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Telemetry reduces colony attendance by sooty shearwaters (*Puffinus griseus*)

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Abstract Twenty four imitation satellite transmitters (ISTs) were attached to breeding sooty shearwater (*Puffinus griseus*) adults late in the 1998/99 breeding season at Taiaroa Head, Otago Peninsula, New Zealand. There was no evidence of any difference in mean weight, change in weight or measurements of adults, nor breeding success of birds carrying ISTs compared with non-treatment birds. However the probability of attending the colony on a given night was reduced to 26% of its initial value from early March to mid April in IST-carrying birds, but not at all amongst non-treatment birds. No difference in ensuing weight, size and emergence date of chicks was detected between treatment and control groups. The maximum recorded attachment duration for an IST using glue was 21 days. Harnesses may be needed for longer studies of foraging behaviour late in the breeding season. Satellite-tracking studies will over-estimate normal foraging trip lengths and possibly under-estimate the amount of food usually provided to chicks if the reduced colony attendance detected in this study is a widespread problem.

Keywords satellite telemetry; impact; colony attendance; Procellariiformes; sooty shearwater; *Puffinus griseus*

INTRODUCTION

Over the past 100 years, the movements of birds have been investigated primarily by recoveries of banded individuals. The development of radio-telemetry using hand-held receivers first provided an opportunity to track individual birds with relatively small territories or feeding ranges in order to provide more detailed information on movements and behaviour. Monitoring of larger scale movements has recently been made possible by the development of transmitter packages small enough to be carried by the larger species and tracked by satellites. It is now possible to track the movements of large seabirds (e.g., Jouventin & Weimerskirch 1990; Prince et al. 1992). Satellite telemetry can provide valuable information on migration routes, stopover sites, foraging sites and at-sea behaviour. Possible interactions with man-made hazards such as longline and krill fishery operations can also be identified (Jouventin & Weimerskirch 1990; Robertson 1996).

The *Kia Mau Te Tītī Mo Ake Tōnu Atu* research project is a long-term study of the sooty shearwater (*Puffinus griseus*), a medium-sized burrowing petrel (Procellariiformes; Richdale 1963). It plans to use satellite telemetry to study where shearwaters feed and rest, which ocean currents may provide important food sources, and which fisheries pose a potential threat from bycatch (Moller et al. 1999; Uhlmann & Moller in press). The El Niño-Southern Oscillation (ENSO) climate fluctuation is linked to a decline in some populations of sooty shearwaters. This is probably due to reduced adult survival in the period

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just prior to the ENSO event (Lyver et al. 1999). The location and timing of the formation of an ENSO weather fluctuation is poorly understood but of interest to climatologists, biologists, fishers and agriculturists trying to understand global climate fluctuations. There is intense international interest in developing early warning predictions of incipient ENSO events, and it may be that fluctuations in sooty shearwater numbers can provide a useful bio-indicator of upcoming events. Detailed information on where sooty shearwaters feed and migrate will help answer the question of whether and how sooty shearwaters are linked to ENSO events, and to understand where and when ENSO weather patterns appear. Before embarking on such a full-scale study using satellite-monitored transmitters we considered it important to investigate possible effects of the transmitters on the sooty shearwaters' behaviour and condition.

Seabirds are homoeothermic and expend considerable energy in flight and diving under water for food (Bryant & Furness 1995). Sooty shearwaters dive up to 67 m (Weimerskirch & Sagar 1996), so the attachment of a PTT (Platform Transmitting Terminal) package could potentially increase their energy expenditure by adding weight and increasing air and water resistance. Effects on body weight, condition, survival and foraging distance, trip length and frequency are all potentially observable penalties of carrying a transmitter. These may, in turn, affect survival and/or the fledging weight of chicks reared by transmittered birds.

Most studies use too few transmitters to assess the effect of carrying them. Previous studies have usually not measured the potential effect of carrying a transmitter, so their reported results may not be representative of the actual behaviour, survival or reproductive output.

Various attachment techniques for radio transmitters have been used for birds in the past. These range from tape (Wilson & Wilson 1989) or harness (Berthold et al. 1992) to different types of glue (Nicholls et al. 1998) and implantation (Meyers et al. 1998). Satellite-monitored transmitters are expensive (NZ$6000 each) and are difficult to attach securely, so it is very important to design the best attachment that will improve the chances of recovering equipment.

