special issue:
Advances in tools for bird population monitoring in New Zealand

Breeding activity of Chatham Island taiko (*Pterodroma magentae*) monitored using PIT tag recorders

Graeme Taylor[1*], Stu Cockburn[1], Dan Palmer[2] and Patrick Liddy[2]

[1]Science and Technical Group, Department of Conservation, PO Box 10420, The Terrace, Wellington 6143, New Zealand
[2]Chatham Island Area Office, Department of Conservation, PO Box 114, Chatham Islands
[*]Author for correspondence (Email: gtaylor@doc.govt.nz)

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Abstract: We developed a new automated recorder, powered by a 12-volt battery, to monitor activity patterns of wild animals marked with passive integrated transponders (PIT tags). The recorder was used to monitor Chatham Island taiko (*Pterodroma magentae*), a critically endangered seabird species with remote and dispersed breeding burrows. We collected information on annual return rates of individuals and pairs, dates of return and departure for the courtship and egg-laying periods, duration and dates of incubation shifts and also chick feeding visits. Taiko return to their burrows in September and October each year to mate. Return dates are independent of moon phase. Females can spend as little as one day ashore during the month-long courtship period. The pre-laying exodus averages 55 and 51 days for females and males respectively. The three main incubation shifts average 14–15 days each but some shifts can be as long as 19 days. Adults feed their chicks 32–35 times over a 3-month period, with males feeding their chicks more often than females. We discuss problems encountered during the development and field testing of the new PIT tag recorders, but also the benefits of these devices over conventional monitoring techniques for cavity-nesting birds.

Keywords: radio-frequency identification technology; transponders; breeding biology; burrowing seabirds

Introduction

Nocturnally-active burrowing seabirds are difficult to monitor for population abundance and trend. During the day most of the population remains at sea feeding and the proportion of birds returning to land nightly depends on a range of factors including season, weather, moon phase, and foraging range (i.e. inshore- versus pelagic-feeding species) (Warham 1996). When birds return to the colony after dark they are difficult to observe in flight or on the ground. Birds may fly over the colony repeatedly, making it impractical to count total numbers visiting the colony. On the ground some birds enter burrows quickly after landing while others sit around on the surface displaying or sleeping. Seabird colonies are comprised of breeding birds, failed breeders, unpaired breeding-age birds and prospecting pre-breeders (Warham 1996). Separating birds into these groups can be problematic.

A variety of methods have been developed to monitor burrowing seabirds (Warham 1990; Taylor 2000b). Counting burrows is the commonest technique used to estimate population size and trends but requires an estimate of occupancy rates to determine species composition and number of breeding pairs (Taylor 2000b). The occupancy rate in short or non-complex burrows can be determined using an infrared video camera on a long tube (burrowscope) (Lyver et al. 1998). These devices are useful for estimating annual breeding success in populations by checking burrows after egg laying and before chick departure. The simplest form of monitoring burrow activity is by placing a row of sticks across the entrance and recording when these are knocked down by birds. However, these sticks are sometimes knocked down by other animals or the wind (Johnston 2002). Infrared cameras and time-lapse video recorders are valuable for monitoring activity at nests, but these techniques are limited to a small number of burrows due to the expense of equipment and the labour costs involved in frequently changing batteries and viewing subsequent activity footage (Johnston 2002; Johnston et al. 2003).

To determine productivity and survival rates of known individuals and pairs requires a programme of capturing and marking birds, traditionally using metal leg bands (Warham 1990). Identifying marked occupants of breeding burrows and determining their breeding status requires the preparation of study burrows, usually by digging access holes to nest chambers and sealing these with a suitable cover (e.g. rock or wooden board). This method works well for some species but is not recommended if the seabird species is sensitive to human disturbance (Blackmer et al. 2004), and is impractical if birds nest in long inaccessible burrows.

This special issue reviews the advances in tools for bird population monitoring in New Zealand. This issue is available at www.newzealandecology.org.nz/nzje/.

Passive integrated transponder (PIT) tags have been used in other seabird studies to examine breeding parameters and activity patterns (Becker & Wendeln 1997; Weimerskirch et al. 2001; Zangmeister et al. 2009). Commercial devices for PIT tag monitoring can be expensive to purchase and not all are designed for use in remote field settings, with some models running off mains power (GT pers.obs.). We designed a new PIT tag recorder that is light-weight, waterproof, powered by 12-volt batteries and stores several weeks of activity data in the memory chip. Using this monitoring tool means that birds are not disturbed after initial handling, and there is the potential to better understand the normal activity patterns of burrowing seabirds by continuous monitoring of their burrow entrances. This paper summarises new biological insights and the conservation benefits obtained using this monitoring system on the Chatham Island Taiko (*Pterodroma magentae*) Recovery Programme.

