Automated system for measuring breeding burrows entry and exit by sooty shearwaters (*Puffinus griseus*)

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ABSTRACT

We describe the construction of a data logger by modification of a burglar alarm system to monitor entry to and exit from breeding burrows by petrel adults and chicks. A single data logger is able to monitor 16 burrows and store 4600 'events' (entries or exits). Monitoring of chick provisioning frequency and behaviour of near-fledging chicks of sooty shearwaters, titi (*Puffinus griseus*) filled the system memory, requiring downloading of data about every two weeks. The practical maximum distance between burrow and control panel is 300 m if high-quality electrical cable is used. A truck battery used to power each panel needed to be recharged about every two weeks. The system was tested on Tuhawaiki Island, The Snares, and Putauhinu Island between April 1998 and May 2000. Imperfect functioning led to loss of data from some burrows. There was also a need for time-consuming filtering of the raw data files to remove 28% of the records. Many events recorded were too rapid to represent passage of the birds in and out of burrows and more entry events were recorded overall than exits. Radio-tracking checks showed that the data loggers did not accurately predict whether chicks were inside or outside burrows. Filming is needed to trace the source of these problems, which may be caused by birds repeatedly tugging at the entrance bar from within the burrow, or displacement of the bar by breathing movements of a bird sitting in the burrow's entrance. If refinements of bars and their placements can resolve these problems, the system potentially offers a wealth of detailed data with minimal disturbance to the birds and the environment. Even with current levels of inaccuracy, the system provides useful data on variation in relative activity among burrows and between nights.

Keywords: Procellariiformes, *Puffinus griseus*, automatic nest monitor, chick provisioning, colony attendance, chick emergence behaviour.

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1. Introduction

The smaller Procellariiforms build nests in burrows dug at dense breeding colonies (Warham 1996). It is often difficult to determine burrow occupancy and observe attendance behaviour of adults if burrows are long, convoluted and interconnected. Repeated and frequent visits to breeding burrows to check on occupants is enormously time-consuming and potentially disruptive to the behaviour under study (Chaurand & Weimerskirch 1994; Schultz & Klomp 2000). Video monitoring of nests is expensive because equipment is costly and relatively few nest sites can be monitored at once (Simons 1985; Brown et al. 1998). Tooth-pick 'barricades' can monitor whether or not a burrow has been visited overnight (Hamilton 1998; Gaston & Collins 1988), but is an impractical tool for gathering information of the timing and frequency of nest attendance. Furthermore, subsequent traffic cannot be detected once a barricade is knocked down. Transponders can offer fine-grain measures of traffic but require capture and handling of birds for initial attachment, receivers are expensive, can only be deployed at a single entrance and are sometimes prone to difficulties because birds must pass close to the receiver to be recorded (Becker & Wendeln 1996, 1997).

We wish to understand sooty shearwater (*Puffinus griseus*; titi; muttonbirds) breeding and fledging behaviour as part of an overall assessment of the sustainability of the traditional harvest of titi by Rakiura Maori (Moller 1996, Taiepa et al. 1997; Hunter et al. 2000a, b; Moller et al. 2000). We adapted a burglar alarm system normally used in office buildings so that we could monitor when parents entered or left burrows and to quantify emergence behaviour of chicks on three offshore islands in southern New Zealand. The principle involved is similar to the event recorder used by Simons (1981 a, b) on fork-tailed storm petrels (*Oceanodroma furcata*) except that birds were not forced to pass through a tube at the entrance to their nesting cavity and our data are recorded electronically rather than mechanically.

This system was developed by collaboration of a security firm (Dunedin Security Centre Ltd.; P.O. Box 5477, Dunedin, New Zealand) and university ecologists.

We report here:

- the design, construction and cost of the automatic data logging system
- potential modifications of the prototype and field procedures to improve its efficacy
- the success and reliability of the data obtained
- an overall assessment of the system's limitations and value.

2. Automated data logging system

2.1 COMPONENTS

The system was adapted from the Concept 2000© burglar alarm system manufactured by Inner Range Pty Ltd (see their web site at: www.innerrange.com.au). Several similar burglar alarm systems could be used. The system records the date and time of entry or exit to a burrow as measured by displacement of a rigid plastic tube suspended in the entrance of the burrow by a wire frame. A switch at the fulcrum of this bar allows an electronic logger to record the direction of travel of the bar to indicate whether the bird was entering or exiting. The switch is spring-loaded, so it 'resets' to the vertical position after the bird has passed. If a bird stops in the entrance, the switch may or may not reset until the bird moves clear of the bar again.

A single 'control panel' (data logger) is able to monitor 16 switches (each set at a different burrow entrance) and to store 4600 'events' (entry/reset or exit/reset each count as separate events). The date, time and burrow number are also logged for each event. Up to eight 'expansion panels', each of which can relay information from an additional 16 burrows, can be connected to the control panel. This gives potential for high statistical power in behavioural comparisons by monitoring up to 144 burrows at once.

As modified for our use, the equipment consists of a control panel (circuit board and programming keypad housed in a metal box (Fig. 1a,b), a battery for power, 4-core security cable connecting each switch to the control panel, and 16 switches (the maximum number that can be supported by each panel). The switches were 'centre-off, double pole utility' switches housed in a piece of plastic conduit and staked down with no. 8 wire to hold them in place in the burrow entrance (see Fig. 1c). As the switches were not waterproofed, the plastic conduit in which they were housed was wrapped in polythene sheeting in the first two years of the study and non-acetic silicon in the third year. A piece of thin, rigid tubing was pushed on to the switch so it extended down over the entrance to just above the floor of the burrow. A metal pole is needed for earthing the box, and a plastic garbage can was inverted over the panel for waterproofing.

No modifications were necessary to the Concept 2000 package except for addition of alligator clips to the power cable to allow connection to a battery. Each of the switches had two resisters (8K2 and 2K2) soldered to them so that the voltage was changed when the switch went to the 'enter' or 'exit' position. An open circuit was used, with each channel (study burrow) having an 'end resister'. Any cut or short-circuit in the cable was thereby registered as a fault in the data files rather than being counted as a burrow with no activity occurring.

A list of all the components used is in Appendix 1.