The aim of this study was to examine the effects of carrying an imitation satellite-monitored transmitter (IST) on the weight change and colony attendance of breeding sooty shearwaters and on the growth of their chicks. We compared these parameters between birds with and without ISTs. We assessed the effectiveness of attaching by glue and tape in order to measure the risk of losing real transmitters.

METHODS

Study location

This study was conducted on a sooty shearwater colony at Taiaroa Head, an exposed coastal headland of steep slopes and terraces of sandstone and basalt on the tip of Otago Peninsula (Fig. 1). The loose, poorly consolidated sandy soils of the Peninsula allow for easy burrowing, and thick grass provides considerable cover over burrow entrances. Burrows were often dug within grass hummocks where surface roots act to bind the sand and prevent burrow collapse. The colony was chosen for this study because it is comparatively large amongst mainland colonies (Hamilton et al. 1997). It contains approximately 620 active burrows, well above the Minimum Viable Population size (Hamilton & Moller 1995), so any effects of the study will have had minimal conservation risk.

Experimental design

To determine burrow occupancy and colony attendance of sooty shearwaters, toothpicks were placed vertically in a line across each burrow entrance (following Hamilton 1998). Colony attendance was measured from the number of these 'barricades' knocked down at least once per night by birds entering or leaving the burrow.

Occupied sooty shearwater burrows in the south-eastern part of the colony at Taiaroa Head were randomly allocated to one of three treatments. Adults in the first group were banded, weighed and measured and an IST was attached to their back; adults in the second group were banded, weighed and measured but had no transmitters attached (hereafter referred to as non-IST birds). To account for the possible effects of capture and handling on the behaviour of these two groups, a third, 'non handled' group of breeding burrows were monitored by barricade knockdown but without catching the adults visiting these burrows.

Once one adult captured from a burrow was allocated to a treatment group, any additional adult captured from that burrow was given the same treatment (we assumed these birds were paired). The locations of burrows in the study site were mapped, and each occupied burrow marked with a numbered

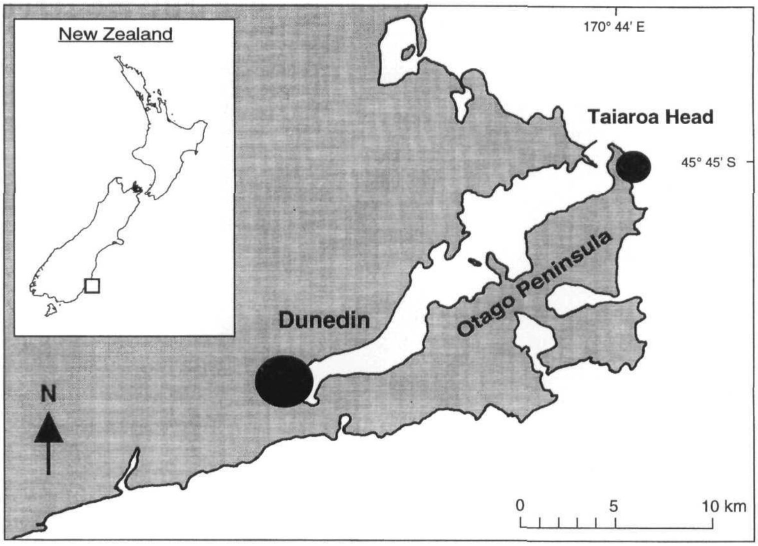

Fig. 1 Study location at Taiaroa Head on the Otago Peninsula.

tag. Only single entrance burrows were monitored in order to eliminate the possibility of adults entering and exiting through different entrances without knocking down the barricades. Burrows were allocated alternately to the IST and non-IST groups to ensure a balanced allocation to treatments with respect to date of first capture and location within the study transect.

