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Estimated population size of the Westland petrel, 2007–2011

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Westland petrels *Procellaria westlandica* are endemic to New Zealand and restrict their breeding activity to a 16 km^2 area near Punakaiki, West Coast, South Island. Birds nest during winter in colonies located on low-lying mudstone cliffs and ridge tops under heavy forest canopy. Estimates of population size and trend are generally lacking and, until this study was conducted, no systematic survey of abundance had occurred. Between 2007 and 2011, 26 previously identified colonies were searched to obtain burrow counts and estimate burrow occupancy. Field work was focused on visiting high density areas at least once during this study, to estimate the number of pairs breeding at each site. A few sites were visited annually to estimate population trends.

When colonies were located, population size was estimated through a three-stage process. First, burrow densities in each colony were determined by using 2-m wide random and non-randomly located transects, and mapped burrows along each transect. Second, the proportion of active nests per burrow was estimated with the use of burrow scopes and 'inspection by hand'. Last, by exploring the approximate boundaries on foot and mapping the densely inhabited area, the area of each colony was measured and multiplied by burrow density to arrive at a population estimate for each colony.

The annual count of burrows in all Westland petrel colonies was estimated to total 6846 (95% CI, 6389–7302) prospective burrows during the period 2007 to 2011. Of these burrows, 2827 (95% CI, 2143–3510) were estimated as being occupied. This figure can be considered to represent the number of annual breeding pairs using these areas. These estimates would appear to be the first detailed population estimate for all known breeding areas of the Westland petrel. They are conservative and represent only the high-density colonies within the breeding areas surveyed. Scattered burrows exist throughout these sites and the population may have been underestimated in these areas by up to 10%. Nonetheless, it is unlikely the global population exceeded 4000 annual breeding pairs at the time of this survey. Permanent transects established at many of the colonies located during this study will facilitate ongoing monitoring and facilitate the development of population trends over time.

1. INTRODUCTION

Westland petrels *Procellaria westlandica* are endemic to New Zealand and nest in burrows in forest near Punakaiki, West Coast, South Island. The species is poorly studied (Waugh & Wilson 2017) which in part can be attributed to the use of burrows for nesting and their nocturnal pattern of attendance at nesting locations. Estimates of population size and trend are generally lacking and, until this study was conducted, no systematic survey of abundance had occurred. Ad hoc abundance estimates from the 1980s report approximately 20 000 individuals in the region (Taylor 2000, Waugh et al. 2006).

In 2006, Latitude 42 Environmental Consultants Pty Ltd were commissioned to develop estimates of population size and trend for the Westland petrel.

A survey methodology to estimate population size and assess long-term trends for the Westland petrel was developed by Baker & Double (2007) and work commenced to gather field data to achieve this (Baker et al. 2007). Although Westland petrels breed throughout a 16 square kilometre area near Punakaiki, which has been designated as a Special Conservation Area, it was decided to locate and concentrate the longer-term study on estimating the population in high density areas (Baker et al. 2007).

Wood (2006) describes a study conducted between 2003 and 2005 in which the Special Conservation Area was searched and all major breeding sites located. These sites were mapped and all burrows detected were counted. Because this report appeared comprehensive in terms of locating all the high-density areas used by Westland petrel, it was used as the basis for site selection in this study.

Wood (2006) identified a total of 28 major breeding sites and referred to them as 'colonies' (but see Definitions under Methods, below), although there are some discrepancies between what was detailed in a summary table and that mapped in the report:

- two colonies, Liddys Top and Studio colonies, were shown in the table twice. Although it was clear that Liddys Top colony was simply duplicated, two different counts of burrows were shown for Studio colony, indicating that an incorrect name may have been attributed to one of the colonies shown as Studio colony;
- an unnamed colony was mapped but not identified in the table;
- the table referred to a Studio sub colony and another colony, Carpentaria, which were not mapped. Despite a discussion with Department of Conservation officers the location of either of these colonies could not be determined.

Thus 26 major breeding sites or areas were definitively mapped and detailed in Wood (2006). Because these were thought to encompass all known major Westland petrel breeding sites they formed the focus for field work (Table 1, Figure 2). There may be another three important sites – Studio sub colony, Carpentaria, and another listed by Wood (2006) incorrectly as Studio colony, identified as discrepancies above – but no other major colonies were located. Other smaller, isolated colonies undoubtedly occur in the Westland Petrel Special Conservation Area, particularly along the edges of streams and deep gullies. However, as Wood (2006) noted, because of the extremely rugged nature of the terrain, it would be impractical to attempt to locate them, given that they probably comprise only a small proportion (i.e., less than 10%) of the global population.

This report presents the field work during the autumn and winter of 2011, consolidated with data from previous field seasons (Baker et al. 2007, Baker et al. 2008), to provide an updated picture of the Westland petrel population.

2. METHODS

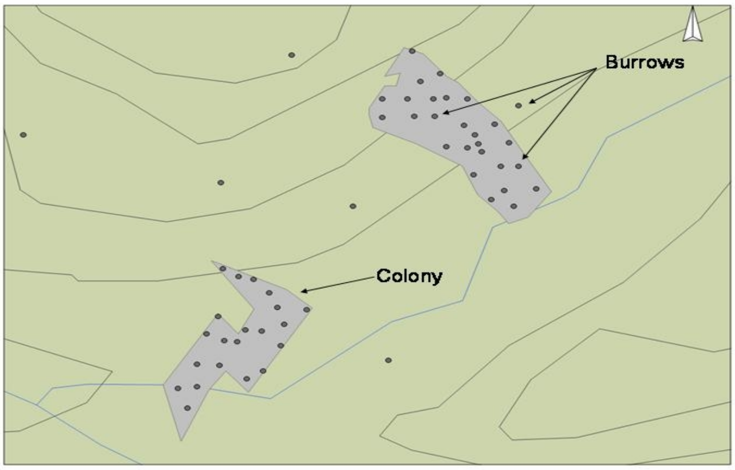
2.1 The site

The Westland petrel breeds in dense lowland forest on the west coast of New Zealand's South Island in an area distributed over 16 square kilometres near Punakaiki. The area experiences a mild (mean temperature 12.5 ^{o}C) and wet (mean annual rainfall of 2346 mm) climate. The birds breed throughout this area, which has been designated as a Special Conservation Area. The area extends from the south bank of the Punakaiki River in the north, to Lawsons Creek in the south (Lyall et al. 2004, Jackson 1958, Figure 1). It should be noted that in former times Westland petrels may have had a more extensive breeding distribution, although the extent of this is unknown. Fossils of Westland petrel recorded north of the Punakaiki River suggest that their distribution may have previously extended beyond its current range (Worthy 1993) but the species is no longer known to be present there (Lyall et al. 2004). There is also apparently suitable habitat to the north of the current colonies although there are no historic records of Westland petrel breeding there (Lyall et al. 2004). This study was confined to the known current breeding areas, and potential breeding habitat to the north of the Punakaiki River was not examined.