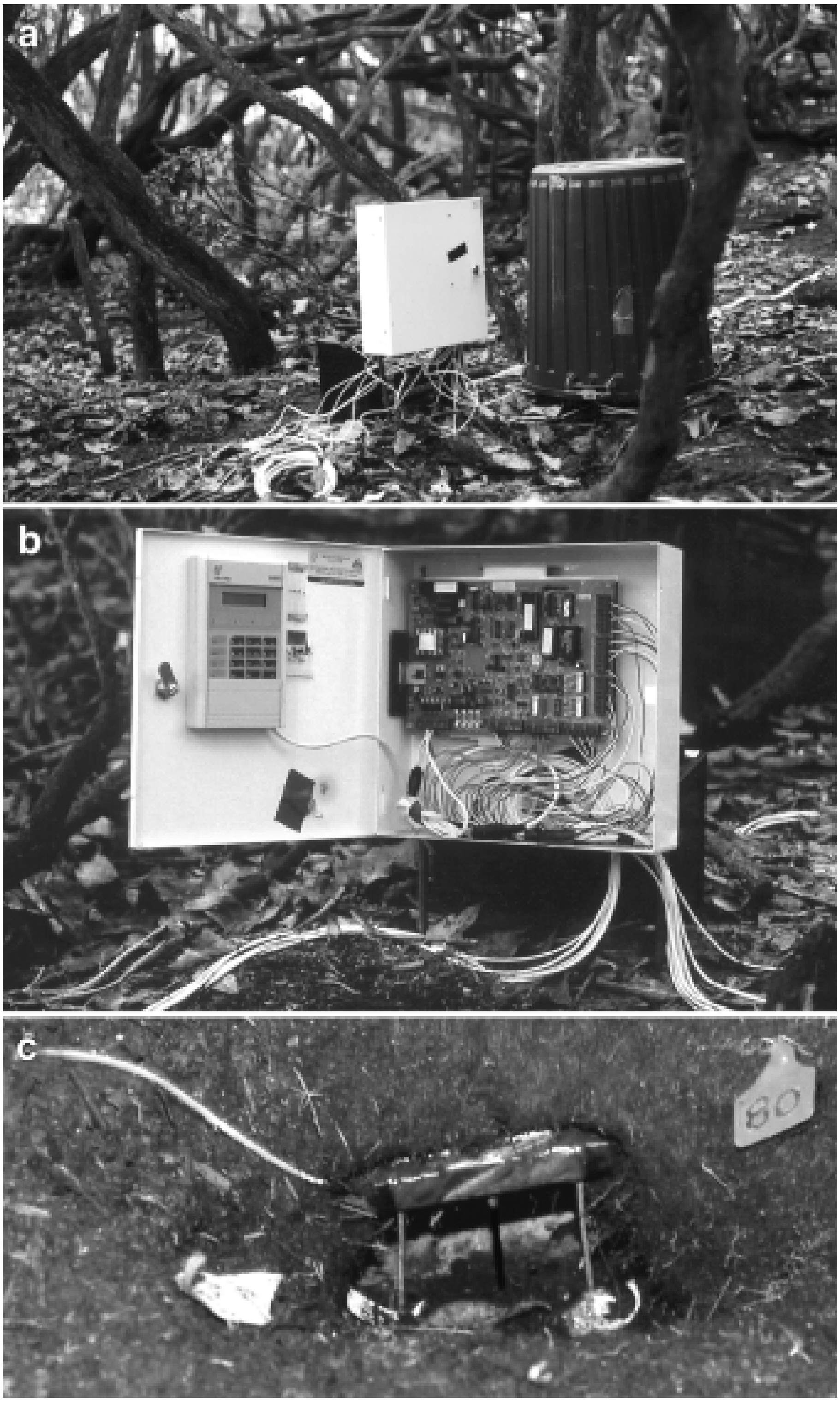

Figure 1. The data-logger system deployed on Putauhinu. (a) The control panel (white metal box) is normally covered by the inverted plastic bin shown to the right. (b) Close-up of the circuitry and the key pad used on site to inspect data records and check that the system is functioning. (c) Wire frame, switch and plastic bar mounted at the entrance of breeding burrow no. 80 to monitor the times that birds enter or leave.

2.2 IMPLEMENTATION

Burrows were chosen for study that had a single entrance and only one nest. In some studies we restricted monitoring to burrows confirmed to have an egg and/or chick, but some early breeding season research on The Snares also sought to monitor visiting to unoccupied burrows (Column 4 of Table 1). Burrow morphology and occupancy was determined using a 'burrowscope' (Lyver et al. 1998), an inspection hatch (Hamilton et al. 1996) and/or probing with a long stick. The bar and switch was positioned vertically 50–100 mm inside the upper lip of the burrow entrance so that the bar was suspended within the middle of the passageway.

It took two people approximately a day to set up and check each set of 16 burrow monitors. Regular monitoring following initial set-up is advised to check setting of switches. Recorded data can be viewed on the keypad after manually tripping a switch in either direction. Switches can also be tested in the field using a small frame and audible sounder that is powered by a 9V battery and emits two tones (one for the 'enter' and one for the 'exit' position). This tester cost approximately $30 in components and $45 for labour to make. We recommend that all switches be checked carefully between field seasons.

TABLE 1. DATASET LOCATIONS, PERIODS OF STUDY, NUMBER OF BURROWS AND INSTANCES OF POTENTIAL MONITORING BREAKDOWNS.

DATA-SET	STUDY AREA	STUDY PERIOD	BURROW SELECTION CRITERION	START JULIAN DAY and date*	END JULIAN DAY and date*	NO. OF NIGHTS	NO. OF BURROWS MONI-TORED	NIGHTS WITH NO RECORDS OF ENTRY OR EXIT		
								No. of nights	Average period† (days)	Percentage burrows > 1 night
1	Snares Site A	Incubation/ hatching	½ occupied, ½ not	326 22 Nov 99	37 6 Feb 00	76	36	353	2.78	72.2
2	Snares Site B	Incubation/ hatching	½ occupied, ½ not	325 21 Nov 99	28 28 Jan 00	68	45	1449	7.14	86.7
3	Snares Site C	Incubation/ hatching	½ occupied, ½ not	326 22 Nov 99	37 6 Feb 00	76‡	16	131	1.97	100
4	Snares Site A	Late chick	½ occupied, ½ not	52 20 Feb 00	132 11 May 00	80	17	638	7.04	94.1
5	Snares Site B	Late chick	½ occupied, ½ not	52 20 Feb 00	132 11May 00	80	18	616	5.76	100
6	Putauhinu Site G	Late chick	Occupied only	104 14 Apr 98	137 17 May 98	33	15	178	3.18	100
7	Putauhinu Site R	Late chick	Occupied only	103 13 Apr 98	124 4 May 98	21	31	69	2.56	64.5
8	Putauhinu Site G	Late chick	Occupied only	96 6 Apr 99	136 16 May 99	40	24	233	4.09	70.8
9	Putauhinu Site R	Late chick	Occupied only	98 8 Apr 99	138 18 May 99	40	23	227	3.11	73.9
Total						514	225	3894		
Mean						57.1	25	432.7	4.18	84.7

* Each night is defined in terms of a Julian evening beginning from 1730 hours to 0800 hours the following morning.

