BURROW OCCUPANCY AND POPULATION SIZE IN THE ATLANTIC PETREL *PTERODROMA INCERTA*: A COMPARISON OF METHODS

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SUMMARY

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To test the accuracy of burrowing seabird monitoring techniques, data from activity signs and playback methods were compared with burrowscope data from 652 Atlantic Petrel *Pterodroma incerta* burrows on Gough Island in the South Atlantic Ocean. In addition, burrow density was monitored over seven breeding seasons (2001–2012), burrow occupancy was assessed, and the Atlantic Petrel population estimate refined using the most recent density and occupancy figures. Activity signs and call playback have limited utility for monitoring this species. Activity signs overestimated actual burrow occupancy by 38% and playback underestimated occupancy by 76%. Playback utility may also be affected by density-related response priming. Mean burrow density using direct surveys was 0.19 ± 0.02 burrows/m^2 (mean ± SE) over seven breeding seasons. There was no significant trend in burrow density 2001–2012, but burrow density varied significantly among years. Burrow occupancy was 52% (95% CI 48%–56%) and 31% (27%–36%) in 2010 and 2012, respectively. The revised estimate of breeding numbers indicates a population size of approximately 900 000 pairs, although confidence in this estimate is low. Our work illustrates the importance of validating methods used to determine burrow occupancy, an important aspect of monitoring burrowing seabird populations.

Keywords: activity signs, petrel, playback response, *Pterodroma incerta*, population estimate

INTRODUCTION

Accurate knowledge of population trends and demographic rates is fundamental for assessing the conservation status of bird species. However, monitoring nocturnal burrowing petrels (Procellariiformes) and other burrow-nesting species can be challenging, especially when nesting birds occupy long, complex burrows. To estimate population sizes, researchers often measure burrow density and the area of breeding habitat, and then estimate the proportion of burrows that are occupied by breeding pairs (e.g. Lawton *et al.* 2006, Barbraud *et al.* 2009). Burrow occupancy has been estimated using activity signs (field signs indicating whether burrows are active) (Gaze 2000, Gardner-Gee *et al.* 2008), or using playback response to recorded calls (Barbraud *et al.* 2009, Soanes *et al.* 2012). Although widely used, inferred measures of occupancy may produce widely inaccurate population estimates, emphasising the importance of validating methods.

Testing methods for accuracy may allow a correction factor to be applied, e.g. the probability that an incubating bird will respond to playback (Ratcliffe *et al.* 1998, Vaughan & Gibbons 1998, Berrow 2000). However, few studies have tested the accuracy of activity signs (Hamilton 1998, Cuthbert & Davis 2002). Although playback response rates are better studied (e.g. Ratcliffe *et al.* 1998, Burger & Lawrence 2001), playback is still highly variable. Given this apparent variability (both in the findings of studies investigating the accuracy of these techniques and in the techniques used) and the importance of population monitoring in the management of endangered species, it is important to evaluate quantitatively the accuracy of monitoring methods used.

Atlantic Petrels *Pterodroma incerta* are endemic to South Atlantic Tristan da Cunha, with almost the entire population breeding on Gough Island (~1.8 million pairs; Cuthbert 2004). The species is considered globally endangered (IUCN Red List, BirdLife International 2011) as a result of chick predation by introduced House Mice *Mus musculus* and its small breeding range (Cuthbert 2004, Wanless *et al.* 2007), and models suggest population declines (Wanless *et al.* 2012).

In this paper we evaluate the activity signs and playback methods using data for the Atlantic Petrel at Gough Island, and we validate the accuracy of these methods with findings from a burrowscope. We present new data on Atlantic Petrel burrow occupancy and trends in burrow numbers, and we provide an updated population estimate.