Methods

Study site and species

The Chatham Islands (44° S, 176° W) are the eastern-most land masses in New Zealand. The Chatham Island taiko (hereafter taiko) (Fig. 1) is an International Union for Conservation of Nature (IUCN) listed critically endangered endemic seabird (Birdlife 2010) that nests in the southern forests of the main Chatham Island. There is an intensive recovery programme to preserve and enhance the taiko population in the Tuku Nature Reserve (Taylor 2000a; Aikman et al. 2001). Burrows are located 4–5 km inland from the coast in dense forest dominated by tree ferns and several endemic tree species. A network of tracks is present to assist field teams who walk for 1–2 hours each way to reach the nearest burrow groups. Burrows are spread out over an area of >1000 ha of forest. In recent years only 15–19 breeding pairs have been identified and an additional 10–12 unpaired males were found occupying non-breeding burrows (Lawrence et al. 2008). Breeding taiko first return from their winter exodus in September or October then both sexes depart on a pre-laying exodus before females return to lay their single egg in late November or December. Taiko have three main incubation shifts. The chick hatches out in January or early February and fledges from April to June (Johnston et al. 2003; Imber et al. 2005). Away from the colonies, taiko forage at sea south and east of the Chatham Islands (Imber et al. 1994).

Since the first taiko burrows were discovered in 1987 (Imber et al. 1994), we have monitored burrow activity by placing rows of small sticks across entrances and recording the status of these fences (sticks up or down). Presence of bird droppings and feathers is also recorded. Most of the burrows have access holes dug to the nest chambers and some of these chambers have been converted to wooden nest boxes to aid nest monitoring and marking of chicks. Infrared video surveillance and burrowscopes are sometimes used to monitor burrow activity (Johnston et al. 2003).

Bird capture and processing

Between 2001 and 2010, we applied PIT tags to 144 taiko (70 chicks and 74 adults). This represents >90% of the world population of this species (estimated to be c. 150 birds in 2010). We injected small (11 × 2 mm) Allflex™ (ISO 11784) transponders dorsally under loose skin in the lower neck region of taiko, using sterile single-use needles

Figure 1. Chatham Island taiko at burrow entrance (October 2006). Photo: GA Taylor

and a Henke Jet™ insertion gun, following standards in the New Zealand Department of Conservation (DOC) PIT Tag Standard Operating Procedures. All birds are also marked with stainless steel leg bands and some have combinations of black and white colour bands to assist identification on infrared cameras. There has been only one recorded instance of PIT tag loss during or after insertion. No injury or sign of infection has been observed after insertion of PIT tags. All birds have been sexed using molecular techniques applied to blood and/or feather samples collected at first encounter (Griffiths et al. 1998; Lawrence et al. 2008).

Development of the automated PIT tag recorder system

Recording of taiko moving through burrow entrances at remote sites required a standalone, cheap, low-powered PIT tag recorder that could store burrow-specific data using radio-frequency identification (RFID) technology. We custom-designed PIT tag recorders (Fig. 2) based on an RFID reader integrated circuit (EM4095). The circuit board was designed incorporating the RFID chip and associated electronics, microcontroller, memory and an internal clock. We used embedded software to control the electronics, and also the algorithms for decoding signals from the Allflex™ transponder tags. A serial interface (RS232) in the recorder facilitated communications with custom Windows Mobile™ based software for the user to download data and change various settings. The time stored in the internal clock was used to control the on/off operation time of the PIT tag recorder and to record the time of detection of each PIT tag. Digitally compressed data were stored in the recorder with each record, including the time stamp, requiring eight bytes of storage space. The memory in the recorder allowed for the storage of c. 2000 entrance activity events. Because the reader is capable of reading transponders several times per second the recorder was programmed to only record each PIT tag once per minute.