Breeding occurs in the Austral winter, and colonies are located on low-lying mudstone cliffs and ridge tops under heavy forest canopy (Waugh et al. 2006). The birds nest in burrows in steep forested terrain, forming dense colonies of up to 4000 birds, although smaller colonies are more common (Waugh et al. 2006).

2.2 Definitions

Although Westland petrels can be expected to be found nesting anywhere throughout the Special Conservation Area, most breeding is concentrated in a number of **breeding sites or areas**. A **breeding site or breeding area** in this study is defined as a geographically defined area in which extensive presence of Westland petrel breeding activity was apparent. Within each breeding site may be scattered burrows and areas of intensive breeding activity or **colonies**. 'Intensive breeding activity' was identified by the presence of more than 20 burrows co-located within an area that had been actively cleared of leaf litter and ground vegetation by petrels, most likely when gathering nesting material. The following diagram is provided to illustrate these concepts.



Schematic diagram showing a typical Westland petrel breeding site containing two colonies and six scattered burrows (see text above).

2.3 Field work

Field work was focused on visiting all the 26 high density areas or sites identified by Wood (2006) at least once during three of the four years of this study, to estimate the number of pairs breeding at each site. A few sites were visited annually to estimate population trends.

In 2007, field work was conducted from 15 May to 15 June 2007, timed to coincide with the period of peak egg laying (23 May) and early incubation. In 2008 field work was carried out in autumn (17–28 March) and winter (12–23 May). In 2011 field work was carried out in the summer (17 January–3 February) and winter (23 May–2 June). Department of Conservation Permit conditions required that field activities cease if rain in excess of 20 mm is recorded in any 24-hour period, to minimise burrow collapse in nesting areas. This restricted the ability to complete all field tasks within the period of peak egg-laying in 2007; hence the decision to carry out some work in summer and autumn in 2008 and 2011, when increased day length and better weather permitted more time to be spent in the field establishing transects and counting burrows, particularly in the more remote areas which were difficult to access.

Each high-density breeding area was located by taking coordinates from Wood’s (2006) contour maps and accessed by what appeared to be the easiest route. In practice, the easiest route could not always be determined from the contour maps, and notes on the best access route were therefore taken to facilitate future monitoring. Garmin 60CSx hand-held GPS units with contour mapping software were used to locate breeding areas and for all other purposes in the field.

Each breeding area was searched to locate Westland petrel colonies (areas of intensive breeding activity, as defined above). When searching each breeding site, 2-m wide strip ‘**search transects**’ were followed to locate colonies. Search transects were established by following a compass bearing and transects were placed at 40-m centres so that they systematically traversed each breeding area. Start and end points of each search transect were recorded using a hand-held GPS. When a burrow was located, the location from the start point of the search transect was recorded, and the number of burrows subsequently found 1 m either side of the transect line counted. Search transects were not used to establish estimates of burrow density, but to provide a permanent record of search effort.

The presence of birds at intensive breeding sites was usually apparent by reduced amounts of vegetation and visible signs of digging, giving the area a ‘gardened’ appearance. In lower density areas, and around the edge of dense colonies, the presence of birds was also indicated by visible holes on the ground which did not have a ‘gardened’ appearance.

Once a colony was located, the population size was estimated through a three-stage process. First, burrow densities in each colony were determined by using 2-m wide strip ‘**colony transects’**, and burrows were mapped along each transect. These transects differed from search transects in that they were confined to identified colonies and were randomly selected. Second, the proportion of active nests per burrow was estimated with the use of burrow scopes and ‘inspection by hand’ (inserting an arm down burrows to determine occupancy and feel for eggs, chicks, adult birds, or nesting material). Last, by exploring the approximate boundaries on foot and mapping the densely inhabited area the area of each colony was estimated and multiplied by burrow density to arrive at a population estimate for each colony.

2.4 Determining burrow densities

Within each located colony 2-m wide strip ‘colony’ transects were used to quantify burrow density. Transects were of variable length and extended to the edge of colonies (as determined by topography). The origin points for colony transects were randomly located along a central line or ‘backbone’ which was run through the colony. In practice, most colonies were centred on ridge lines, and the backbone was located along the ridgeline. From each of the origin points, two transects with bearings selected to run orthogonally from the ridgeline or backbone were established to ensure that transects spanned the colony. This ensured adequate coverage of the colony and facilitated subsequent density assessment. The total length of transects in each colony varied according to the area of each colony. The aim was to ensure the total transect length exceeded 5–10% of the total area of each colony, and that transects adequately covered the range of perceived densities and habitat types within each colony.

Colony transect lengths were either measured using a 100-m surveyor's tape or were calculated using a GPS. There was a bias when using GPS to calculate transect lengths on steep slopes, which required adjustment of GPS measured lengths following calibration. This was achieved by comparing measurements of the length of 55 transects with the distances calculated by the GPS. The adjustment was estimated by fitting a calibration equation using ordinary least squares regression. The adjustment equation was:

$$\text{Adjusted length} = (\text{GPS} - 2.4)/0.8122$$

At each transect, a 100-m tape or line was pegged along the ground to mark the centre line and the transect then searched for burrows. Burrows located up to 1 m either side of the centre line were counted. When a burrow entrance was located on the edge of a transect it was only counted if at least half of the entrance was within the transect to avoid over-inflating the counts.

Burrow-like structures were categorised as either 'potential burrows' or 'not-a-burrow', following the guidelines outlined by Waugh et al. (2003). Using these guidelines, a 'potential burrow' was defined as a tunnel more than 20 cm long, with an entrance size more than 14 × 8 cm. Holes that superficially resembled burrows but were not of an appropriate size or in a suitable environment (for example exposed to light, or containing debris or tree roots) were initially counted but designated as 'not-a-burrow' (Waugh et al. 2003). Initially both categories of holes were recorded, but this practice ceased after 2007 because field staff became proficient at reliably distinguishing potential burrows from other holes that were not burrows.