METHODS

Species and study area

Atlantic Petrels are a small (~550 g) petrel. On Gough Island (40°21′S, 9°53′W), they nest up to ~400 m a.s.l., primarily in fernbush, composed of the ferns *Histiopteris incisa* and *Blechnum palmiforme* and the Island Tree *Phylica arborea*, but also nest at lower densities in coastal tussock (Cuthbert 2004). Burrows are relatively short and broad (0.5–2.5 m, 20 cm entrance width) with a simple lightly curving structure and little branching. Breeding occurs during the austral winter, with eggs laid from mid-June to mid-July, chicks hatching in mid-August to mid-September and surviving chicks fledging by January (Cuthbert 2004). Fieldwork to evaluate burrow density was conducted in July–August of 2001, 2004, 2006, 2009, 2010, 2011 and 2012. Activity signs and playback accuracy were assessed from fieldwork in July–August 2010, and burrow contents were inspected by burrowscope during early- to mid-incubation (July–August) of 2010 and 2012.

Burrow density

Burrows were surveyed along three permanent, long-term monitoring transects located in fernbush in the southeast of the island. Quadrats (8 × 8 m, n = 43) were placed consecutively on alternating sides of each 120 m transect (Cuthbert 2004) and searched systematically for burrows, with observers searching both under and within vegetation. Atlantic Petrel burrows were distinguished from those of other petrels nesting in this zone by burrow entrance dimensions (Cuthbert 2004). Burrows that had two connecting entrances were counted as one burrow, and burrows on the edge of the quadrat were included if more than half of the entrance fell inside the quadrat. Burrows shorter than 40 cm were not included, as Atlantic Petrels do not breed in such short burrows (R.J.C. unpubl. data). Surveys were conducted during the day (~07h30–17h30) to minimise inadvertent damage to burrows, reduce the potential for disruption of adults changing incubation shifts (mostly at night) and limit inclusion of non-breeders (e.g. Schulz *et al.* 2005). These methods were followed in all years of fieldwork (2001–2012) in order to monitor trends in burrow density.

Activity signs, playback and burrow contents

Each Atlantic Petrel burrow was checked for activity signs. Fresh digging, droppings, feathers and/or fresh vegetation indicated that the burrow was "active" (e.g. Cuthbert & Davis 2002). Burrows that appeared unused (i.e. not cleaned out or with vegetation growing in the tunnel) were classed as "inactive." To limit between-observer variability, the first two quadrats per transect were checked by both observers. Thereafter, at least two burrows per quadrat were cross-checked, as were burrows with ambiguous signs. After checking activity signs at a burrow, playback response was determined by playing a standard recording of Atlantic Petrel burrow calls (repeated sequences of two burrow calls recorded during July 2010) at the burrow entrance, played at the same volume for 15–20 sec or until a bird responded. Thereafter, a burrowscope (head Ø 40 mm and hose length 2 m, 752 × 582 pixel wireless screen; Sextant Technology, Wellington, New Zealand) was used to identify actual burrow occupants, checking all branches and chambers. Burrows were considered occupied if they contained an incubating bird or egg, while those that were fully explored and contained no bird or egg were deemed empty. By mid- to late incubation, burrows are primarily occupied by breeding birds (R.J.C. unpubl. data), as is typical of other petrel species (Imber *et al.* 2005), and incubating birds can be distinguished from non-breeding "loafers" by burrowscope. Burrows that could not be fully explored (where the presence/absence of a nest could not be confirmed) were classified as "inaccessible." The presence of a dead bird or signs of a failed breeding attempt (eggshell) were noted.

Data analyses

Burrow numbers were used to calculate burrow density, and trends in burrow density were assessed using the software package TRIM (TRends and Indices for Monitoring data; Pannekoek & Van Strien 2001), which is routinely used to assess bird monitoring data (Sheehan *et al.* 2010). TRIM estimates yearly indices and trends through fitting a generalized linear model with a log link and a Poisson distribution. TRIM incorporates corrections for overdispersion and serial correlation of counts in the analysis, as well adjusting for missing counts (in 2006 only one of the three transects was surveyed). A linear trend was first fitted to the time series to estimate the overall population trend for the whole survey period (2001–2012; e.g. Woehler *et al.* 2001) and the overall multiplicative annual rate of increase (λ) is presented as well as the statistical significance of this trend. We then fitted linear trends with all years set as change points and with stepwise removal of non-significant change points in TRIM, to assess if there were significant interannual variation in the time series or if the data were better fit by a linear trend. Significance values for change points was set at $P < 0.05$.