The EM4095 integrated circuit on which the RFID reader was based is relatively simple with its operating frequency set by the characteristics of the antenna. To keep the cost of the recorders low, we chose not to use electronic tuning requiring expensive high voltage components. Instead we manually tuned the size and shape of the antenna to match the same frequency as that of the PIT tags. For the taiko project, we used a simple hand-wound coil made from transformer winding copper wire and wrapped in electrical tape. Once constructed to a fixed shape (diameter, turns and wire gauge) this antenna could be distorted to fine-tune it to the required frequency (134200Hz). The recorder provided feedback on the current operating frequency to the user via the serial interface to make this task generally straightforward in the field. Many different fixed antenna shapes could be used to suit different-sized or -shaped burrows.

Taiko burrows are widely dispersed and this required a separate power supply located at each site. Minimising power consumption was important. Our system was designed to operate off a 12-volt power supply. Different-sized batteries were used depending on the practicalities of different sites but generally we used 7-amp-hour Yuasa™ 12-volt NP series gel cells. These provided about one week of operation when the recorders ran all night and several weeks if a motion sensor was used. In 2007 batteries were charged using a petrol generator at a field hut and carried by pack to each burrow. In 2008 and 2009 batteries were charged from solar panels positioned at a central charging location. From 2010 small solar panels were used to charge batteries adjacent to burrows where spaces in

Figure 2. PIT tag recorder set up at a taiko burrow. Note the antenna layout around the burrow entrance and stick fence, motion sensor on stake, white PIT tag recorder box housing the RFID reader and datalogger (partly obscured), wire cables and 12-volt battery. The recorder unit and wires are normally covered with vegetation to stop taiko dragging cables into the burrow. Photo: GA Taylor

the forest canopy allowed. Connecting the batteries to solar panels provided continuous power for the units unless the panels were positioned in areas with little direct sunlight (e.g. valley floors and sites with few canopy gaps).

Most power is consumed by the antenna current of the PIT tag recorder, and because we designed the system so that the birds passed through the antenna itself, the current could be reduced substantially compared with readers designed to maximise read range. Furthermore, additional power savings were accrued because the antenna was turned off outside the hours when taiko could be expected at the burrow entrance; this was achieved by the recorder comparing the time in its internal clock to times set by the user. Taiko only visit burrows from 1 h after sunset to 1 h before sunrise so the times were adjusted seasonally to meet these requirements. The recorder also allowed for the connection of a motion sensor (Fig. 2). Power to the antenna could be turned off unless motion was detected, at which point the antenna would switch on for a period determined by the user. The time from the sensor triggering and reading the PIT tag was about 0.2 s. The times of any detections of motion were recorded even if a PIT tag was not read. The motion sensors were also custom-made, using pyro-electric sensors (Nias AMN 32111) and associated electronics embedded into epoxy resin in a PVC tube. These were connected to the recorder via a cable, with the sensor pointing at the burrow entrance.

The cost to construct each PIT tag recorder was approximately NZ$180 in 2010, including assembly labour. In addition, a simple power cable (NZ$25), battery (NZ$35 to $65) and antenna ($8 to $10) were required for each unit. The motion sensors cost NZ$150 to construct.

Field monitoring protocols

Antennae were installed at the entrance of all active taiko burrows ($n = 37$) between October 2007 and December 2010. There were insufficient PIT tag recorders available to monitor all burrows so a priority list was developed each season, which targeted burrows at different stages of the breeding season. PIT tag recorders were set up from mid-September at sites expected to have early-returning birds based on the activity patterns observed in the previous breeding season or by weekly monitoring of entrance stick fence status. Recorders were then shifted to the remaining breeding sites by late September or early October to capture the presence of both birds in the pair when they returned. After the breeding birds were identified and had departed on their pre-laying exodus, some PIT tag recorders were moved to non-breeding burrows from mid-October to 20 November. Recorders were present at most breeding sites from 20 November onwards to monitor breeding activity. A few non-breeding burrows were also monitored in December and January to identify any visits from females and record pair-bonding activity. All recorders were removed and stored in May after adult visits had stopped and all chicks had departed from the burrow.

Compilation of data

At each burrow visit field staff downloaded data on the recorders onto a small waterproof hand-held computer using custom software, and cleared the logger memory after each successful download. All PIT tag data was then downloaded in the office and stored on Microsoft Excel™ spreadsheets for summarising activity. The data were sorted by burrow and date, and summary information was extracted over each breeding season (2007–2010). The data were summarised to provide a roll call of presence/absence at each burrow (identification of singles or pairs, and the presence of other prospecting taiko), and to identify dates of taiko return and departure from their burrows during different stages of the season (courtship period, laying, incubation changeovers, hatching period, chick-feeding visits and departure for winter exodus). The calendar date information is presented as medians, range and sample size. Numeric information of time spent on activities is presented as mean (±SD), range and sample size.