Burrow monitoring and adult condition

Between 6 March and 16 April 1999, burrows were inspected several times per night for barricade knock-down. If the barricade showed that an adult had entered a burrow in either of the two experimental groups, a sock-shaped 'exit net' made from fishing net was placed over the burrow entrance to catch adult birds as they left later that night. Nets were inspected for birds at half-hour intervals between 4.00 am and 6.00 am. The following measurements were recorded: length of tarsus, mid-toe, mid-toe without claw, claw, tail, wing, bill, head and bill, nare to bill tip and bill width. We used a 2 kg (± 2 g) Pesola™ balance to measure mass, a 400 mm (± 0.1 mm) closed-end steel ruler to measure wing length, and vernier calipers (± 0.1 mm) for all other measurements.

On the first night one bird died during transit to a nearby building for IST attachment. This bird had been held in a cotton bag for up to two hours before processing. This bird and its burrow were excluded from all analysis, and thereafter all handling and attachment of ISTs was conducted at the capture site to reduce handling time. Under this procedure, both IST and non-IST birds were restrained and handled for 10 minutes maximum.

Preparation and attachment of ISTs

ISTs were modeled to the same shape and weight as transmitters currently being used by procellariid researchers. The average weight of ISTs was 24.2 g (95% CI 23.8–24.6 g, $n = 24$) which equates to about 3% of average adult sooty shearwater mass. This percentage conforms to tracking protocols used for albatrosses (Prince et al. 1992; Weimerskirch et al. 1993, 1997; Sagar 1995) and for short-tailed shearwaters (Nicholls et al. 1998).

A flexible two-component mould made from Exaflex® provided transmitter casts with a low, flat package configuration (following Freeman et al. in press). The dimensions of the mould were 90 mm × 30 mm × 60 mm. ISTs were modeled out of bees' wax and covered with two layers of epoxy adhesive (Araldite® – five-minute crystal) to provide a waterproof and pressure resistant coating. Small pieces of lead were added to adjust the weight. The surface of the cotton webbing attached to the bottom of the transmitters was 49 mm × 64 mm with trimmed edges. The transmitter itself (Fig. 2) was designed to have a streamlined front with the dimensions of 19 mm × 64 mm × 14 mm, and a battery encasement of 17 mm × 26 mm × 7 mm protruding to the left side. Each transmitter was equipped with a 230-mm nylon-coated stainless-steel antenna protruding at an angle of 45°. The lower part of the antenna was supported by a piece of metal to keep it straight.

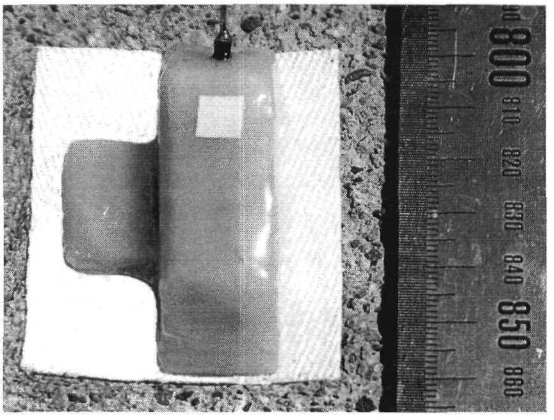

Fig. 2 Imitation satellite transmitter viewed from above. The ruler shows mm graduations.

Two techniques were used to attach the IST onto the top of the feathers between the wings at the pectoral girdle on the bird's back. The first technique involved attaching the IST to a piece of cotton fabric using Araldite® and then gluing the fabric onto the feathers. The second technique was to attach the IST directly to the feathers using tesa-tape (Tesa-Band®, Beiersdorf, Germany) according to the method described by Wilson & Wilson (1989). Small drops of Loctite® 401 glue were used to improve the adhesion of the tape. Low sample sizes led us to pool data for taped and glued deployments in our analyses.

Late breeding season recapture

Attempts were made to recapture adult birds using exit nets every night between 4 and 10 May 1999, and thereafter on three nights per week until 22 May 1999. All adults captured were identified and weighed. Recaptured adults with ISTs were inspected for signs of detachment.

Chick survival

Chick survival for each treatment group was estimated by catching chicks using exit nets after 20 April 1999, when they started to come out of their burrows at night to exercise their wings (Hamilton 1998).