Methods were compared using data from the 2010 field season, when activity signs and playback were used at each burrow prior to burrowscope inspection. Only data from burrows that could be fully explored by burrowscope (94%, n = 652 of 694 burrows surveyed) were used, excluding inaccessible burrows. Birds that called only after burrowscoping had commenced (1.2%, n = 8) were excluded from playback response data because their calls could have been in response to disturbance rather than to playback. One burrow containing an egg only was excluded from the comparison of playback and signs.

To determine breeding numbers, a population size estimate was calculated using average Atlantic Petrel burrow density in 2012 from the 43 monitoring quadrats, the proportion of occupied burrows (actual occupancy from the two seasons with burrowscope inspections 2010 and 2012), and the estimated area of available habitat. We used habitat area estimates of 10.4 km^2 of fernbush and 4.6 km^2 of coastal tussock (derived by physical mapping of vegetation types in which Atlantic Petrels were found; Cuthbert 2004), and assumed that the relationship between Atlantic Petrel burrow density in coastal tussock and fernbush areas has remained constant (burrow density in coastal tussock half that in fernbush; Cuthbert 2004).

Results are presented as mean ± standard error (SE), along with 95% binomial confidence intervals (CI). Analyses were

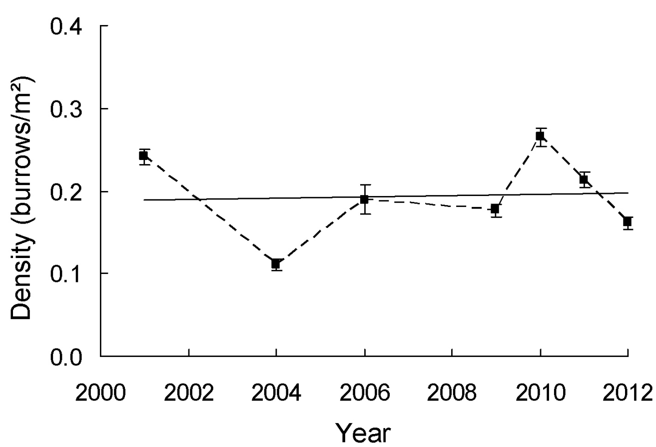

Fig. 1. Average Atlantic Petrel burrow density estimates (mean ± SE) in seven years (2001–2012) from long-term monitoring transects and best-fit regression line (solid line).

conducted using TRIM and SPSS 14.0, and statistical significance set at $P < 0.05$.

RESULTS

Burrow density trends

There was no significant trend in burrow density in the seven breeding seasons that we evaluated over the 11-year period from 2001 to 2012, with the multiplicative annual rate of increase being $\lambda = 1.02 \pm 0.01$ (Fig. 1). Analysis in which all years were set as change points, using stepwise removal, indicated significant interannual variation in burrow density ($P < 0.005$ for between-year trend comparisons) in all years except 2010, 2011 and 2012, in which the rate of decline was constant (Fig. 1). The average density was 0.19 ± 0.02 burrows/m^2; annual mean density ranged from 0.11 ± 0.01 to 0.27 ± 0.01 burrows/m^2. Burrow density in 2012 was 0.16 ± 0.01 burrows/m^2.

Activity signs and playback accuracy

Activity signs overestimated burrow occupancy, while playback response underestimated occupancy (Table 1). When checked using the burrowscope, 52% of all burrows in quadrats were occupied (Table 1). However, 84% of all burrows were classified as "active" using activity signs, while only 12% of all burrows contained birds that responded to playback (Table 1). The proportion of burrows apparently occupied according to signs (84%) and from playback response (12%) differed significantly from actual burrow occupancy ($\chi^2_1 = 265.7$ and $\chi^2_1 = 409.2$, respectively, both $P < 0.001$).

When the activity signs method was compared with burrowscope findings, activity signs correctly classified burrow occupancy (occupied or empty) for 61% (n = 395) of burrows. Of the 547 burrows that were classified as apparently occupied using activity signs, only 62% (n = 338) were actually occupied (Table 1). However, 23% of the 105 burrows that appeared inactive using activity signs were identified as occupied by the burrowscope (Table 1).