To facilitate repetition of surveys for both long-term monitoring and other studies, colony backbones and transects were mapped using a hand-held GPS receiver, and a bearing for each transect recorded using a compass. Permanent markers were fixed to trees to assist in subsequently locating start and end points of transects.

2.5 Estimating burrow occupancy

To determine the proportion of burrows occupied by breeding petrels, a combination of techniques was used, including inspection by hand, photographing burrow contents using an Olympus Mu 770 SW digital camera, or inspection using a Sextant Technology custom-built burrow scope (Hamilton 2000, Boland & Phillips 2005), to enable burrows to be fully explored without destroying any nests and to minimise the problem of missing birds due to bifurcating burrows (*cf*. Hamilton 2000). The aim was to inspect a minimum of 100 burrows per colony, although this was not always possible because the number of burrows was limited, or because of time constraints. Because burrow density was generally low in all colonies, there were insufficient burrows along transect lines to achieve a reasonable sample size by searching transect burrows alone. Therefore, burrows were randomly selected in the majority of colonies and searched from entrance to terminus. The contents of each burrow were categorised as one of the following classes: unknown; empty; bird in burrow; bird on nest; bird on egg; egg, no bird. All burrows checked were marked by applying a small amount of spray paint at the burrow entrance to avoid repeating counts.

To investigate the error associated with the inspection techniques (McKechnie et al. 2007), 83 study burrows were re-examined at the Scotsman Creek colony in 2007 and 2008. These burrows were fitted with inspection lids, enabling subsequent unambiguous verification of burrow contents, without the need to destroy burrows to obtain this information.

2.6 Estimating the area of colonies and population size

Each colony area was mapped by using transect data and a hand-held GPS. Points of latitude, longitude, and elevation were collected along colony boundaries and these points imported into the Geographic Information System software MANIFOLD, which was used to calculate the area of each colony. Population size of each colony was then calculated by multiplying the area by the mean density of burrows and the occupancy rate of burrows for each colony. The resulting estimates of occupied nests (or annual breeding pairs) per colony were summed for each area. The estimates for each area are conservative, and do not include birds nesting at lower densities throughout the areas.

2.7 Data analysis

Burrow counts of transects were undertaken by one observer only. However, to assess observer variability in detection and counting of burrows, or miscounting and misidentifying holes in the ground as bird burrows, multiple counts were conducted along most colony transects in 2007, and at some transects in colonies in the Study, Rowe, and Liddys Centre breeding areas in 2008 and 2011. The 2007 count data were statistically modelled by Poisson regression, a special case of a Generalised Linear Model (McCullagh & Nelder 2002), with observer and area as fixed effects. After allowing for both mean observer and mean area differences, there was no evidence to suggest that the model and data were incompatible, based upon regression diagnostics and model checking (Baker et al. 2007). There was also no evidence of a difference between observers and hence an observer bias. There was no reason to believe that the 2008 and 2011 data should have different distributional properties than the 2007 data and it was assumed that the current data were also compatible with a Poisson model. Thus, raw counts only, not modelled counts, are presented for data collected in 2008 and 2011, and the standard deviation is estimated as the square root of the count, a property of the Poisson model.

Statistical computation was carried out with GenStat software (www.vsn-intl.com).

3. RESULTS

3.1 Field work

In 2007, visits were made to breeding sites 7, 10, 14, 18, and 19 (Soloman and Reubs, Study, Middle, Rowe, and Liddys Centre breeding sites, respectively ─ Table 1). In 2008, the sites visited were sites 2, 4, 10, 14, 17, 18, 19, 20, and 21 (Bees Nest, Dougies Bluff, Study, Middle, 262 East, Rowe, Liddys Centre, Studio, and Liddys Top, respectively ─ Table 1). In March 2008, access to sites 5 (3 Bluffs), 9 (Power Barrow), and 12 (Robs) via a side creek when leaving site 4 (Dougies Bluff) was impassable due to the rugged terrain.

In 2011, visits were made to sites 1, 2, 3, 5, 6, 9, 10, 12, 13, 15, 16, 19, and 22–26 (Middle Bluff, Bees Nest, Fucawe, 3 Bluffs, Viejo, Power Barrow, Study, Robs, Noisy Knob, Able, 262 West, Liddys Centre, Howards, and Lawsons 2, 1, and 3, respectively – Table 1). Within the time allocated to field work in 2007, 2008, and 2011, all of the breeding sites selected for survey were searched. A total of 171 colony transects were established in 28 colonies located within the 26 breeding sites studied (Annex 1), and all colonies were mapped. In addition, 39 search transects were used during searches for colonies (Annex 1). Coordinates for all 'backbones' and transects are provided by Baker et al. (2008).

3.2 Spatial measurement of colonies

The area of the 28 colonies was estimated to total 16.3 ha (163 000 m^2, Annex 1). The mean size of colonies was 5624 m^2, median size 2282 m^2, and range from 100 m^2 to 56 205 m^2.

3.3 Density of burrows

The number of potential burrows for colonies in 2007, 2008, and 2011 are shown in Table 2, with counts presented as burrows per 100 m of transect.

The density of potential burrows ranged from 1.01 to 48.07 burrows/100 m of transect. It was greatest at Solomans 3, Study, and Noisy Knob where the number of burrows exceeded 20 burrows/100 m of transect. Density was lowest at Studio, Back of Beyond, Lawson 3, Fucawe, Middle 1, Dougies 2, and Solomans 1 (range 1.01–6.47 burrows/100 m of transect; Table 2).

3.4 Occupancy rates of burrows

In 2007, a combination of digital cameras, grubbing techniques, and burrow-entrance inspection using torches was used to determine occupancy of burrows. Trialling of different field equipment and inclement weather reduced the ability to cover more representative sampling efforts to determine burrow occupancy. A total of 447 burrows were inspected at the Rowe 1 and Solomans colonies, and 83 burrows at the Study colony at Scotchmans Creek. All burrows inspected at the Study colony were fitted with inspection openings. These burrows were double counted to assist in understanding the effectiveness of the techniques used to determine occupancy rates.

Of the 83 burrows inspected at Study Colony, 49 (59.03%) were found to be occupied when the inspection lids were removed (Table 3). Of the 49 occupied burrows, a mean of 31 (63.3%) were occupied (Table 3) based on occupancy detection techniques — 27 birds were correctly detected, and 14 birds were missed by both observers. For 22 burrows, occupancy could not be determined because the burrow terminated well beyond the point of the inspection lid. A more detailed inspection by DOC staff member Chippy Wood at the completion of egg-laying, carried out two weeks after the field work, indicated that 6 (27.3%) of these burrows were occupied.