Results

The PIT tag recorders were progressively improved over the course of the project. Various problems (discussed below) were encountered with this new monitoring system in the first few seasons, which resulted in gaps in the data collection for individual burrows. Thus while we collected many new insights into the behaviour of taiko between 2007 and 2010, we are yet to obtain a complete record of breeding season activity from any one burrow. These points need to be taken into account when reviewing the results below.

Annual roll call and recapture rates

In the 2006/07 season 44 taiko visited our monitored burrows. Based on a combination of hand capture and PIT-tag-recorder data, all but one of these birds was present again in 2007/08 (97.7% return rate). We identified 45 taiko visiting monitored burrows in 2007/08 and all of these birds were recorded alive in the 2008/09 and 2009/10 seasons, a return rate of 100% in both years. The apparent mean annual survival rate of taiko in the known burrow groups averaged 99% between 2006 and 2009.

Taiko returned from their winter exodus and reoccupied burrows during all four phases of the moon (Table 1). Twenty birds (41%) returned in the period after full moon and prior to last quarter although the difference was not significant ($\chi^2 = 7.2$, 3 d.f., $P > 0.05$.).

Recording of breeding parameters

Breeding birds started to return from their winter exodus on 21 September (Table 2) with failed breeders from the previous season returning earlier than successful breeders. Males spent 8 days on average in the burrow during the courtship period compared with 3 days spent ashore by females (Table 3). Two females visited for only two nights and one day before departing on their pre-laying exodus. The average pre-laying exodus of males and females was 51 and 55 days respectively (Table 3). The laying period extended from 22 November to 13 December (Table 2). Fourteen males (58%) returned on either the same night as the female or up to four nights before she returned to lay her egg. The exception was one male in a newly formed breeding pair that returned 11 nights before the female laid her egg. Seven pairs returned from their pre-laying exodus on the same night, some birds only minutes apart, after 50+ days at sea. One female returned to lay an egg and departed again to sea just 99 min later.

The PIT tag recorders confirmed that taiko have three main incubation shifts, two of these by the male. These shifts ranged from 12 to 19 days each (Table 3), but were usually 14–15 days long. The partners returned from sea to their burrow and changed over incubation quite quickly; males stayed for only c. 18 min on average after the female returned, and females for c. 30 min. Changeovers were as short as 7 min, although one

Table 1. Number and percentage of taiko returning to their burrow, after the winter exodus, in relation to moon phase.

Moon phase	Number	%
New Moon to First Quarter	9	19
First Quarter to Full Moon	10	21
Full Moon to Last Quarter	20	41
Last Quarter to New Moon	9	19

Table 2. Breeding dates for Chatham Island taiko revealed by PIT tag recorders (2007–2010)

Breeding activity	Earliest date	Median date	Latest date	*n*
Return of male from winter exodus	21 Sep.	4 Oct.	15 Oct.	24
Return of female from winter exodus	22 Sep.	5 Oct.	17 Oct.	24
Date pair first together in burrow	22 Sep.	6 Oct.	17 Oct.	22
Male departs on pre-laying exodus	25 Sep.	13 Oct.	8 Nov.	21
Female departs on pre-laying exodus	26 Sep.	10 Oct.	20 Oct.	25
Laying date	22 Nov.	2 Dec.	13 Dec.	27
Male returns from pre-laying exodus	20 Nov.	4 Dec.	12 Dec.	27
Date of departure from nest at end of incubation	22 Jan.	28 Jan.	4 Feb.	8

Table 3. Breeding activities for Chatham Island taiko as revealed by PIT tag recorders (2007–2010)

Breeding activity	Mean	SD	Range	*n*
Time in breeding burrow by male during courtship period (days)	7.9	2.6	3–12	15
Time in breeding burrow by female during courtship period (days)	3.1	1.6	1–7	18
Time spent together by pair in burrow during courtship (days)	2.5	1.3	1–6	17
Male pre-laying exodus period (days)	51.1	10.8	27–63	9
Female pre-laying exodus period (days)	54.9	3.5	50–61	8
Length of initial incubation shift by female (days)	1.5	1.9	0–5	24
Length of first main incubation shift by male (days)	15.7	2.1	12–19	10
Length of first main incubation shift by female (days)	14.5	1.8	12–17	8
Length of second main incubation shift by male (days)	13.9	2.1	11–17	9
Time for female to leave nest after return of male (min) (a) around laying, (b) mid-incubation *	(a) 78.7 (b) 29.3	59.7 18.7	8–195 13–64	15 10
Time for male to leave nest after return of female during early and late incubation (min) **	17.8	5.9	7–29	16