Probability of return to the breeding colony next season

The proportion of adults returning to the breeding colony in the following season in each treatment group was monitored in October-December 1999. Exit nets were set up at burrows from the first two treatment groups between 4:30–5:00 am from 1 to 6 December 1999. Wider searches and hand capture of incoming and outgoing birds were also undertaken to detect returning adults that might not have been using the same burrow as in the previous season. Birds captured were identified by their bands, weighed and checked for signs of former IST attachment (glue remnants, damaged feathers).

RESULTS

Adult condition at first capture

A total of 210 burrows was monitored. From these, 48 adult birds were caught between 6 March and 2 April 1999. A total of 24 birds from 19 burrows carried an IST and 24 birds from 18 burrows were measured but did not receive an IST.

There was no evidence of a significant difference in weight at first capture between IST and non-IST birds (t-test $P = 0.45$, CI $\pm$ 0.15, n = 48). Nor was there evidence of a difference between IST and non-IST birds for any of the morphometric parameters (Table 1).

Colony attendance

Colony attendance, as determined by barricade knockdowns, was monitored for 30 nights from 7 March until 16 April. Nineteen burrows were monitored for IST, 18 burrows for non-IST and 33 burrows where neither of the attending adults were handled.

A logistic regression showed a significant decrease in colony attendance by IST compared to non-IST carrying birds only ($P = 0.037$, F = 4.56, DF = 1, 56). The regression shows 53% of burrows were visited by IST parents each night at the beginning of the study in early March, but only 14% near the end of the study in mid April 1999 (Fig. 3). This equates to a reduction in attendance to 26% of its original level in the IST group over a period where attendance remained unchanged amongst non-IST parents. There is no evidence of a trend in the proportion of barricades knocked down by IST and non-IST carrying adults combined in the analysis before measurements and IST-attachments were conducted (Fig. 3: Before handled).

The difference in colony attendance between the three different treatment groups is shown in Fig. 4A-C. The main effect of attaching ISTs is evident in late March and early April, but attendance was about equal by the very end of the study. The same can be seen for IST compared to non-handled birds (Fig.

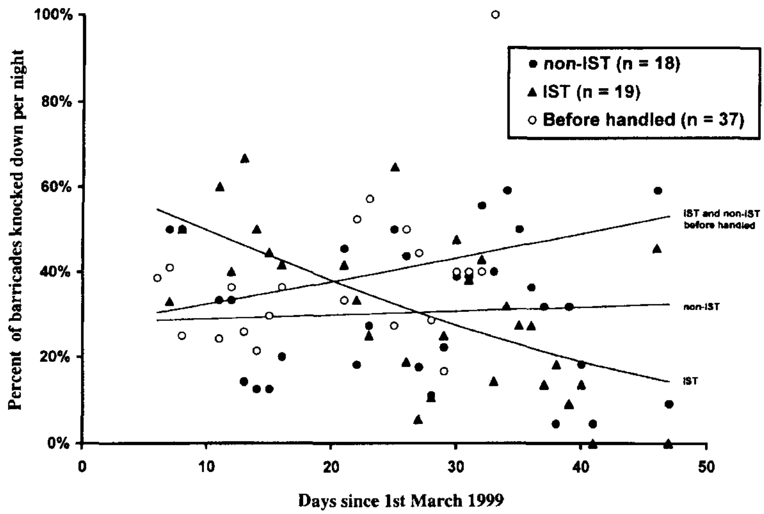

Fig. 3 Trends of colony attendance for IST and non-IST carrying sooty shearwater adults. Open circles show attendance of adults at marked burrows before the birds were handled.

Table 1 Mean weight and body measurements of adult sooty shearwaters allocated IST and non-IST groups, March–April 1999. P-values give the probability that the mean parameters were the same between the two groups at their initial capture, using 2-tailed unpaired t-tests.