† Average length of sequentially linked nights without exit or entry.

‡ Record of 27 nights with no exits or entries at all burrows indicates general power failure. These days have been excluded from the data analysis in the three right-hand columns.

The maximum distance between a burrow and the control panel is probably around 200 m if using inexpensive 4-core security cable, but the maximum distance we trialled was about 50 m. Higher-quality cable can be purchased that may allow at least 500 m of cable without sufficient voltage drop to case problems. However, we suggest that the practical limit is in the region of 300 m (from purely logistical considerations of handling such long cables). Use of an expansion panel connected to the control panel may introduce additional voltage loss that may reduce these maxima.

In the first year of the study soldering was used to make all wire connections. As soldering was timing-consuming and not 100% effective in the subsequent two years, 'telephone connectors' were used to connect wires in the field. This facilitated setting up and dismantling the system and extending cables if necessary when moving switches.

Large ('light-commercial') start-up truck batteries (12 V, 70 A.h) were used to power the system. Battery life depended on the amount of bird activity but generally we only needed to recharge batteries every two weeks. We used the cheapest truck batteries available but higher performance deep-cycle batteries are available (NZ$200 + GST each) that could extend the duration of power from a battery by four times. It would be possible to make a simple device to automatically switch from one battery to the next when the charge on the first dropped below a critical threshold. One could then leave two or more charged batteries at the site on each visit to prolong the study period. A simple automatic battery transfer system such as this should cost less than NZ$100 (and may be commercially available). However, as it is necessary to check the switch integrity at least every two weeks, there is nothing to be gained by having such long unmonitored study periods. It is important to minimise the number of connections to reduce risk of failure and voltage loss.

Data from the system were downloaded to a laptop computer every 1–2 weeks using 'shareware' programs (we used Telemate™ but several standard data transfer programs would be adequate). Recorded events can be viewed on the keypad or using a laptop computer at the site but the program that comes with the system must be modified to download the data on to disc or hard drive. This minor modification was supplied free of charge by the manufacturer. It is not standard, so it must be specified upon purchase. Once the storage capacity of the program is reached, it starts to record over the top of earlier records, so it is important to download data regularly. Data will be stored in the 'non-volatile' memory chip for up to 15 years even after the main power supply has been disconnected.

No doubt the birds noticed the change at their burrow entrance when switches were installed, but this system is very unobtrusive and required no handling or direct disturbance of the birds. Cables running between the switches and control panels were staked down to prevent birds or New Zealand sealions (*Phocarctos hookeri*) becoming entangled. The cables quickly became covered by soil and leaves and soon did not appear obvious to humans. During the burrow prospecting period early in the season (November and December) adults dug out the gate at least once in 16% of study burrows on The Snares. One burrow was dug out three times, three burrows twice, and four burrows once. Similarly, 7% of the burrows had the gate dug out upon our return to The

Snares in mid April. Digging disrupted only 1.3% of 2898 burrow days (42 days data from 69 different burrows).

2.3 COST AND DURABILITY

The overall cost of the basic system, including all components necessary to set up a system to monitor 16 burrows (batteries, wire, logger and switches but excluding the laptop required for downloading data), was NZ$2,500 in 1998. An 'expansion panel' (servicing another 16 burrows) and associated cables and switches cost an additional $2,200. The cost of individual components is listed in Appendix 1.

We estimate that replacement batteries will be needed after 3–4 years. If heavy-duty deep-cycle batteries were used, 6–7 years life could be expected (Gary Young, Norman's Auto Electrical Ltd, Dunedin pers. comm.). Keeping the batteries charged between field seasons will lengthen their life. The only repairs likely to be needed in the short term are replacement of switches (these operate mechanically and are unsealed, so they are prone to damage). Soil acidity on The Snares and Putauhinu is high and results in rapid corrosion. Salt air will corrode switches and connections quickly, and wind-blown sand or dust could accumulate inside the mechanism to prevent them functioning reliably.

The system was remarkably resilient and few repairs were needed except the occasional replacement of switches. One panel became unserviceable due to static discharge during downloading but this problem was eliminated by constant grounding of both the panel and the person downloading the unit. The Concept 2000 systems have been installed in buildings for at least 10 years without sign of failure (reliability is the key design requirement of security electronics). We see no reason why the system should not last for at least 10 years provided it is kept dry and damage does not occur from accident during transport.

3. Test sites and periods used

The system was trialled on Tuhawaiki Island on the Catlins coast in early 1998 to measure chick-provisioning rates (Uren 1999). Inclement weather often disrupted access to the site, and battery failure resulted in several gaps in the data so we do not use them in this paper. However, most of the teething problems inevitable in the use of new equipment were worked out during this first project. Although we made small adjustments and improvements in the installation and set-up of the equipment, in particular in waterproofing of the switches and connections, we have not needed to modify it substantially since.

The remainder of this report evaluates the system using data from more complete and extensive trials on The Snares (100 km southeast of Stewart Island) and Putauhinu Island (4 km off the southwest coast of Stewart Island).

This system was set up in the late chick phase of the 1997/98 and 1998/99 seasons on Putauhinu to investigate chick emergence as part of a study of selectivity of muttonbird harvests (Hunter et al. 2000b). Adults were only very occasionally visiting burrows at this stage. The system was then used on The Snares to collect information on adult activity during the egg-laying, incubation and early chick provisioning in the 1999/2000 season (Table 1); and finally late in the same season, spanning the late chick provisioning phase (when adults are visiting intermittently) through to fledging of the chicks. Before 17 April all activity registered by the alarm system would have been of adults, but chick emergence predominates from 20 April onwards (Hunter et al. 2000b).

The only break in the data runs were for 27 days at Snares Site C in Dataset 3 (Table 1). Otherwise the system continuously collected data, sometimes even after we had left the island. Altogether we collected data from 224 burrows over 514 days. Minor problems were registered at a few burrows. The entrance bar was brushed off the switch in 1.4% of 2898 burrow days (42 days' data from 69 different burrows) on The Snares. Twice the entrance bar was too long and got stuck in soil and leaves, and on one occasion a cable was disrupted by a sealion.

Large differences in mean length of days without activity were recorded between sites on The Snares (Table 1). Preliminary analyses of comparisons between the entrances recorded at occupied and unoccupied burrows and suggests that significant differences may occur.