In 2008 and 2011, determination of burrow occupancy was greatly improved over the techniques used during 2007 when a new generation burrow scope was used. As with experience during field work on flesh-footed shearwaters (Baker et al. 2011), the Sextant burrow scope provided excellent vision of burrow contents. Occupancy rates for colonies viewed by burrow scope in 2008 and 2011 are given in Table 4.

In 2008, 485 burrows were inspected: in the Study (187 burrows), Rowe 1 (198 burrows), Liddys 1 (50 burrows), and Liddys 2 (50 burrows) colonies. In 2011, 593 burrows were inspected: at the Bees Nest (95 burrows), Dougs Bluff (65 burrows), Study (209 burrows), Rowe 1 (115 burrows), Liddys 1 (56 burrows), and Liddys 2 (53 burrows) colonies.

In the absence of data to assess the accuracy of occupancy rates estimated by use of the burrow scope in 2008 and 2011, it was assumed that the equipment was as effective at detecting Westland petrels as it was detecting flesh-footed shearwaters in another study (Baker et al. 2011). In this study the status of 80.8% of occupied burrows was correctly determined, suggesting that the burrow scope data are reasonably accurate.

Assuming that burrow occupancy can be modelled by a Binomial distribution, the best estimate of occupancy is the proportion occupied p, with an estimated variance of $p(1-p)/n$, where n is the number of burrows examined. Thus, a measure on uncertainty in occupancy rate is given by a 95% confidence interval $p-2\times\mathrm{sqrt}(p(1-p)/n)$, $p+2\times\mathrm{sqrt}(p(1-p)/n)$.

The 2008 and 2011 data were used to provide burrow occupancy rates for all colonies. There was evidence of considerable inter-annual variation in the occupancy of burrows at all colonies where this was checked, with occupancy rates lower at all sites inspected in 2008 than they were in 2011. The rates ranged from 0.24 to 0.34 for colonies inspected in 2008, and from 0.478 to 0.646 for colonies inspected in 2011 (Table 4). The occupancy rate (95% CI) for all burrows inspected in 2008 and 2011 was 0.299 (0.257–0.341) and 0.546 (0.505–0.587), respectively. The mean occupancy rate (95% CI) across both years was 0.435 (0.405–0.465).

To avoid unnecessary disturbance and save time, no effort was made to determine if birds occupying burrows were incubating eggs at the time of inspection, but the detailed inspection carried out at the completion of egg-laying in 2007 indicated that 41 of the 49 burrows (83.7%) at the Study colony contained eggs.

Population estimates

Based on data for 'potential burrows', the predicted counts/100 m of transect were scaled up to derive an estimate of the total burrows for each colony surveyed in 2007, 2008, and 2011 (Table 5). A population estimate for the period 2007–2011 was developed using the single-year data from Table 5 and the mean burrow count and occupancy data where colonies were surveyed in more than one year (colonies 2, 10, 18, and 19). Where occupancy rates were not estimated for a colony, the mean occupancy rate for all burrows inspected in the year that burrows were counted was used. Because of no reliable occupancy data for 2007, the mean occupancy rate derived from all colonies inspected in 2008 and 2011 was applied for those colonies where burrow counts were estimated in 2007. It should be noted that the use of transects was inappropriate for estimating burrow density for colonies 1, 24, and 25, and the total number of burrows estimated for these small colonies was based on visual inspection of the sites.

The 'annual' estimate of burrows in all Westland petrel colonies totalled 6846 (95% CI, 6389–7302) prospective burrows during the period 2007 to 2011. Of these burrows, 2827 (95% CI, 2143–3510) were estimated as being occupied (Table 6). This figure can be considered to represent the number of annual breeding pairs using these areas.

4. DISCUSSION

The estimates presented in this report would appear to be the first detailed population estimate for all known breeding areas of the Westland petrel and form a baseline for re-survey of this species through time. They are conservative estimates and represent only the high-density colonies within the breeding areas surveyed. Scattered burrows exist throughout these sites and the populations in these areas may be underestimated by up to 10%. Nonetheless, it is unlikely the global population exceeds 4000 annual breeding pairs.

The greatest limitations to working with this species relate to the extremely rugged nature of the breeding site and the difficulties imposed by the weather, which restricts access to dry periods to ensure that breeding colonies are not damaged by trampling. It was difficult to predict the likelihood of access to sites well in advance, which hampered detailed field planning. There is a limited time around the period of peak egg-laying (about 4 weeks) and heavy rainfall during this short period could lead to extensive delays to the programme. Given these constraints, field work was generally restricted to investigation of breeding sites and establishment of transects during the summer when the birds were absent and the days longer, and during the winter breeding season to concentrate on burrow scoping around the time of peak egg-laying. This technique relied on the assumption that burrow densities remain relatively constant from one season to the next. At the time this study was initiated this view was widely held among those who had worked on Westland petrels in the past (Wood 2006, S. Waugh unpublished) and appeared reasonable given the stable nature of the substrate encountered in colonies.

However, data from permanent transects established in the Study and Rowe 1 colonies raised some questions on the validity of this assumption, with significantly fewer burrows being detected in both these areas in 2008 and 2011 than in 2007 (Study – 91 and 71 or 32.2% and 28% fewer burrows in 2008 and 2011 than counted in 2007 in 948 m of transects; Rowe 1 – 11 and 27 or 12.4% and 30.3% fewer burrows in 2008 and 2011 than counted in 2007 in 477 m of transects). This can be partially explained by the difficulty of re-establishing the 'permanent' transects. Even though markers were placed at the start and termination of each transect, and at no greater than 20-m centres along the transect length, the nature of the terrain is such that rocks, fallen trees, and other vegetation made it difficult to ensure that transect lines were in exactly the same position as they were previously. It is conceivable that the placement of transects was such that a different set of burrows was encountered in each year. However, if the transects were representative of each colony, it would be expected that there would be both negative and positive differences in counts. In fact, there was a negative difference for 11 of 12 transects at the Study colony and 3 of 4 transects at Rowe 1. Only for the Liddys 1 and 2 colonies was the pattern of differences evenly spread. Although this issue is unlikely to have significantly affected this global population estimate, it has implications for future work that may look to establish trends at fixed monitoring sites, and future studies should take this into account.