Only 24% of birds in burrows known to be occupied responded to call playback and 45% of the 571 burrows in which no response to playback was heard were occupied (Table 1). Birds in adjacent burrows responded to playback in at least 11 of the 43 quadrats. Response likelihood tended to increase with burrow density (Fig. 2), despite there being no relationship between burrow density and occupancy rates ($r = 0.09$, $P = 0.55$, n = 43).

TABLE 1
Effectiveness of activity signs and playback response in estimating Atlantic Petrel burrow contents (inferred contents) when compared with actual contents seen via burrowscope for n = 652 burrows (data from 2010 breeding season)

Actual contents: burrowscope	n	Activity signs		Playback response	
		Active	Inactive	Yes	No
Occupied	338	314	24	81	257
% of 338 occupied	–	93	7	24	76
Empty	314	233	81	0	314
% of 314 empty	–	74	26	0	100
Total	652	547	105	81	571

Burrow occupancy and population estimate

Overall, Atlantic Petrel burrow occupancy during early incubation was estimated to be 52% (CI 48%–56%) in 2010, or 339 out of 652 accessible burrows, and 31% (CI 27%–36%) in 2012 (125 of 298 accessible burrows). These occupancy figures exclude inaccessible burrows in which the contents could not be determined with certainty, and therefore are minimum estimates, as some early breeding failures would have been overlooked.

Based on the 2012 burrow density estimate of 0.16 burrows/m^2 and burrow occupancy rate during incubation of 42% (the average of the 2010 and 2012 occupancy rates), the current breeding population of Atlantic Petrels is about 860 000 pairs, varying between ~630 000 pairs (31% occupancy in 2012) and ~1 100 000 pairs (52% occupancy in 2010). However, these estimates should be treated with caution: the total area of breeding habitat is underestimated to an unknown extent (complex topography and limited map definition did not allow inclusion of slope angle in calculations; Cuthbert 2004), and only local (not island-wide) variance in burrow density was accounted for.

DISCUSSION

This study illustrates that activity signs or call playback are unlikely to be accurate enough for monitoring long-term trends in Atlantic Petrel populations on Gough Island. Activity signs incorrectly classified 39% of burrows, overestimating occupancy overall, while playback response under-represented occupancy, with only 24% of Atlantic Petrels responding to playback. Burrowscopes are an important tool for accurate monitoring of this and likely other petrel species. In total, 94% of Atlantic Petrel burrows could be fully explored using a burrowscope. This is within the range of other petrel species with similar burrow geometry (Cuthbert & Davis 2002, Waugh *et al.* 2003). Entrance excavation to aid scoping could have reduced the proportion of inaccessible Atlantic Petrel burrows, but this can lead to nests being abandoned (Lawton *et al.* 2006) and might increase the risk of predation by Subantarctic Skuas *Catharacta antarctica*. Entrance excavation is thus unsuitable for long-term monitoring.

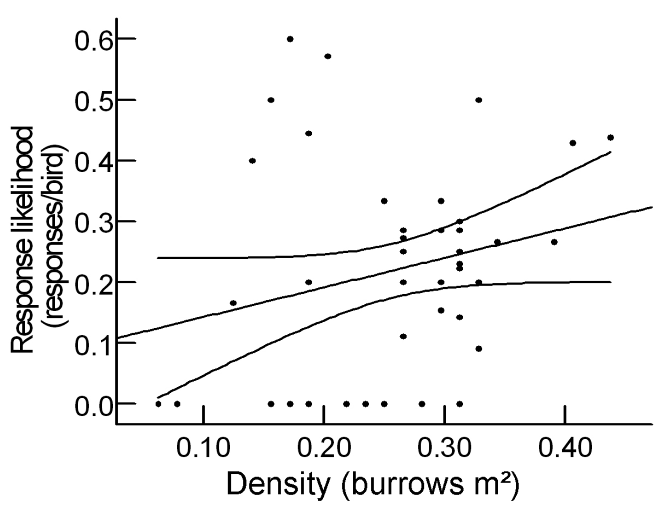

Fig. 2. Relationship between Atlantic Petrel response likelihood and burrow density in each quadrat, n = 43. Lines indicate the linear regression and the upper and lower 95% CI.