	IST (n = 24)		Non-IST (n = 24)		
Morphometric parameters	x	SD	x	SD	*P*-value
Weight (g)	816	89.4	811	215.6	0.45
Tarsus (mm)	58.8	1.7	58.6	1.8	0.63
Mid-toe (mm)	70.3	1.9	70.2	1.8	0.82
Mid-toe without claw (mm)	61.1	1.6	60.8	1.8	0.66
Claw (mm)	11.8	0.6	11.6	0.7	0.54
Tail (mm)	86.4	3.6	86.2	3.7	0.88
Wing (mm)	301	5.5	302	6.3	0.75
Head & Bill (m)	101	3.5	99	3.3	0.11
Bill (mm)	42.3	1.5	42.3	1.5	0.97
Nare to Bill-tip (mm)	34.3	2.2	34.8	1.3	0.38
Bill width (mm)	14.8	0.5	14.8	0.6	0.90

4B) and for non-IST birds compared with non-handled birds (Fig. 4C).

A χ^2-Test showed no evidence of a significant difference in the proportion of IST adults (n = 5) and non-IST adults (n = 6) recaptured between 13 March and 16 April 1999 ($\chi^2 = 0.1$, DF = 1, $P = 0.7277$).

An unpaired t-test of adult weight change since first capture found no evidence of a significant difference between IST and non-IST birds ($P = 0.229$, n = 6, 5). The mean ± CI weight change per day was 0.65 ± 0.104 g and –0.16 ± 0.805 g for the IST and non-IST groups respectively. Low sample size means that we had very low statistical power to adequately test whether there was a difference in weight change between the treatment groups.

Return of adults to the colony in the 1999/2000 breeding season

The colony was visited at night on 25 September 1999 and no birds were seen. On the next visit (30 September) birds were observed arriving at the colony just after dusk. Colony attendance was monitored from 7 October until 1 December, 1999. A χ^2-Test found no evidence for a difference in the proportion of IST and non-IST burrows used ($\chi^2 = 0.298$, DF = 1, $P = 0.585$). Since sooty shearwaters normally return to the same breeding burrow in successive years (Richdale 1963) this observation suggests that there was no difference between groups in the probability of returning to breed in the next breeding season.

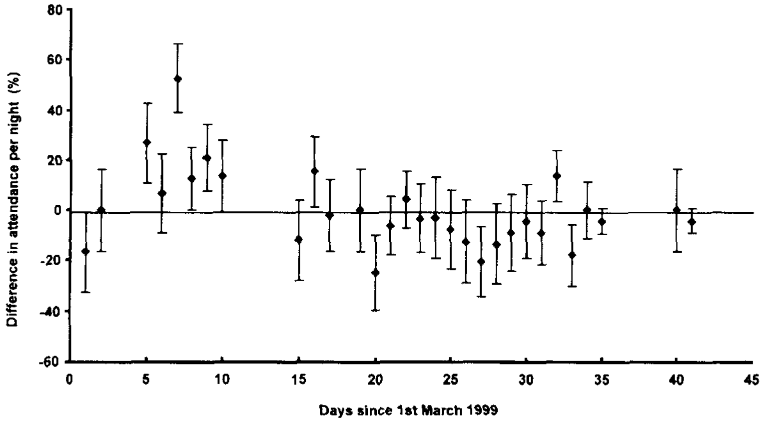

Fig. 4A Difference in colony attendance (mean ± SE of the difference) for IST carrying and non-IST sooty shearwater adults in the late breeding season. The y axis shows percent attendance of IST birds minus percent attendance of non-IST birds. Above 0 indicates increased colony attendance by IST birds, and below 0 indicates reduced colony attendance by IST birds compared with non-IST birds. The line shows the average difference in attendance of –0.3% between the two groups.

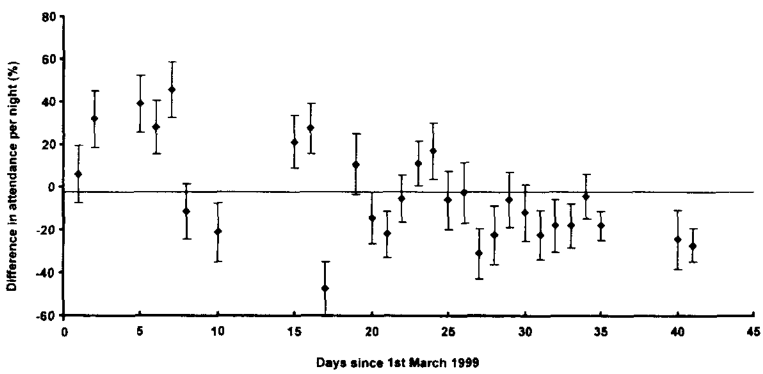

Fig. 4B Difference in colony attendance (mean ± SE of the difference) for IST carrying and non-handled sooty shearwater adults in the late breeding season. The y axis shows percent attendance of IST birds minus percent attendance of non-handled birds. Above 0 indicates increased colony attendance by IST birds, and below 0 indicates reduced colony attendance by IST birds compared with non-handled birds. The line shows the average difference in attendance of –3.6% between the two groups.