Baker & Double (2007) identified Study, Rowe 1, and Liddys 1 and 2 colonies as suitable for long-term monitoring. Permanent transects have been established in these areas to facilitate this (Baker et al. 2007). Permanent transects were also established at many of the other colonies located during this study (Baker et al. 2007, 2008), to facilitate ongoing monitoring at some time in the future, if so desired by others. There would be considerable benefit if long-term population monitoring at more colonies was to flow on from this project (Waugh et al. 2015).

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7. TABLES AND FIGURES

Table 1: High density breeding sites of Westland petrels identified by Wood (2006) and which were the focus of this study. Note that although Wood referred to these areas as colonies, many areas consisted of a number of small colonies. In this study, the term 'colony' refers to an area of intensive breeding activity, identified by the presence of more than 20 burrows (see Definitions in section 2.2). However, the word 'colony' is retained in the name of each high-density breeding site for consistency with Wood (2006) in the naming of these areas. The four sites shaded green indicate those sites which could not be located because of inconsistencies in the Wood (2006) report (see text). The sites shaded grey indicate two sites which were systematically searched without any evidence of a breeding colony being present.

Site no.	High density breeding site	Field Work – sites visited in			Wood (2006)
		2007	2008	2011	Burrow total
1	Middle bluff 'colony'			X	32
2	Bees nest 'colony'		X	X	711
3	Fucawe 'colony'			X	343
4	Dougies bluff 'colony'		X		1 712
5	3 Bluffs 'colony'			X	139
6	Viejo 'colony'			X	62
7	Soloman and Reubs 'colony'	X			1 293
8	Unnamed 'colony' mapped by Wood (2006)				not provided
9	Power Barrow 'colony'			X	91
10	Study 'colony'	X	X	X	3 260
11	Track in				43
12	Robs 'colony'			X	262
13	Noisy knob			X	363
14	Middle 'colony'	X	X	X	561
15	Able 'colony'			X	90
16	262 West 'colony'			X	110
17	262 East 'colony'		X		274
18	Rowe 'colony'	X	X		1 057
19	Liddys centre 'colony'	X	X		796
20	Studio 'colony'		X		392 and 599
21	Liddys top 'colony'		X		217
22	Back of beyond 'colony'			X	499
23	Howard land			X	not provided
24	Lawson 2 'colony'			X	10
25	Lawson 1 'colony'			X	22
26	Lawson 3 'colony'			X	209
	Studio sub 'colony'				199
	Carpentaria + 2 sub colonies				599

Table 2: Number of potential burrows per 100 m of transect for Westland petrel colonies in 2007, 2008, and 2011. Counts for 2007 were modelled by Poisson regression. For other years the data are assumed to be compatible with a Poisson model, and thus raw counts only are presented, and the standard deviation is estimated as the square root of the count, a property of the Poisson model. Burrow densities in colonies 1, 24, and 25 were too low to permit estimation of a value from transects.

Colony ID	Colony	Year	Burrows / 100 m of transect	SE	Lower 95% Cl	Upper 95% Cl
1	Middle Bluff	2011	Not estimated			
2	Bees Nest	2008	9.533	1.285	6.962	12.104
		2011	9.191	1.300	6.592	11.791
3	Fucawe	2011	3.913	0.834	2.245	5.582
4	Dougies 1	2008	11.625	2.122	7.380	15.870
4	Dougies 2	2008	6.257	1.365	3.526	8.988
5	3 Bluffs	2011	7.662	1.916	3.831	11.493
6	Viejo	2011	9.275	2.479	4.317	14.232
7	Solomans 1	2007	6.470	2.200	2.070	10.870
7	Solomans 2	2007	18.000	8.361	1.278	34.722
7	Solomans 3	2007	48.070	8.506	31.058	65.082
9	Power Barrow	2011	7.100	1.833	3.433	10.766
10	Study or Main	2007	29.280	1.445	26.390	32.170
		2008	16.491	1.190	14.111	18.872
		2011	17.522	1.227	15.068	19.976
12	Robs	2011	10.417	1.334	7.750	13.085
13	Noisy Knob	2011	21.502	1.939	17.625	25.380
14	Middle 1	2008	5.702	1.024	3.654	7.750
14	Middle 2	2008	9.686	1.294	7.097	12.274
17	262 East	2008	14.047	4.235	5.577	22.518
18	Rowe 1 & 2	2007	18.658	1.978	14.703	22.614
		2008	16.352	1.852	12.649	20.055
		2011	12.998	1.651	9.696	16.299
19	Liddys 1	2007	9.296	1.643	6.009	12.582
		2008	10.458	1.743	6.972	13.943
		2011	7.843	1.509	4.824	10.862
19	Liddys 2	2007	13.269	2.153	8.964	17.574
		2008	13.967	2.208	9.550	18.384
		2011	11.872	2.036	7.800	15.944
19	Liddys 3	2008	8.238	0.958	6.323	10.153
20	Studio	2008	1.009	0.220	0.569	1.449
21	Liddys Top 1A	2008	11.622	1.964	7.693	15.551
21	Liddys Top 1B	2008	13.441	3.592	6.256	20.625
22	Back of Beyond	2011	3.089	0.538	2.014	4.165
24	Lawson 2	2011	Not estimated			
25	Lawson 1	2011	Not estimated			
26	Lawson 3	2011	3.130	0.602	1.925	4.335

Table 3: Occupancy status of 83 marked burrows fitted with inspection openings at Main Colony, Scotchmans Creek, determined at various stages of the 2007 breeding season. Two observers independently inspected burrows using hand-grubbing, torch and digital cameras to determine whether burrows were occupied, and then checked occupancy by removing inspection lids to verify burrow contents.

Burrow occupancy status at time of field work		Burrow contents identified by Observers					Actual contents determined subsequently at:	
Status	No.	Status	Observer 1	Observer 2	Mean	Proportion verified	completion of laying	completion of breeding - chicks fledged
occupied	49	occupied	34	28	31	63.3%	41	20
		empty					7	26
		no data		2			1	3
		unknown	15	19	17			
empty	12	empty	5	3	4	33.3%	10	11
		occupied					1	0
		no data					1	1
		unknown	7	9	8			
unknown	22	unknown	22	20	21		0	0
		occupied					6	1
		empty		2	2		16	21
Total	**83**		**83**	**83**	**83**		**83**	**83**

Table 4: Burrow occupancy at colonies in 2008 and 2011 determined by use of burrow scopes, hand-grubbing, torch, and digital cameras.

