fig. 6 Locations for a sooty shearwater (*Puffinus griseus*) (♂, TX-21290) tracked for 465 km northwards along the Chilean coast 17 Feb - 21 Feb 2000 over the continental shelf (mainly over water <200 m deep) after flying across the South Pacific Ocean.

Otago and Canterbury coasts for birds carrying PTTs during the incubation period, compared to the 3 pre-breeding PTT–carrying adults, and they spent most time flying over waters >1000 m deep (Fig. 3).

The cumulative point-to-point distance moved in successive days of tracking during the incubation period rose more steeply than for birds tracked during the pre-breeding period (Fig. 4). The male flew a minimum of 18000 km in 36 days, whereas the female flew 4100 km in 13 days. During this time, the female made 3 separate foraging trips (i.e. she returned 3× to the breeding colony). The male alternated prolonged stretches of fast travel with relatively short periods of slow travel. The most southern location recorded was 56°S (Fig. 1). Again, the effect of the duty-cycle had to be taken into account when comparing the incubation period and pre-breeding birds fitted with alternating cycle transmitters.

The male flew to the coast of Chile and did not return to the burrow. It maintained a minimum continuous average speed of 45 kmh^{-1} for 4 days from the mid-Pacific until reaching the Chilean coast at *c.*40° S (Fig. 4). Within this section of the track, minimum point-to-point speeds of up to 81 km h^{-1} were recorded (Fig. 5). It then moved a further 465 km north along the Chilean coast from 17 Feb to 21 Feb 2000 over water <200 m deep (Fig. 6). This bird's overall trajectory represented either a rapid dispersal from the breeding colony, or, improbably, a trip to a favoured feeding range. Spear & Ainley (1999) have, however, postulated a similar migratory movement for sooty shearwaters in the southern Pacific.

Survival of deployed birds

Three of the 5 birds tracked in this study were recaptured later back at the breeding colony, including the male that went to the coast of Chile (Table 1). The battery recorder on that bird's PTT indicated battery exhaustion 1 day before transmission was lost. This was the only PTT to show any indication of reaching the limit of its predicted battery life. Failure of the attachment probably resulted in the less than optimum amount of data being transmitted from the remaining birds.

Of those not recaptured, 1 bird (TX-23738) tracked during the pre-laying period was from a burrow in which a chick was reared until at least 1 Mar 2000. The PTT most likely fell off this bird after 34 days, because the battery recorder indicated that it was not yet exhausted (Table 1) and the bird appears to have survived during the experiment because the chick was reared. The 2nd bird (TX-21289, from the incubation-period group) was not recaptured and may have died, because its battery recorder did not show any signs of exhaustion on day 13 when transmission stopped: the attachment system used could potentially keep the PTT on the bird for longer than 13 days (Söhle 2001).

DISCUSSION

This was the 1st time that flight-paths of sooty shearwaters were recorded using PTTs. The sample sizes were too small to be a basis for generalisations on the movements of birds from the Taiaroa Head colony or to compare those movements between different stages of the breeding season. With data from a single summer, inter-year variation could be not explored. Maximum distances flown from Taiaroa Head in the pre-laying period ranged from 500 km to 1800 km. The maximum distances flown from Taiaroa Head during the incubation period were 2300 km to 8600 km. The minimum point-to-point flying speeds for the 5 birds were 1-81 km h^{-1}.

A study on effects of imitation PTTs (ISTs) on adults during the pre-breeding period showed that birds carrying ISTs lost weight between attachment and the 2nd capture (Söhle 2001). However, colony attendance was similar for both IST and PTT birds, perhaps because ISTs became detached after a few days so birds did not have to adjust their attendance. The movement of a sooty shearwater to Tasmania during the pre-laying period might not reflect normal adult behaviour during this stage of the breeding season, because its behaviour may have been affected by the attachment of a PTT. A related study showed that during the incubation period breeders were affected by handling and the attachment of a transmitter (Söhle 2001). Their attendance at the colony was 40% lower than that of control birds. Söhle *et al.* (2000) showed a similar reduction in colony attendance during the late breeding season. Accordingly, it may not be normal for a bird to fly to the Chilean coast, especially in light of the Spear & Ainley (1999) hypothesis of movement across the southern Pacific Ocean. However, these data on the activity of a few birds do demonstrate the range and complexity of the movements of sooty shearwaters breeding at the Taiaroa Head colony. As with the short-tailed shearwater, the sooty shearwater has been shown to travel long distances at high sustained speeds for large parts of a day when commuting or migrating (Nicholls *et al*. 1998; Klomp & Schultz 2000).

During the breeding season sooty shearwaters interact with, and are caught by, both line and trawl fisheries in New Zealand waters (Robertson et al. 2003; Uhlmann & Moller 2000). Our location data indicate that sooty shearwaters breeding in New Zealand visit a much larger potential area than the previously-assumed trans-equatorial migration routes, but do little to expand our knowledge of their activity during the flights. Further, these tracked flights have demonstrated that birds can fly as far as Australia during the pre-laying "exodus" or "honeymoon" period, and that they make long and rapid flights, specifically into cooler sub-antarctic waters, during incubation. Further satellite tracking, or the deployment of Global Positioning System logging units will be needed to extend our knowledge of the distribution of this and other species, to help our understanding of any direct interactions between diet, fisheries, and the potential for overlaps with the feeding ranges of other, similar-sized, shearwaters.

ACKNOWLEDGEMENTS
Pre-breeding PTTs were funded by Dr Henrik Mouritsen and Professor Barry Frost; breeding period PTTs were funded by D.G. Nicholls and C.J.R. Robertson. Sandra McGrouther and later Perry Reid allowed access to the sooty shearwater breeding colony at Southlight Farm, Taiaroa Head. Analysis and selection of the DIAG file data was undertaken courtesy of facilities at Southlight and Wild Press laboratories. Paulus Tak, Wendy Sullivan, Darren Scott, Tarius Haggood, Adrienne Markey, Rob Barrett, Paul Scofield, Kim Garrett, Christine Hunter, Sebastian Uhlmann, Jamie Newman, Jane Kitson, Chris Jones, Graeme Loh, Lyndon Perriman, David Tung, Harm Kossen, and many others participated in the fieldwork And this work could not have been done without their support and dedication.

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