4. Filtering data records

The data from the alarm devices were downloaded and stored as text files and then transferred to Excel™ for filtering. We first deleted non-data output such as programming codes, date setting and daytime switch checks. These amounted to about 19% of the records (Table 2: column 3). Full capacity of the memory for research will not be realised because of accumulation of these non-biological data and downloading of data must therefore be more frequent than the theoretical minimum expected from bird visitation rates.

Data from each evening (spanning the evening of one date and early morning of the next date) was given a unique identifier ('Julian day'). Using the Excel™ sort routines we arranged the data to show burrow number, date, time, and event ('Enter'; 'Exit'; or 'Reset', where reset indicates that the switch returned to a vertical position). An Excel Macro™ routine was used to calculate time intervals between successive events at each burrow within the same Julian day. A disproportionately large number of the intervals between successive 'events' (either an exit or entry until the next entry or exit) were less than 5–6 seconds (Fig. 2). Similarly shaped histograms occurred for intervals between a reset and the next exit or entry (Fig. 3). The mode at very short intervals was evident for datasets with both adults and chicks at burrow entrances (Figs 2, 3). Birds do not readily move backwards and probably would need at least 10 seconds to leave a burrow, turn and re-enter it immediately. These frequent very short intervals obviously therefore did not represent real passage of the bird in or out

TABLE 2. NUMBER OF RECORDS OBTAINED AT EACH STAGE OF THE DATA FILTERING PROCESS.

DATASET[*]	ORIGINAL NO. OF RECORDS	PERCENTAGE NON-DATA AND DAYTIME RECORDS	MODAL CUT-OFF INTERVAL		PERCENTAGE ELIMINATED BY EITHER MODAL CUT-OFF[†]	NO. OF EVENTS REMAINING	
			Event to event (s)	Restore to event (s)		Entries	Exits
1	14192	10.49%	5–6	5	10.11%	3311	1492
2	18959	13.05%	5–6	5	10.50%	3422	2819
3	22382	27.71%	5	5	8.38%	3965	2339
4	3837	22.96%	5	5	7.22%	732	475
5	6102	17.26%	5	5	7.41%	1195	885
6	1361[‡]	0.73%	5	5	5.22%	419	230
7	955[‡]	0.63%	5	5	5.76%	281	167
8	6445	16.03%	6	5	12.74%	848	823
9	8152	25.68%	6	5	15.21%	1129	693
Total	82385					15438	10002
Mean		19.02%[‡]	5.33	5	9.17%		

[*] See Table 1 for dates and locations.

[†] Where multiple events sometimes occurred on the same record (i.e. within the same second) they were later coded as separate records. The percentage of events deleted are therefore slightly inflated. The cut-off often left a ‘Reset’ record which we then eliminated, but these final adjustments are not included in % reduction reported here.

[‡] Non-data records have been removed already from the totals in Datasets 6 and 7, which were therefore excluded from this mean.

of the burrow. Both adults and chicks were often seen sitting in the burrow entrance, and adults and chicks were occasionally observed pecking the entrance bar. It is also conceivable that the breathing and shuffling movements of a bird sitting still under the bar caused these very short intervals between events.

We censored all very short visits (< 5 or 6 sec, depending on the observed modality in each dataset) from the records (Table 2: columns 4 & 5). The steps outlined in the filtering process are illustrated for one burrow in Appendix 2. These steps required five days’ intensive work for each dataset, which resulted in 13 weeks’ work.

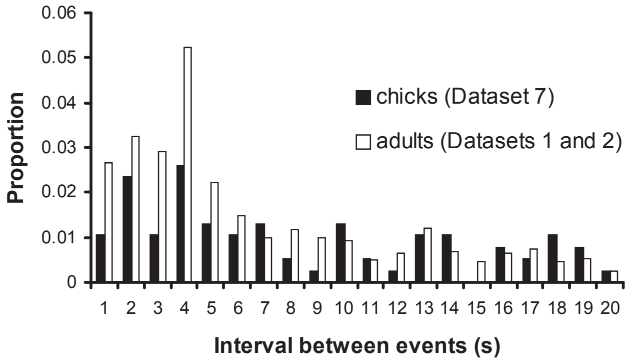

Figure 2. Frequencies of intervals between successive events (either entry or exit) for chicks and adults. Not included in the histogram are 81.0% and 72.1% of the intervals for chicks and adults, respectively, which were greater than 20 seconds.

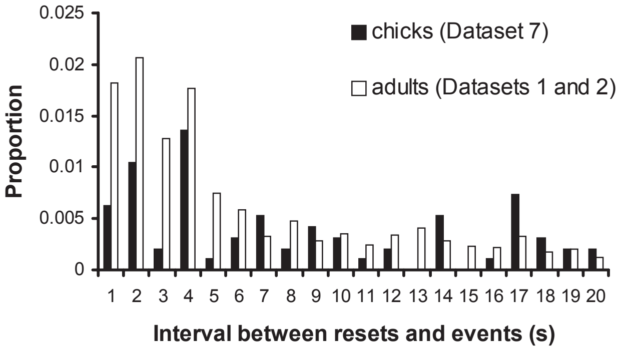

Figure 3. Frequencies of intervals between a reset and the next event (either entry or exit) for chicks and adults. Not included in the histogram are 30.7% and 32.6% of the intervals for chicks and adults, respectively, which were greater than 20 seconds.

Censoring by either modal cut-off method eliminated about 9% of the original records (Table 2: column 6). This left 10 002 exit events, and about half as many again of entries. The imbalance of entries and exits is a clear warning that the data are biased or unreliable in some way. This imbalance was not restricted to a few malfunctioning burrow switches. Indeed, 28.9% of individual burrows monitored showed highly significantly ($P < 0.001$) fewer exits than entries, and a null hypothesis of equal entries to exits was rejected in 50.3% of all burrows monitored (Table 3). There were often > 3 exits between successive entries (or the last entry and dawn) during the chick emergence phase (Fig. 4). Had the system worked perfectly, nearly all of the sequences would have had a single exit between successive entries and vice versa. Only 35% and 33% of cases had a single entry between successive exits in Datasets 1 and 8, respectively. Similarly, there were sometimes several entries between successive exits (Fig. 5).

TABLE 3. NUMBER OF BURROWS IN EACH DATASET, RANGE OF NUMBER OF ENTRIES AND EXITS RECORDED, AND NUMBER OF BURROWS WITH SIGNIFICANTLY MORE ENTRIES THAN EXITS (USING CHI-SQUARE TEST).