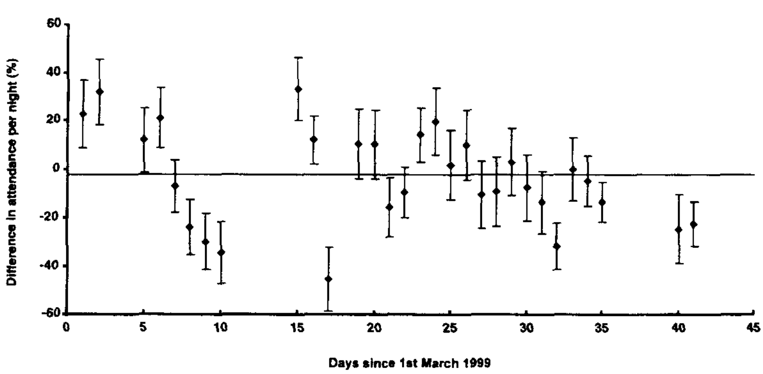

Fig. 4C Difference in colony attendance (mean ± SE of the difference) for non-IST carrying and non-handled sooty shearwater adults in the late breeding season. The y axis shows percent attendance of non-IST birds minus percent attendance of non-handled birds. Above 0 indicates increased colony attendance by non-IST birds, and below 0 indicates reduced colony attendance by non-IST birds compared with non-handled birds. The line shows the average difference in attendance of –3.3% between the two groups.

Chick condition and emergence

Twenty-three chicks (found in 63% of the breeding burrows monitored) were caught. There was no evidence of a significant difference in the proportion of IST and non-IST burrows yielding chicks ($\chi^2 = 1.508$, DF = 1, $P = 0.2194$), so there is no evidence that breeding success was altered by IST attachment. An ANCOVA on chick measurements, using date as the covariant, showed no evidence of a significant difference between IST and non-IST burrows for any of the measurements recorded (Table 2). Nor did an unpaired t-test indicate any significant difference between the day that IST and non-IST chicks emerged from burrows ($P = 0.8794$, n = 23).

The chick from burrow 4 emerged on the 3 April after the burrow collapsed. It sheltered in a nearby hole covered by tussock and was last seen alive on 10 April. On 15 April, our next visit to the colony, its carcass was found in front of the burrow. On the 24 April the chick from burrow 37 was found dead. It had not been caught before that day. Other than these, no dead chicks were detected.

Length of IST attachment

Five out of 22 IST birds were recaptured with the IST still attached (Table 3). The known attachment duration ranged from two to 21 days. No bird with IST attached by tape was recaptured. Two birds (B2 and M10) recorded short attachment durations (2, 5 days) but were not subsequently recaptured, so the IST may have remained attached for much longer. Bird F6 was recaptured after three days with no signs of detachment, but 31 days later it was recaptured without the IST.

DISCUSSION

Impact of ISTs on adults

We detected no differences in weight change between IST and non-IST adults. However these results are based on very low sample sizes, making it difficult to detect differences even if they did exist. Adult weights are also highly variable and will have been affected by whether or not the adults had fed their chick before being caught on a given night. Logistic difficulties in recapturing the birds also means that individuals were weighed over different time periods. This will have added variability but not bias because it applies to both groups.

Colony attendance by IST adults was lower than non-IST adults in the mid period of our study because there was a steady reduction in attendance

Table 2 Mean weight, tail length and wing length of near-fledging sooty shearwater chicks from IST and non-IST parents, May 1999. The *P*-values are the probability that mean parameters differed between the two groups, as determined by an ANCOVA in which day of season was the covariate.