*Excludes four females that stayed an extra day in the burrow after egg laying when male was already present.
**Excludes one male that departed to sea after incubating an egg for 16 days and prior to his partner returning, and another incubating male that stayed for 2 days in the burrow after return of the female.

male stayed on for 2 days after his mate returned. Exact hatching dates and total incubation period could not be determined using PIT tag recorders as birds stay within the burrow for a day or two after hatching, to guard their chicks (Johnston 2002). However, the incubation period was less than 54 days in five of the burrows that we monitored (assuming the sitting bird departed to sea after their chick hatched).

Chick-feeding activity

Only one complete record was obtained of a pair feeding their chick in the nest throughout the nestling period. The pair hatched their chick just before 25 January 2010. The female last visited the nest on 12 April and the male on 14 April. The burrow entrance sticks were still intact on 21 April when the chick was transferred to the Sweetwater Covenant (a predator-fenced new colony site). Over the 80-day chick-feeding period, the pair visited the burrow on 33 occasions (13 by female and 20 by male), averaging one feeding visit every 2–3 nights. The longest feeding gaps by this pair were 11 days by the female and 8 days by the male. The pair returned to feed their chick on the same night only once. The female stayed ashore by day on five occasions whereas the male spent just one day in the burrow with its chick.

The only other pair with a near complete chick-feeding record was monitored in 2009. We logged 32 visits to their chick, but may have missed 1–2 feeds by the female soon after the chick hatched in January, before the PIT tag recorder was activated on continuous mode. The male visited the chick 19 times (including staying ashore on four separate days) and the female made 13 visits (staying ashore on one day). The last visit by the female was on 9 April and the male on 17 April. The chick was transferred to Sweetwater Covenant on 21 April where it fledged on 6 May. The entrance sticks at its original natal site remained undisturbed on 6 May, indicating a 19-day parental abandonment period.

Table 4 shows the time spent ashore in burrows by birds when visiting to feed their chicks was typically around 2–3 h but six visits were as short as 32–40 min. The actual time taken for parents to deliver food to the chick is unknown as the recorders only provide entry and exit times. After exiting the nest chamber the birds could spend up to 30 min at the burrow entrance before finally departing to sea. The pattern of chick feeding was not easy to interpret as battery failures and other problems meant some visits were missed by most PIT tag recorders during this study (from observed entrance stick knockdowns).

Problems encountered with the new PIT tag recorders

Powering of the PIT tag recorders at each site proved difficult and resulted in numerous performance problems with the 12-volt batteries. Between 2007 and 2009 many data collection failures were caused by batteries losing power before staff could return to burrow sites to replace them. Using motion sensors greatly reduced the power consumed by batteries but impacted on the reliability of the data (see below). The very wet, enclosed and cold conditions at the burrow sites meant moisture sometimes made its way into the apparently waterproof recorders, occasionally causing failures in data collection. Moisture in the recorders was combated using silica gel and extra covers to reduce exposure to rain.

Issues with the antennae detuning after exposure to the environment for a long period were an ongoing problem for the field staff. The antenna frequency tended to slowly drift off peak, reducing read-range reliability, but sometimes an antenna would dramatically detune and a replacement antenna would be required. The exact cause of the major detuning is yet to be discovered. Some data were lost due to corruption in the recorder unit memory and mishandling of the data after transfer to the hand-held computer. The infrared motion sensor units also proved to be problematic. While these devices saved on battery consumption, it was found that important monitoring data were often missed when using them. Some failures of the motion sensors were due to water ingression, and an electronics design flaw also caused problems.

Table 4. Time (min) taiko parents (by sex) spent in burrows during chick-feeding visits. Sample size is number of separate feeding events by birds in 18 burrows over three seasons, where both the time of arrival and departure was recorded by PIT tag recorders. Excludes burrows where the birds spent a day ashore with the chick.