DATASET	NO. OF BURROWS	NO. OF EVENTS PERBURROW		NO. AT EACH SIGNIFICANCE LEVEL		
		ENTRIES	EXITS	$P < 0.05$	$P < 0.01$	$P < 0.001$
1	36	1–339	0–154	2	3	18
2	45	4–322	4–174	3	4	12
3	16	61–427	23–362	1	0	11
4	17	3–120	1–98	2	3	3
5	18	0–169	1–131	2	2	7
6	15	0–79	1–40	1	1	4
7	31	0–30	0–52	7	3	2
8	24	5–145	0–109	6	4	3
9	23	4–323	1–122	2	2	5
All	225	0–427	0–362	26 (11.6%)	22 (9.8%)	65 (28.9%)

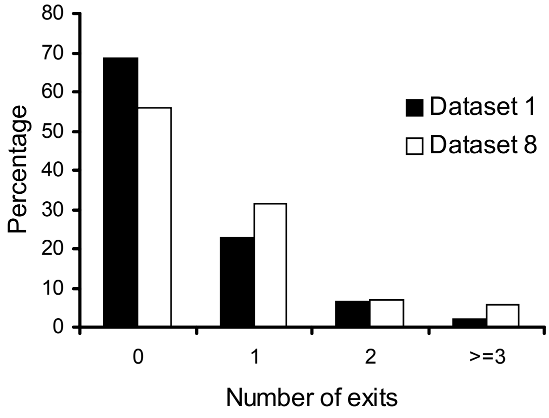

Figure 4. Frequency of there being none, one, two, or more exits between successive entries for Datasets 1 and 8.

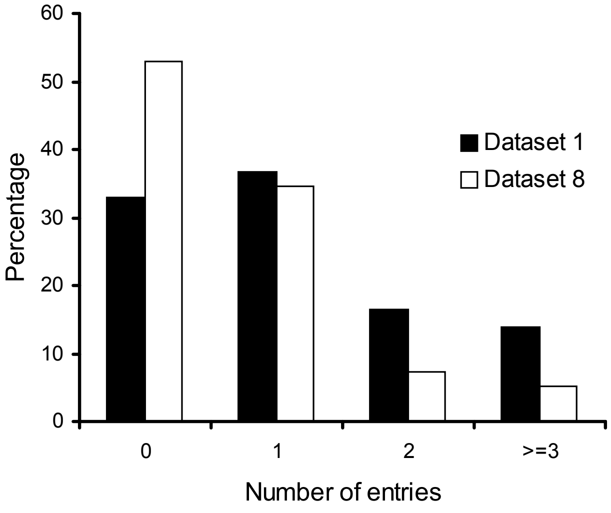

Figure 5. Frequency of there being none, one, two, or more entries between successive exits for Datasets 1 and 8.

5. Accuracy check using radio-tracking

Late-stage chicks were radio-tracked on Putauhinu at the same times as Datasets 6–9 were being gathered by the alarm system. Small (10 g) single-stage transmitters (Holohill, Canada) were taped to the back feathers of chicks. A hand-held receiver and yagi aerial were used to determine whether the chick was in or out of its burrow in one spot-check that usually started between 20:00 and 21:00 hours (range 18:45–23:30); and then again usually between 03:30 and 05:30 (range 03:00–06:55). Most of the 40 chicks radio-tracked each year were attached to chicks that had no alarm monitor on their burrow entrance, but we overlapped the two monitoring systems for 10 and 27 chicks in the 1997/98 and 1998/99 seasons respectively (Table 4). The time of locating each chick was noted, so the last event recorded for the chick's burrow was consulted to predict whether the radio-tracked chick should have been outside or inside its burrow (Table 4). We approached the study burrows closely (within 5 m of all of them) so we can be certain that we accurately determined whether each chick was in or out of its burrow at each spot check. The data-logger successfully predicted that the chick was in its burrow on 94%, 62%, 80%, and 76% of occasions in Datasets 6, 7, 8, and 9, respectively (last column of Table 4). It was much less successful at predicting when the chick was out of its burrow

TABLE 4. COMPARISON OF RADIO-TRACKING MONITORING (R) WITH ALARM ENTRY/EXIT INDICATION (A) THAT THE CHICK WAS IN OR OUT OF ITS BURROW. CONCORDANCE IS INDICATED WHEN A RADIO-TRACKING EVENT (BIRD IN OR OUT OF ITS BURROW) OCCURRED WHEN THE PRIOR ALARM EVENT ALSO SUGGESTED THAT A BIRD WAS IN OR OUT OF ITS BURROW.

	DATASET 6					DATASET 7					DATASET 8					DATASET 9			
BURROW	R IN	A IN	R OUT	A OUT	BURROW	R IN	A IN	R OUT	A OUT	BURROW	R IN	A IN	R OUT	A OUT	BURROW	R IN	A IN	R OUT	A OUT
102	15	9	1	0	34	17	9	2	1	123	4	4	1	1	50	2	2	0	0
111	6	6	3	0	79	4	4	1	0	106	55	48	4	4	90	23	21	3	0
118	30	30	13	3	80	5	4	1	0	119	18	14	5	3	89	20	15	4	1
115	24	23	2	2	82	6	3	0	0	126	15	9	0	0	81R	24	23	5	2
123	24	23	6	3						113	24	21	4	3	81L	4	4	2	2
126	27	27	6	2						110	19	11	0	0	78	33	14	3	0
										103	18	13	4	0	41	6	6	3	0
										19	33	24	2	2	42	55	35	7	5
										105	57	47	3	1	76	42	37	2	2
										124	11	7	1	1	45	28	18	6	2
										127	55	55	3	0	33	19	16	1	0
										114	10	1	2	0	34	45	45	3	1
															82	11	6	0	0
															64	37	25	4	2
															74	4	1	1	1
Total	126	118	31	10		32	20	4	1		319	254	29	15		353	268	44	18
Concordance		94%		32%			62%		25%			80%		52%			76%		41%

(32%, 25%, 52%, and 41%, respectively). Some entry into burrows by a chick or occasionally an adult might have disrupted these checks, but the rate of visiting other burrows would have had to have been very high indeed to explain these discrepancies. Nor could such visits explain the net preponderance of entries over exits.

The overwhelming evidence is that the alarm system did not reliably record the times of exit and/or entry, so current datasets cannot be used to describe details of behaviour within each night or for individual burrows.