Activity signs appear to be of limited use among a number of petrel species (Imber *et al.* 2005, Lawton *et al.* 2006). Generally, use of activity signs is limited by the method's subjective nature; despite selecting apparently quantitative categories, classification is known to vary even among observers who have received the same training (Gaze 2000, Cuthbert & Davis 2002). Recent weather conditions, multiple burrow entrances, time since incubation changeover, stage of breeding season, or use of burrows by prospecting birds and other species may also limit the accuracy of activity signs (Waugh *et al.* 2003, Gardner-Gee *et al.* 2008). Even when signs provide a better index of occupancy (e.g. Gardner-Gee *et al.* 2008), population estimates hinge on knowing that a bird present in a burrow is a breeder, not a prospecting non-breeder. We emphasise the importance of being aware of these limitations when designing surveys of burrowing seabird species.

Studies on other procellariiforms have also reported playback response of < 34% (Hamilton 1998, Ratcliffe *et al.* 1998, Vaughan & Gibbons 1998). Response rates can vary within species (18%–70%; Ratcliffe *et al.* 1998, Vaughan & Gibbons 1998), and within individuals (Berrow 2000). The probability of a bird responding is influenced by factors including breeding condition, moon phase, and playback characteristics such as duration and volume (e.g. Ratcliffe *et al.* 1998, Berrow 2000, Burger & Lawrence 2001). Playback response may also be influenced by "priming" related to relative burrow proximity. If birds in more densely clustered burrows are primed to respond to playback, having already heard it played at adjacent burrows, playback responses should be spatially clustered. The relationship between response likelihood and burrow density seen here indicates that priming is plausible. Given the variability in seabird response rates and the many factors that influence them, it is important that all studies evaluate and account for response probability when conducting playback studies (Ratcliffe *et al.* 1998, Soanes *et al.* 2012).

There is no evidence of a change in Atlantic Petrel burrow density since long-term monitoring was initiated in 2001. While the population currently appears to be stable, our results indicate relatively high interannual variability in burrow density, despite surveys consistently taking place at the same time of year. This may be a function of the number of birds attempting to breed, or of variation in observer perceptions of what constitutes an Atlantic Petrel burrow (largely eliminated by use of a burrowscope). Burrow occupancy figures of 31%–52% are not unusual among procellariiforms: occupancy can be ≥ 70% (e.g. Cuthbert & Davis 2002, Ryan & Ronconi 2011) or as low as 21% (Waugh *et al.* 2003). However, on Gough Island, low levels of occupancy (4%–42%) are seen among several petrels (Cuthbert *et al.* 2013) that also appear to be affected by predatory House Mice (Cuthbert 2004, Wanless *et al.* 2012). It is too early to tell whether the apparent recent decrease in Atlantic Petrel burrow occupancy is due to the long-term impact of House Mice on the population or to interannual variation in this parameter: further monitoring of occupancy (using a burrowscope) is essential for the species.

Previous population estimates of Atlantic Petrels on Gough Island have ranged from > 100 000 pairs (Richardson 1984) to 1 800 000 pairs (Cuthbert 2004), with the latter being the first quantitative estimate for the species. Our updated population estimate indicates an average breeding population in the order of 900 000 pairs. However, given interannual variation in occupancy rates, the crude estimate of the species' total breeding area, and the assumption that burrow densities are similar throughout the habitat, this estimate should be treated with caution. Further work to test island-wide variance in burrow density and better mapping technology will allow this population estimate to be refined further. Our best estimate is 52% lower than the estimate of 1 800 000 pairs in 2001 (Cuthbert 2004). Despite the potential negative effects of mice on Atlantic Petrel populations, the estimated rate of decline is only ~0.7% a year (Wanless *et al.* 2012), and the lower population estimate in 2010–2012 may primarily be due to more accurate burrow occupancy estimates.

This work is broadly applicable to other studies of burrowing seabirds that use inferred methods (activity signs, playback) to assess burrow occupancy. Since reliable population assessments require robust occupancy data, it is particularly important to validate methods. In the case of Atlantic Petrel populations, future monitoring should use a burrowscope to yield the reliable, comparable data necessary to assess the long-term impact of House Mice and other factors on this endangered species.

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