Colony ID	Colony	Year	Burrows	Burrow occupancy							
				Occupied				Empty		Unknown	
				No.	%	LCI	UCI	No.	%	No.	%
2	Bees Nest	2011	95	56	58.9	48.9	69.0	36	37.9	3	3.2
4	Dougs Bluff	2011	65	42	64.6	52.8	76.5	20	30.8	3	4.6
10	Study	2008	187	57	30.5	23.7	37.2	119	63.6	11	5.9
		2011	209	110	52.6	45.7	59.5	97	46.4	2	1.0
		mean	396	167	42.2	37.2	47.1	216	54.5	13	3.3
18	Rowe 1	2008	198	59	29.8	23.3	36.3	126	63.6	13	6.6
		2011	115	55	47.8	38.5	57.1	57	49.6	3	2.6
		mean	313	114	36.4	31.0	41.9	183	58.5	16	5.1
19	Liddys 1	2008	50	17	34.0	20.6	47.4	32	64.0	1	2.0
		2011	56	33	58.9	45.8	72.1	19	33.9	4	7.1
		mean	106	50	47.2	37.5	56.9	51	48.1	5	4.7
19	Liddys 2	2008	50	12	24.0	11.9	36.1	36	72.0	2	4.0
		2011	53	28	52.8	39.1	66.5	25	47.2	0	0.0
		mean	103	40	38.8	29.2	48.4	61	59.2	2	1.9
	All colonies	2008	485	145	29.9	25.7	34.1	313	64.5	27	5.6
		2011	593	324	54.6	50.5	58.7	254	42.8	15	2.5
		mean	983	413	42.0	38.9	45.2	567	52.6	42	3.9

Table 5: Estimated total number of burrows (shaded columns) and occupied burrows (bolded type) for Westland petrel colonies surveyed in 2007, 2008, and 2011, based on scaled-up counts for 'potential burrows'. Burrow occupancy rates were not estimated for all colonies and the mean occupancy rate for all burrows inspected in the year that burrows were counted is presented. For 2008 and 2011 these rates were 0.299 and 0.546, respectively. For colonies where burrow counts were estimated in 2007, the mean occupancy rate derived from all colonies inspected in 2008 and 2011 is applied (0.435 – see Table 4). Occupancy rates derived in this manner are indicated by grey shading in the relevant cells. The use of transects was inappropriate for estimating burrow density for colonies 1, 24, and 25, and the total estimate of burrows for these small colonies was based on visual inspection of the sites.

Colony ID	Colony	Year	Area (m^2)	Burrow occupancy rate	Burrows / 100 m of transect	Potential burrows	Lower 95% Cl	Upper 95% Cl	Occupied burrows	Lower 95% Cl	Upper 95% Cl
1	Middle Bluff	2011	600	0.546	not estimated	20	20	20	**11**	**10**	**12**
2	Bees Nest	2008	6 364	0.299	10.110	322	235	408	**96**	**83**	**110**
		2011	6 364	0.589	9.191	292	210	375	**172**	**143**	**202**
3	Fucawe	2011	1 750	0.546	3.913	34	20	49	**19**	**17**	**20**
4	Dougies 1	2008	761	0.299	11.625	44	28	60	**13**	**11**	**15**
4	Dougies 2	2008	2 102	0.299	6.257	66	37	94	**20**	**17**	**22**
5	3 Bluffs	2011	1 500	0.546	7.662	57	29	86	**31**	**29**	**34**
6	Viejo	2011	1 007	0.546	9.275	47	22	72	**25**	**24**	**27**
7	Solomans 1	2007	4 318	0.435	6.470	140	79	200	**61**	**57**	**65**
7	Solomans 2	2007	1 290	0.435	18.000	116	71	162	**51**	**47**	**54**
7	Solomans 3	2007	2 733	0.435	48.070	657	521	793	**286**	**266**	**305**
9	Power Barrow	2011	1 146	0.546	7.100	41	20	62	**22**	**21**	**24**
10	Study or Main	2007	18 905	0.435	29.280	2 768	2495	3041	**1 204**	**1 121**	**1 287**
		2008	18 905	0.305	16.491	1 559	1334	1784	**475**	**370**	**580**
		2011	18 905	0.526	17.522	1 656	1424	1888	**871**	**757**	**986**
12	Robs	2011	4 995	0.546	10.417	260	194	327	**142**	**131**	**153**
13	Noisy Knob	2011	3 026	0.546	21.502	325	267	384	**178**	**164**	**191**
14	Middle 1	2008	1 491	0.299	5.702	43	27	58	**13**	**11**	**14**
14	Middle 2	2008	5 945	0.299	9.686	288	211	365	**86**	**74**	**98**
17	262 East	2008	440	0.299	14.047	31	12	50	**9**	**8**	**11**
18	Rowe 1 & 2	2007	12 346	0.435	18.658	1 152	908	1396	**501**	**466**	**536**
		2008	12 346	0.298	16.352	1 009	781	1238	**301**	**235**	**366**
		2011	12 346	0.478	12.998	802	599	1006	**384**	**309**	**458**

Colony ID	Colony	Year	Area (m^2)	Burrow occupancy rate	Burrows / 100 m of transect	Potential burrows	Lower 95% Cl	Upper 95% Cl	Occupied burrows	Lower 95% Cl	Upper 95% Cl
19	Liddys 1	2007	3 559	0.435	9.296	165	107	224	**72**	**67**	**77**
		2008	3 559	0.34	10.458	186	124	248	**63**	**38**	**88**
		2011	3 559	0.589	7.843	140	86	193	**82**	**64**	**101**
19	Liddys 2	2007	6 907	0.435	13.269	458	310	607	**199**	**186**	**213**
		2008	6 907	0.24	13.967	482	330	635	**116**	**57**	**174**
		2011	6 907	0.528	11.872	410	269	551	**216**	**160**	**273**
19	Liddys 3	2008	5 996	0.299	8.238	247	190	304	**74**	**63**	**84**
20	Studio	2008	56 205	0.299	1.009	284	160	407	**85**	**73**	**97**
21	Liddys Top	2008	2 282	0.299	12.002	137	98	176	**41**	**35**	**47**
22	Back of Beyond	2011	9 856	0.546	3.089	152	99	205	**83**	**77**	**89**
24	Lawson 2	2011	100	0.546	not estimated	10	10	10	**5**	**5**	**6**
25	Lawson 1	2011	200	0.546	not estimated	10	10	10	**5**	**5**	**6**
26	Lawson 3	2011	5 000	0.546	3.130	78	48	108	**43**	**40**	**46**