Sex	Mean	SD	Range	*n*
Male	163	107	32–452	98
Female	142	84	43–463	78

Discussion

PIT tag recorders have improved the annual recapture rates of taiko at known burrows compared with previous monitoring methods. Prior to 2007 the recapture rate was typically 50–60% per annum using techniques such as hand-capture, video recording and burrowscopes to identify leg-band combinations (GT unpubl. data). After 2007, identification of taiko using known burrows increased to almost 100% as most of these birds were detected by the PIT tag recorders.

Taiko appear highly synchronised and often display coordinated attendance patterns. For example, females can be present ashore in burrows for as few as 30 h between late September and mid-December, with just a brief visit during courtship (two nights and one day), a 54-day pre-laying exodus period, and then returning to lay an egg in late November or December. If the male is already in the burrow on the night the female arrives, she can lay the egg and depart to sea again within 2 h. The male then sits on the newly laid egg for over a fortnight before the female finally returns for the longest period she is ashore for the entire season (c. 2 weeks in the second half of December). After that, she returns again briefly around the hatching period then visits the burrow for 10–20 nights over the next three months to feed the chick.

These new insights into taiko activity at the breeding colony help to explain why it has been difficult to catch breeding females at their nest sites. By comparison males are ashore a lot more often with visits typically lasting a week during courtship, there sometimes being a second short visit in late October / early November, and then two long incubation shifts of 12–19 days each between late November and late January. Data from the two nests with the most complete chick-feeding records showed that both these males attended and presumably fed their chick more often than their partners. Males also choose the nest site, dig out the burrows, and defend these burrows from intruders (Imber et al. 2005). All this extra time ashore increases the risk profile of males compared with females at a breeding site with invasive predators.

Comparison with other petrel species

Female petrels use a sperm storage duct to store viable sperm for long periods (Warham 1990), but the pre-laying exodus of taiko is one of the longest recorded periods from mating to egg-laying in any seabird species. Most other petrel species ($n = 49$; reviewed by Warham 1990) have a pre-laying exodus of under a month. Only the grey-faced petrel (*Pterodroma macroptera gouldi*) appears to have a longer pre-laying exodus than taiko, averaging 60 days (range 53–80 days) for females and about 49 days for males (Imber 1976; Warham 1990). Burrows were not monitored daily throughout the courtship and pre-laying period in that study, and the pre-laying exodus may have been overestimated (Imber 1976). Black-capped petrels (*Pterodroma hasitata*) have a pre-laying exodus of c. 50 days (Warham 1990), slightly less than taiko.

Mean incubation shifts of taiko were longer than those of 83% of petrel species (n = 36) reviewed by Warham (1990). Apart from four albatross species, only the incubation shifts of grey-faced petrels (mean 15.6 days) and dark-rumped petrels (*Pterodroma phaeopygia*; mean 16.5 days) were comparable with taiko incubation shifts (Imber 1976; Simons 1985; Warham 1990). Relative to their body size, *Pterodroma* petrels have the longest incubation shifts in the order Procellariiformes (Warham 1990).

The only comparable information on chick feeding frequencies in other species of *Pterodroma* petrels were the observations on dark-rumped petrels recorded by Simons (1985). Nest chambers were monitored with a video camera, and an average of 44.5 visits were recorded over a 120-day nestling period, considerably more visits than received by taiko chicks. Chick desertion periods were reported in other *Pterodroma* species with 15 days common in cahow (*P. cahow*), 2–3 weeks in dark-rumped petrels, and 10–14 days in Kermadec petrels (*P. neglecta*) (Warham 1990). The 19-day desertion period recorded in one taiko burrow is comparable with these other species.

Pinet et al. (2011) found a relationship between moon phase and the return dates of Barau's petrel (*Pterodroma baraui*) to the colony after the winter exodus. Their study birds over two seasons had a peak return date that coincided with the full moon. A similar comparison of moon phases with taiko return dates from the winter exodus showed no significant relationship with moon phase although 41% of birds did return just after full moon. There is an increasing period of darkness in the early evening during this part of the lunar cycle. Previous research tracking taiko with radio transmitters (Imber et al. 2005; GT unpubl. data) revealed that non-breeding taiko preferred to come ashore to the colony before moon rise or after moonset, possibly a response to former avian predators. Similar cautious behaviour at burrow entrances was observed during video surveillance (Johnston et al. 2003), and was supported in the current study by the repeated logging of taiko at burrow entrances by PIT tag readers (sometimes up to 30 min) when the birds departed to sea.