Treatment group	Weight (g)	SD	Tail (mm)	SD	Wing (mm)	SD	n
IST	926.7	43.49	89.94	1.16	303.3	1.85	10
Non-IST	914.9	47.29	87.55	1.26	300.7	2.02	13
P-value	0.856		0.177		0.350		23

Table 3 Known duration of Imitation Satellite Transmitter (IST) attachment.

IST No.	Days between successive recaptures of IST adults	Minimum days that IST remained attached
F6	3, 31*	3
F10	1, 20	21
B2	5	5
M5	4, 9	13
M10	2	2

*Recaptured without IST

as the season progressed by IST but not by non-IST or non-handled birds (Fig. 3, 4). Less difference was evident amongst groups by the very end of April. This is as expected from overall reduced colony attendance by all adults and the onset of the northern migration by this time (Richdale 1954) and/or because many ISTs may have fallen off by then (Table 3).

Our results suggest that even though adults may maintain their own weight and body condition while carrying an IST, they do nevertheless incur some cost in foraging time or efficiency. Our overall results are very similar to the only other detailed study known to us of this kind, that by Freeman et al. (in press) for Westland petrels (*Procellaria westlandica*). Westland petrels carrying satellite-monitored transmitters reduced their colony attendance but there was no evidence of adults losing weight compared to non-carrying adults (Freeman et al. in press). Parents may need to forage longer to acquire more food to replace additional energy lost from carrying the transmitter. Alternatively, if the IST reduces the bird's foraging efficiency, it may take them longer to acquire the same amount of food as a non-IST adult. If the transmitters affect flight speed or energetic costs of flight, they may return to the colony less frequently. It is even possible that attachment of satellite-monitored transmitters reduces the survival of the adults. We had too few recaptures to adequately test this possibility.

We found no evidence for a reduction in colony attendance between non-handled and non-IST birds (Fig. 4C). This suggests that any effects of capture, banding and measuring adults is slight.

Impact on chicks

No significant differences were found in chick weight or size between chicks with IST or non-IST carrying parents. Nor was there any evidence that the day of emergence differed between fledglings of IST and non-IST parents. Freeman et al. (in press) also could not detect differences in weight or wing length of chicks from telemetered and non-telemetered parents. However both studies had relatively small sample sizes, and so had low power to detect differences.

Lower colony attendance of IST adults over the longer term would probably result in the chicks of IST birds eventually receiving less food. This study was conducted in the late stages of the breeding season when reduced feeding (Richdale 1954) is likely to have the least effect on the chicks. It should be repeated with larger sample sizes earlier in the breeding season. We predict that significant differences will then be detected because of prolonged exposure to the interference caused by the ISTs.

Implications for satellite tracking studies

Other studies have recorded survival of satellite-monitored transmitters for longer periods than we did, e.g. between 18 and 45 days (Nicholls et al. 1998; Klomp & Schultz 2000). Sign of moult of body feathers of our birds (R. P. Scofield, pers. comm.) suggests that our ISTs were lost because feathers were shed at this time of the year. A harness would present several potential new logistical problems, but would retain satellite packages towards the end of the breeding season when colony attendance is reduced.

As colony attendance is reduced, satellite-tracking studies would over-estimate foraging trip lengths and possibly under-estimate food provided to chicks. Reduced colony attendance may not be indicated by a change in adult weight, the most commonly used measure of telemetry effects in satellite tracking studies. A prolonged decrease in provisioning chicks may adversely affect chick growth, fledging success and feather development. The probability of recruitment of sooty shearwater chicks into the breeding population increases with size at fledging (Sagar & Horning 1997) so telemetry could affect colony population dynamics.

Seabirds like shearwaters that forage over areas of thousands of square kilometers to exploit patchy food supplies may be particularly vulnerable to the costs of carrying a transmitter. Research on weight loading and increased drag in air and water may identify ways of reducing the penalty of carrying a transmitter. Shortening of the antenna may help.

This study signals a warning to other researchers using satellite telemetry without checking for effects caused by transmitters. Perhaps the equipment attached alters the behavioural patterns being investigated in other species too, and affects population recruitment. The latter may be of concern where telemetry is applied to threatened species. More replicated studies using imitation transmitters are now needed to see how widespread the problem is.

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