Table 6: Population estimate for the Westland petrel, based on the estimated number of potential burrows (unbold type) and occupied burrows (bold type) for colonies surveyed over three years (2007, 2008, and 2011). Occupancy rates for some areas and colonies were not estimated during the study and the mean occupancy rate for all burrows inspected in the year that burrows were counted is presented. For 2008 and 2011 these rates were 0.299 and 0.546, respectively. With no occupancy data for 2007, the mean occupancy rate derived from all colonies inspected in 2008 and 2011 was applied (0.435 — see Table 4) for those colonies where burrow counts were estimated in 2007. For colonies that were surveyed more than one year (colonies 10, 18, and 19), the mean burrow count and occupancy rates for the colony are used. The use of transects was inappropriate for estimating burrow density for Colonies 1, 24, and 25, and the total estimate of burrows for these small colonies was based on visual inspection of the sites.

	Colony	Area (m^2)	Burrow occupancy rate	Estimated number of burrows	Lower 95% Cl	Upper 95% Cl
1	**Middle Bluff**	**600**	**0.546**	20	20	20
				11	**11**	**11**
2	**Bees Nest**	**6 364**	**0.435**	307	222	392
				134	**97**	**170**
3	**Fucawe**	**1 750**	**0.546**	34	20	49
				19	**11**	**27**
4	**Dougies Bluff**	**2 863**	**0.299**	123	89	157
				37	**26**	**47**
5	**3 Bluffs**	**1 500**	**0.546**	57	29	86
				31	**16**	**47**
6	**Viejo**	**1 007**	**0.546**	47	22	72
				25	**12**	**39**
7	**Solomans 1**	**4 318**	**0.435**	140	79	200
				61	**34**	**87**
7	**Solomans 2**	**1 290**	**0.435**	116	71	162
				51	**31**	**70**
7	**Solomans 3**	**2 733**	**0.435**	657	521	793
				286	**227**	**345**
9	**Power Barrow**	**1 146**	**0.546**	41	20	62
				22	**11**	**34**
10	**Study or Main**	**18 905**	**0.422**	1 838	1 593	2 082
				775	**672**	**879**
12	**Robs**	**4 995**	**0.546**	260	194	327
				142	**106**	**178**
13	**Noisy Knob**	**3 026**	**0.546**	325	267	384
				178	**146**	**210**
14	**Middle 1**	**1 491**	**0.299**	43	27	58
				13	**8**	**17**
14	**Middle 2**	**5 945**	**0.299**	288	211	365
				86	**63**	**109**
17	**262 East**	**440**	**0.299**	31	12	50
				9	**4**	**15**
18	**Rowe 1 & 2**	**12 346**	**0.364**	988	762	1 214
				360	**277**	**442**
19	**Liddys 1**	**3 559**	**0.472**	164	106	222
				77	**50**	**105**
19	**Liddys 2**	**6 907**	**0.388**	450	303	598
				175	**118**	**232**

	Colony	Area (m^2)	Burrow occupancy rate	Estimated number of burrows	Lower 95% Cl	Upper 95% Cl
19	**Liddys 3**	**5 996**	**0.299**	**247**	**190**	**304**
				74	**57**	**91**
20	**Studio**	**56 205**	**0.299**	**284**	**160**	**407**
				85	**48**	**122**
21	**Liddys Top**	**2 282**	**0.299**	**137**	**98**	**176**
				41	**29**	**53**
22	**Back of Beyond**	**9 856**	**0.546**	**152**	**99**	**205**
				83	**54**	**112**
24	**Lawson 2**	**100**	**0.546**	**10**	**10**	**10**
				5	**5**	**5**
25	**Lawson 1**	**200**	**0.546**	**10**	**10**	**10**
				5	**5**	**5**
26	**Lawson 3**	**5 000**	**0.546**	**78**	**48**	**108**
				43	**26**	**59**
	TOTALS		**— potential burrows**	6 846	6 389	7 302
			— occupied burrows	**2 827**	**2 143**	**3 511**

Figure 1: Westland petrel breeding distribution. The dashed purple line indicates the Westland Petrel Special Protected Area, and the blue line the known breeding distribution. Source: Lyall et al. (2004).