Problems with motion sensors and antennae

The problem with the motion sensors not picking up some taiko activity could be partly related to their sensitivity as we found that more burrow entrance activity was recorded if the sensors were very close to the burrow entrance and pointing into the tunnel. Taiko are heavily insulated from cold water by dense layers of feathers and their legs are often cold when ashore (GT pers. obs.). Thus heat loss is mainly detected from the face region. A bird landing from flight possibly could have its head inside the burrow entrance before the sensor activated. Previous time-lapse video monitoring of burrows revealed that taiko could land from flight and enter their burrow within 3 s (DOC taiko video files). Many taiko arrivals were simply not detected by the sensors or the units turned on too late to record the PIT tag. Departing individuals were normally detected by the sensors as these birds spend more time in their burrow entrance. However, if the sensor was not well positioned, the bird might have already passed through the antenna before the sensor triggered the recorder. Some early sensor models also had a problem with water shorting the electrics causing the cables to burn, presenting a fire risk. The sensors used from 2010 are now fully waterproof. Overall, only the data gathered from recorders without motion sensors during the chick feeding period were reliable in determining the frequency of feeding events.

The problem with the antennae detuning over time seems to be related to the uptake of moisture in the damp and humid environment where taiko breed. Similar devices used in other projects (e.g. penguin monitoring) in drier conditions also detune over time, but not as fast as we have experienced in the taiko project. The aerials can be manipulated in the field by altering the shape of the coil to maximise the signal. Eventually they need to be replaced with new aerials. More permanent solutions may be possible but will need to be developed and field tested.

Advantages of the new PIT tag recorders

The PIT tag recorders developed in this project were inexpensive (compared with some commercially available models), operated on power sources that allow their use in remote field settings (12-volt batteries), and stored large quantities of data (thousands of rows of data each). This meant that burrows could be checked less frequently (assuming the past reliability issues with the equipment are now resolved), with weekly visits providing significantly better data than before, including actual lay dates (by female return dates) and confirmation of partner presence for each burrow. As fewer field trips were required, this made the project more cost effective, reducing vehicle transport costs (which are very expensive on the Chatham Islands) and labour costs so DOC staff could to undertake other projects and purchase more equipment. Management decisions (e.g. maintaining poison grids around burrows, supplementary feeding chicks) need to be based on the best available data.

The latest versions of the PIT tag recorder include a permanently sealed housing, reduced cost of construction, much more memory and the ability to duty-cycle the antenna. Duty cycling turns the antenna off and on very quickly (e.g. 10% of every second) thus reducing power consumption. Results from the motion sensing indicate that taiko spend enough time inside the antenna range for this to reliably capture transponders. Connecting each battery to its own solar panel also overcomes many former difficulties with power consumption. A dual-antennae version of the PIT tag recorder is now available and will be trialled in 2011/12 on burrows with more than one entrance.

Comparison of PIT tag recorders with other burrow monitoring methods

The data gathered by PIT tag recorders are far more detailed than any obtained previously using other monitoring methods for taiko. Recording disturbance to sticks placed across burrow entrances provided limited information on burrow activity (active or inactive) and did not identify the cause of the stick-fence knockdowns. The identity of taiko in past seasons was determined either by using a burrowscope and/or video camera to attempt to view colour-leg-band combinations on birds, or by hand-capturing birds at their burrows each year. Not all birds visiting burrows were identified by these methods. Sometimes the colour bands on birds were not seen clearly. Some taiko (especially non-breeders) visited burrow groups at very infrequent intervals, eluding capture by conventional means.

Studies of burrowing petrels normally do not monitor individuals in such intensive detail as we were able to do in this study (Warham 1990; Brooke 2004). Simons (1985) study of dark-rumped petrels seems to be the only other comparable project on *Pterodroma* petrels. Even projects in which individual birds are handled regularly have limited opportunity to record nightly activity of all petrels throughout a breeding season. The PIT tag recorders used in this project can allow an unprecedented level of detail to be collected about the daily lives of individual petrels. This information will improve survival estimates for adults and juveniles, and provide more detailed information about breeding behaviour. For endangered species, these data allow managers to respond to changes in the activity patterns of birds (e.g. begin supplementary feeding of chicks if the recorder shows that parent feeding frequencies are too low or one partner has gone missing during the chick-rearing period). For common species these monitoring tools can be used as means of studying in detail a subset of birds to help interpret what is happening in a wider study group where just burrow entrances are counted, burrow fence activity monitored, or study entrances are checked just a few times each season.

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