6. Use for comparing relative activity levels

There was a significant correlation (*r* = 0.583; *n* = 59; *P* << 0.001) between the number of radio-tagged chicks found out and the number of different burrows with at least one exit recorded by the alarm system that night (Fig. 6). Similarly, the total number of exits recorded correlated with the number of radio chicks found out of their burrows (*r* = 0.386; *P* = 0.002). There was also a significant correlation (*r* = 0.827; *P* << 0.001) between the number of entries and the number of exits recorded each night. These correlations give confidence that the alarm system is already providing a relative index of activity amongst burrows and nights, even though some behavioural interference (pecking of the

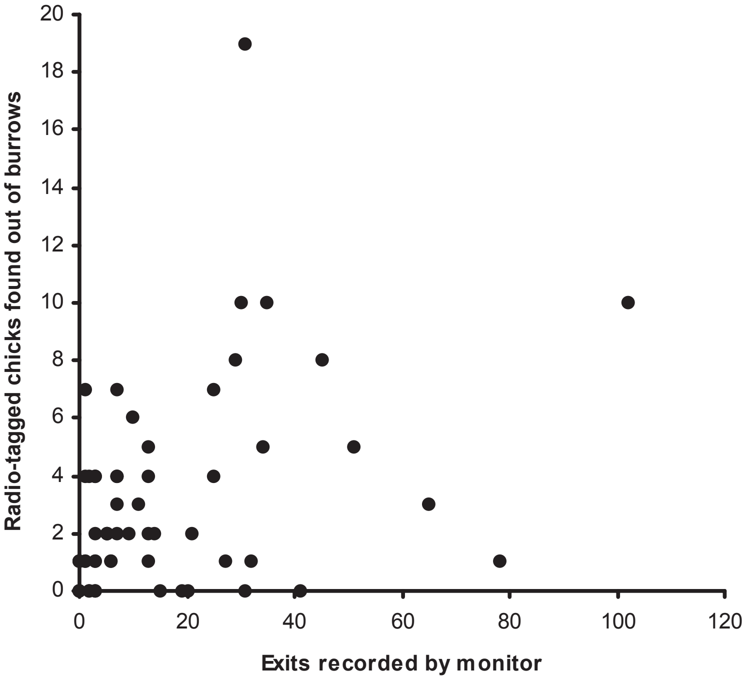

Figure 6. Number of times a radio-tagged chick was found out of its burrowv. number of exits recorded by the automatic burrow monitor on the same night. Only burrows with a radio-tagged chick are considered in this analysis.

bar or resting under it) has destroyed the accuracy of the data for detailed behavioural work.

7. Evaluation of utility and improvements

7.1 OVERCOMING INACCURACIES

The lack of exact matches in entries and exits within the same night and lack of concordance between radio-tracking and data-logger information potentially result from:

1. birds pushing the bar forward before stopping and backing (either back into the burrow, or back out of it);
2. pecking or pulling behaviour being more frequent from within or outside the burrow;
3. an unknown second entrance/exit to the study burrow;
4. uneven micro-topography of the floor of the burrow entrance combined with the irregular shape of the bird making exiting more likely to be recorded than entering, or vice versa;
5. some roosting of adults during the day in the burrow (so exits and entries do not match on that same night; a long-term balance would be expecte,d however);
6. a pair might be 'keeping company' during incubation;
7. entry of other chicks into the burrows of the radio-tracked and alarm-monitored chicks.

However, we suspect that a large number of the nights with a mismatch in entries and exits resulted from failure in the equipment. Potential reasons include:

a. corrosion in the switch could affect just the 'enter' or just the 'exit' position of the switch;
b. accumulation of sand or dirt inside the switch might block travel in one direction more than another;
c. shorting-out of the circuitry in wet weather;
d. any bending of the rigid plastic tube to one side rather than back and forward could cause missed traffic;
e. swivelling of the plastic bar on its longitudinal axis probably sometimes allowed the bird to slide past the bar without triggering a record of an 'event';
f. roll of the conduit cover over the switch would mean that the bar no longer sits vertically in the entranceway, and one direction would potentially be more likely to record passage than the other.

We suspect that reasons (3)–(7) are too infrequent to cause the size of the discrepancies we measured. We now recommend filming traffic and bird behaviour at entrances to allow matched observations with data logged at the same time by the alarm system. This might pinpoint potential solutions to the problem as well as guiding researchers to what might or might not be reliable inference from the imperfect data obtained. Problems (b), (d) and (e) were reported in the field by workers checking the circuitry. However, to prevent damage to the moisture-sensitive control panels no checks for potential problem (c) could be conducted during wet weather. Mechanical failures might be averted by making the bar stiffer (averting problem (d)); broadening the bars (averting (e)), shortening or lengthening the entrance bars (e, f), using a tee-bar design (e, f), mounting the switch in a much more solid structure to avert roll (f).

Regular inspections of the balance between entries and exits for individual burrows could identify which switches and bars require adjustment to obtain better records. It is especially important to ensure adequate waterproofing of the switches to minimise loss of data. In some circumstances it may be possible to position the switch and bar further back from the entrance of the burrow so that birds sitting in the entranceway cause less confusion. Less time would then be required to filter the data and more reliable identification of ‘enter’–‘exit’ pairs might be possible.

7.2 LIMITATIONS AND ADVANTAGES OF THE SYSTEM

Disadvantages of the system, apart from the reasonably high initial cost, include the need for heavy labour, time to set it up and the time wasted filtering unreliable data. New operators may expect better efficiency than we obtained while we learned about the system, but some overall data loss and wasted time when back from the field seem inevitable even if the ways we recommend to minimise them are followed at the field site.

Control and extension panels have similar power requirements. When using extension panels a great distance from the control panel, power losses can be considerable. Separate control panels offer greater flexibility in location of sites and eliminate the time required to run cables to connect the control and extension panels. Set-up and replacement of batteries for systems with an extension panel must follow a specific sequence and are greatly facilitated by having two people and the ability to communicate between the two sites. However, separate data downloads are needed if two control panels are used rather than a single control panel with an expansion pack.

Any electronic equipment is susceptible to adverse environmental conditions. Downloading of the system panels required exposing the circuit panels and could not be completed in windy or wet conditions. Although a waterproof container could be modified to house this equipment, downloading in inclement weather would still be difficult. We chose to leave the electronic components in the metal box provided so that the system could be earthed. We also recommend that persons operating this equipment in the field should first touch an earthed metal object to discharge any static electricity build-up and prevent damage to the equipment before working with the system panels. A large plastic bin was placed over the system to provide a waterproof covering.

We chose the simplest and cheapest system available for our prototypes. Larger and more recent burglar alarm data loggers, available at increased expense, have capacity to monitor up to 200 burrows at once. Low-resistance cables could extend the area encompassed by the system if more widely spaced burrows are needed for the ecological and behavioural questions being researched. The weakest link in the current set-up is undoubtedly the switches. Although cheap, they are unsealed and therefore prone to deterioration. A more expensive but possibly more reliable option would be to use magnetic reed switches, which are totally sealed.