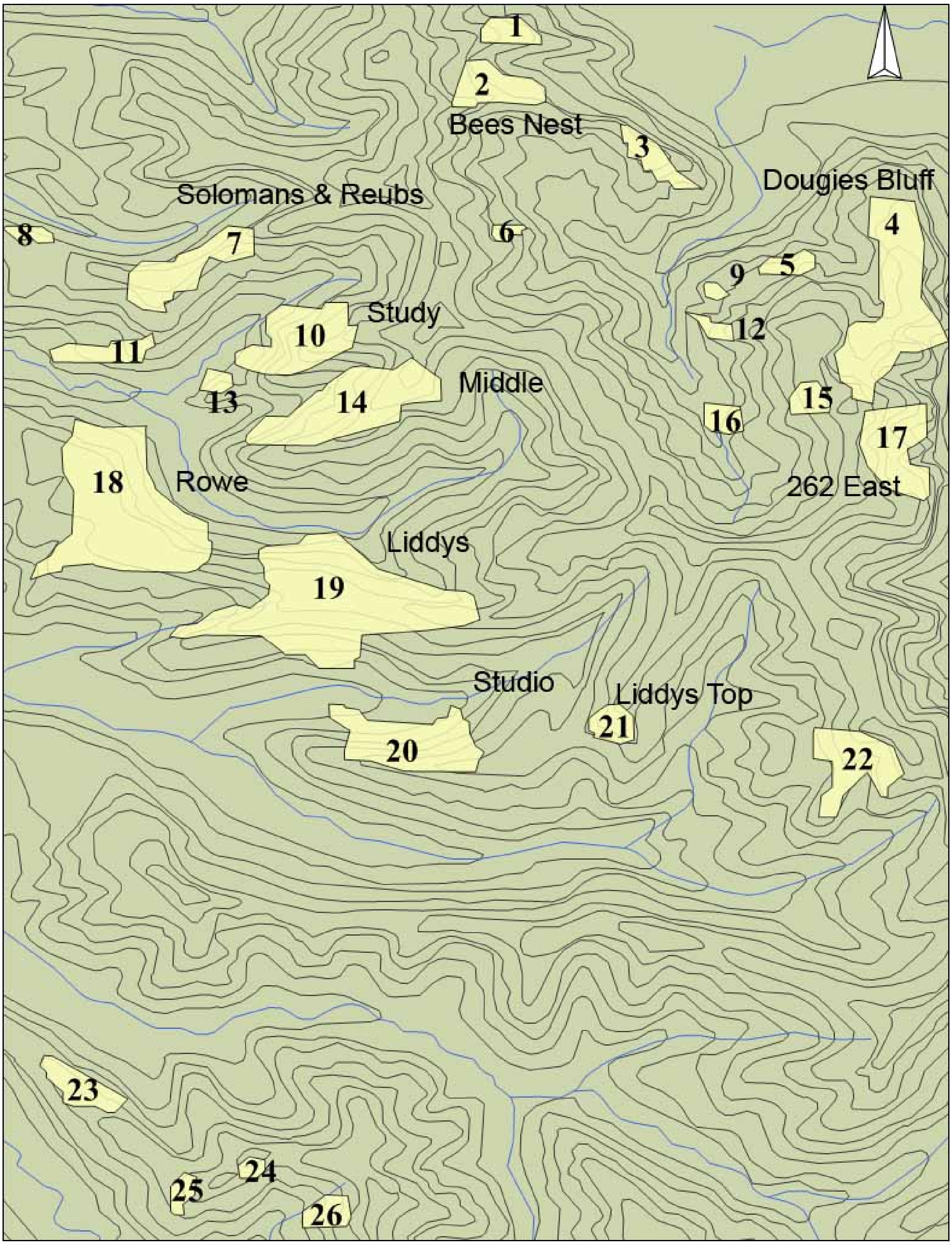

Figure 2: The distribution of high-density breeding sites of Westland petrels identified by Wood (2006) and which formed the focus of this study.

1 – Middle Bluff Colony; 2 – Bees Nest Colony; 3 – Fucawe Colony; 4 – Dougies Bluff Colony; 5 – 3 Bluffs Colony; 6 – Viejo Colony; 7 – Soloman and Reubs Colony; 8 – Unnamed Colony; 9 – Power Barrow Colony; 10 – Study Colony; 11 – Track in; 12 – Robs Colony; 13 – Noisy Knob; 14 – Middle Colony; 15 – Able colony; 16 – 262 West Colony; 17 – 262 East Colony; 18 – Rowe Colony; 19 – Liddys Centre Colony; 20 – Studio Colony; 21 – Liddys Top Colony; 22 – Back of Beyond Colony; 23 – Howard land; 24 – Lawson 2 Colony; 25 – Lawson 1 Colony; 26 – Lawson 3 Colony.

Annex 1: Summary information on colony and search transects established in 28 colonies located within the 26 breeding sites of Westland petrel studied.

Colony ID	Breeding area	Colony	Year	Area (m^2)	Burrow density	No. burrows estimated	Colony transects		Search transects		Total transects	
							length (m)	n	length (m)	n	length (m)	n
1	Middle Bluff	Middle Bluff	2011	600	not calculated	20			672	3	824	3
2	Bees Nest	Bees Nest	2008	6 364	0.0477	303	577	12			577	12
3	Fucawe	Fucawe	2011	1 750	0.0196	34	562	12			562	12
4	Dougies Bluff	Dougies 1	2008	761	0.0581	44	258	6			258	6
		Dougies 2	2008	2 102	0.0313	66	336	7			336	7
		Dougies 3	2008	Scattered burrows - not a colony					360	1	440	1
		Dougies 4	2008	Scattered burrows - not a colony					120	1	145	1
5	3 Bluffs	3 Bluffs	2011	1 500	0.0383	57	209	5			209	5
6	Viejo	Viejo	2011	1 007	0.0464	47	151	3	199	4	393	7
7	Soloman and Reubs colony	Solomans 1	2007	4 318	0.0305	132	311	4			311	4
		Solomans 2	2007	1 290	0.0749	97	120	1			120	1
		Solomans 3	2007	2 733	0.1925	526	156	2			156	2
8	Unnamed colony (Wood 2006)											
9	Power Barrow	Power Barrow	2011	1 146	0.0355	41	211	4	93	1	323	5
10	Study	Study or Main	2007	18 905	0.1215	2298	1 164	12			1 164	12
11	Track in		Not searched - scattered burrows only									
12	Robs	Robs	2011	4 995	0.0521	260	586	9			586	9
13	Noisy Knob	Noisy Knob	2011	3 026	0.1075	325	572	9			572	9
14	Middle Colony	Middle 1	2008	1 491	0.0285	43	544	7	639	21	1 328	28
		Middle 2	2008	5 945	0.0484	288	578	10			578	10
15	Able		Not located despite intensive search									
16	262 West		Not located despite intensive search									

Colony ID	Breeding area	Colony	Year	Area (m^2)	Burrow density	No. burrows estimated	Colony transects		Search transects		Total transects	
							length (m)	n	length (m)	n	length (m)	n
17	262 East	262 East	2008	440	0.0702	31	78	3	176	2	292	3
18	Rowe	Rowe 1 & 2	2007	12 346	0.0656	809	732	7			732	9
19	Liddys centre	Liddys 1	2008	3 559	0.0523	186	344	4			344	4
		Liddys 2	2008	6 907	0.0698	482	286	4			286	4
		Liddys 3	2008	5 996	0.0412	247	898	8			898	8
		Liddys 4			no burrows found	0			266	2	325	2
20	Studio	Studio	2008	56 205	0.0050	284	2 082	10			2 082	10
21	Liddys top	LT1A	2008	1 806	0.0581	105	301	7			301	7
		LT1B	2008	476	0.0672	32	104	4			104	4
22	Back of Beyond	Back of Beyond	2011	9 856	0.0154	152	1 068	12			1 068	12
23	Howard land	Howard land	2011		no burrows found							
24	Lawson 2	Lawson 2	2011	100	not calculated	10			212	4	258	4
25	Lawson 1	Lawson 1	2011	200	not calculated	10	382	2			382	2
26	Lawson 3	Lawson 3	2011	5 000	0.0157	78	863	7			863	7
	Total 28 Breeding areas	Total 30 'colonies'		160 824		6 968	13 474	171	2 737	39	16 817	210
	Average colony size			5 744								