Manual checking of burrow occupancy creates much more disturbance and puts a great deal more stress on the birds from frequent handling than the automated system. Procellariiforms are easily disturbed by human contact, especially during incubation (Warham 1996), so electronic methods potentially minimise impact compared with methods requiring regular close approach to the burrow at night. Automation is especially helpful to minimise impacts of researchers where collapsible soil makes repeated traffic up to the burrow entrance by researchers a threat to the burrows underfoot. It is also probable that scent deposited by humans is detected by birds and that this might attract small mammalian predators that are known to prey on titi eggs, chicks and adults (Hamilton 1998; Lyver 2000; Lyver et al. 2000; Jones 2000). The electronics may similarly attract attention of (or might even repel) predators, but the automated system at least obviates the need for close inspection and prevents renewed deposition of human scent each day.

The system we developed is particularly useful for gathering large numbers of data in remote situations. Research party size on offshore nature reserves is restricted by the Department of Conservation to minimise environmental impact of research teams on island ecology. The automated system was therefore particularly useful for obtaining more information while using fewer personnel. We were also able to leave the system running for several weeks after we had left the island and still retrieve usable data upon our return. Provided that the teething problems can be ironed out, the system could collect valuable data with minimal impact and at modest price.

7.3 APPLICATIONS FOR TITI RESEARCH

Without any knowledge of when adults return and the length of time spent in the burrow, both unknowns for sooty shearwaters, the number of birds that are missed by manual checking of burrows is not known. Automated systems like that described here can calibrate the accuracy of the information gained from occasional visits using traditional methods. This system also has potential to provide more accurate information on provisioning rates than previous work that relied on manual checking of burrows at set intervals and frequent (at least once a day) weighing of chicks. We used the system for two seasons on Putauhinu to look at activity of chicks once they start coming out of the burrows at night. Our main aim was to understand whether larger chicks had different emergence behaviours from smaller chicks, and therefore whether they were more or less vulnerable to harvest (Hunter et al. 2000a). We hoped the method would give detailed information on what times the chicks emerge from burrows and how long they stay outside. So far the system has proved too inaccurate to realise this goal. Unless double-beams are used to infer direction of travel, infra-red light beams will not give the full information required, especially if the birds enter and leave the burrows several times a night, as found in our study. Radio transmitters and toothpick barricades can be used to monitor these chicks, but these techniques can only determine whether a chick was active or not for a certain night, not when or for how long. Our study demonstrated that the burrow monitor can at least derive an index of relative activity between different burrows and between nights, even though further improvements will be needed before it can precisely inform when exactly each chick or adult entered or left the burrow.

We used the system in 1998/99 during the sooty shearwater breeding season on The Snares to (i) monitor activity rates during the egg-laying period, (ii) compare activity rates and bird disturbance between occupied and unoccupied burrows, and (iii) compare visiting rates among areas of differing burrow density. It appears that potential interference within burrows by visiting birds during the burrow prospecting period is frequent and intense, judging from our measures using this automated system (Fig. 7). Density dependence is potentially crucial for accuracy of predictions of sustainability of the titi harvests (Hunter et al. 2000a). The detailed and continuous nature of the data provided by this system reveals much stronger evidence for testing density dependence than techniques such as toothpick barricades.

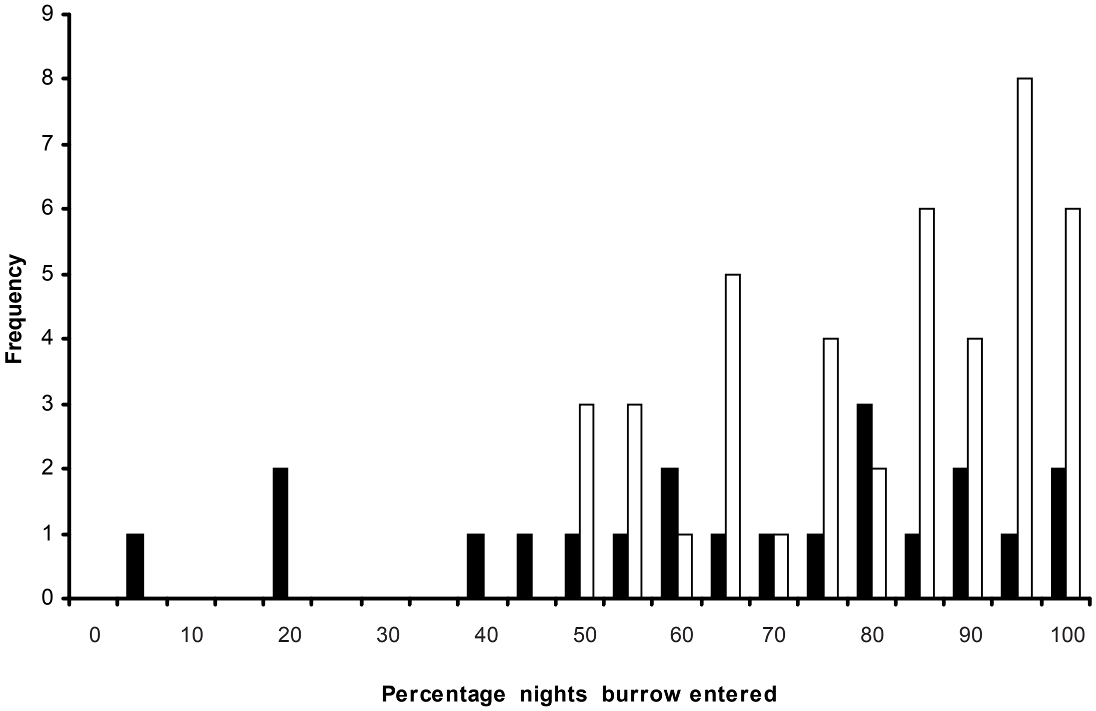

Figure 7. Percentage of nights (5% steps) that burrows with an egg or chick (open bars) and without an egg or chick (closed bars) were entered on The Snares between 4 and 22 January 2000 (21 occupied and 43 occupied burrows were monitored).

7.4 APPLICATIONS FOR OTHER SPECIES

The behavioural features (pecking, resting in the entrance) that probably contributed to the inaccuracy of our data may not occur in other species. Simons (1981a, 1981b) does not mention any problems with birds interfering with entrance bars in his study of fork-tailed storm-petrels, so little modification from the existing design may be needed for some species. Some procellariiforms take readily to nest boxes, others not, so inter-specific variation in reaction to equipment at burrow entrances is expected.

Transponders provide the only comparable intensity of data gathered, and have the added bonus that traffic and burrow attendance of individual birds can be logged. Becker & Wedeln (1997) used transponders to obtain detailed data on common terns (*Sterna hirundo*) but antennae needed to be within 11 cm of the bird to register their code. They monitored birds at nests and resting platforms when the bird sat still for a long period. Trials are needed to see whether the rapid passage of a titi past the entrance would allow enough time for detection, and turning or retreat just inside the entrance may again give confusing data—once the signal is lost it may be impossible to tell whether the bird has just left the burrow or just retreated enough within it to not be detected by the antennae. However, the main obstacle to using transponders is cost. A separate antenna and an electronic ‘board’ are required per burrow, costing US$1,220 (about NZ$2,772 at January 2001 exchange rates). The total budget for our system (NZ$4,700) to monitor 32 burrows would therefore have provided transponder equipment to monitor just 1–2 burrows. A cheaper system exists that uses magnets and data loggers (Granadiero et al. 1998) to identify individual birds. This system was initially developed for Cory’s Shearwater *Calonectes diomedea* but is now being trialled with other species (M. Bolton pers comm.)

The detailed nature of the information gained and minimal disturbance to the birds may make the automatic burrow monitoring system particularly valuable for threatened petrel recovery programmes such as that for Chatham Island taiko (*Pterodroma magentae*). Thirty-three active burrows were known after the last breeding season, spaced in three clusters of 6–8 burrows, and the remainder in 1–2 burrows close together (H. Aikman pers. comm.). Two of the largest clusters are near to each other but on opposite sides of a small river, so both could be monitored at the same time from one panel. Activity could be monitored continuously even while the management and research team are not there. If accuracy problems can be resolved, it would be possible to consult the data records at the central panel in the middle of the night to learn which burrows have adults at home and thereby target placement of exit-nets to catch emerging adults as dawn approaches. Similarly, catching fledglings could be more efficiently focused on burrows showing signs of chick emergence. Risk of triggering predation by rats (*Rattus rattus, R. exulans*), feral house cats (*Felis catus*) and potentially even hedgehogs (*Erinaceus europaeus*) can be minimised by using the automated system to gain useful information about where and when to intercept the adults and chicks.

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Appendix 1

COMPONENTS USED FOR AUTOMATIC MONITORING OF PETREL BREEDING BURROWS

ITEM	COMPONENT NUMBER/DESCRIPTION	QUANTITY	COST (NZ$)*
Switches	DP3T, Dick Smiths: part no. P7689	32	192
Electrical cable	Four-core tinned security cable	600 m	570
Telephone connectors	Snap Con™ PSA 900113Utilux H42111	64	31
Resisters	8K2 and 2K2 (0.5 watt)	64	5
‘Topcap’ (standard trunking)	Plastic cover over switches: 25 × 25 mm	140 mm × 32	15
Steel wire	No. 8 gauge	500 mm × 32	56
Solder			10
Labour for assembly		130 hours	1950
Control panel	Concept 2000	1	800
Expansion panel	Concept 2000	1	700
Switch tester	Home assembly	1	75
Truck batteries	Marshall: N7022–CCA600	2	260
Earthing rod		1	10
Plastic bucket as cover		1	30
Total			**4704**

* In 1998 value excluding GST. The cost of battery chargers and a laptop computer for downloading data have not been included.

Appendix 2

EXAMPLE OF FILTERING PROCESS

NUMBER OF RECORDS OBTAINED FOR BURROW 66 (B66) FROM THE RAENGA DATASET FOR THE NIGHT OF 10–11 APRIL 2000.

STAGE 1 Original records[*]		STAGE 2 After removal of duplicates[†] and non-data records		STAGE 3 After removal of daytime records		STAGE 4 After removal of both modal cut-offs	
10 Apr 2000							
19:43:37	Alarm on B66	19:43:37	Alarm on B66	19:43:37	Alarm on B66	19:43:37	ENTER
19:43:37	Restore on B66	19:43:37	Restore on B66	19:43:37	Restore on B66		
19:48:49	Tamper on B66	19:48:49	Tamper on B66	19:48:49	Tamper on B66	19:48:49	EXIT
19:48:53	Restore on B66	19:48:53	Restore on B66	19:48:53	Restore on B66		
23:48:57	Alarm on B66	23:48:57	Alarm on B66	23:48:57	Alarm on B66	23:48:57	ENTER
23:49:18	Restore on B66	23:49:18	Restore on B66	23:49:18	Restore on B66		
23:52:30	Tamper, Restore on B66	23:52:30	Tamper, Restore on B66	23:52:30	Tamper, Restore on B66	23:52:30	EXIT
23:52:35	Tamper on B66	23:52:35	Tamper on B66	23:52:35	Tamper on B66		
23:52:36	Restore on B66	23:52:36	Restore on B66	23:52:36	Restore on B66		
11 Apr 2000							
3:34:23	Alarm on B66	3:34:23	Alarm on B66	3:34:23	Alarm on B66	3:34:23	ENTER
3:34:24	Restore on B66	3:34:24	Restore on B66	3:34:24	Restore on B66		
5:20:44	Tamper on B66	5:20:44	Tamper on B66	5:20:44	Tamper on B66		
5:20:45	Restore on B66	5:20:45	Restore on B66	5:20:45	Restore on B66	5:20:44	EXIT
6:17:33	Alarm on B66	6:17:33	Alarm on B66	6:17:33	Alarm on B66	6:17:33	ENTER
6:17:42	Restore on B66	6:17:42	Restore on B66	6:17:42	Restore on B66		
15:12:40	Alarm, Restore on B66	15:12:40	Alarm, Restore on B66				
16:28:20	LAN reset						
16:28:20	SYSTEM AREA on - System reset						
16:28:20	BIRD TUNNELLS on - System reset						
16:28:20	TAMPER AREA On - System reset						
16:28:20	Reset. Ver = 223						
16:28:22	Alarm on Control A/C Fail						
16:28:22	Alarm on Control Ext. Siren Tamper						
16:28:22	Alarm on Control Int. Siren Tamper						
16:28:23	Comms reset.						
16:28:27	Alarm on Terminal 1 LAN Fail						
16:29:47	Restore on Terminal 1 LAN Fail						
16:30:12	PHIL logged in at terminal 1						
16:30:28	Enter Set Time/Date by PHIL						

[*] 'Alarm' = switch activated inwards, potentially by a bird entering the burrow. 'Tamper' = switch activated outwards, potentially by birds leaving the burrow. 'Reset' = switch mechanism returning to neutral position following previous activation.

[†] In this case there were no duplicates to remove.