Estimating the number of white-chinned petrels breeding on Antipodes Island

Introduction

White-chinned petrels (*Procellaria aequinoctialis*) nest on 8 island groups between latitudes 46°S and 55°S (ACAP 2009) in the Southern Ocean. Their total population was estimated at more than 1 million breeding pairs in 2009 (ACAP 2009), but they are frequently killed during fisheries interactions and at those few sites with trend information populations appear to be declining (ACAP 2009). They are regarded as "Vulnerable" by IUCN (Birdlife International 2018).

Until recently the size of the New Zealand populations of white-chinned petrels was unknown, but estimates of the Auckland (184,000 pairs) and Campbell Island (22,000 pairs) populations were made in 2015 (Rexer-Huber 2017) and Antipodes Island (43,000 pairs) between 2008-2011 (Thompson 2019).

Since the 2008-2011 population assessments of white-chinned petrels on Antipodes Island there have been two significant changes to the environment: extensive peat avalanches across the island and the eradication of mice (*Mus musculus*). On 6 January 2014 protracted rainfall caused peat avalanches over about 13% of the land area of Antipodes Island during which many white-chinned petrels were killed in their burrows and a large area of land was made unsuitable for nesting. In the winter of 2016 mice were eradicated from the island using aerially broadcast poison (ref). There is no direct evidence that mice have had an impact on white-chinned petrels on Antipodes Island, but elsewhere mice have been identified as significant predators of burrowing petrels (Dilley et al. 2018, Wanless et al. 2007).

In this paper we present population estimates of white-chinned petrels on Antipodes Island made during the summer of 2020-21, assess whether there has been any detectable change since 2011 and explore the possible impacts of the 2014 landslides and the 2016 mouse eradication.

Methods

To reliably estimate the size of the breeding population of white-chinned petrels requires:

1. An estimate of the area of land on the island in which petrels burrow, ideally stratified by vegetation and/or topography.
2. Estimates of the density of burrows in each of the identified strata.
3. An estimate of the proportion of the burrows that are occupied by breeding birds.

Area of land occupied by white-chinned petrels

To estimate the area of land occupied by white-chinned petrels we subtracted the published nesting distribution of grey petrels on Antipodes Island which Bell et al. (2013) found rarely co-occurred with white-chinned petrels. We also examined satellite imagery of Antipodes Island and divided the island into habitat classes based on vegetation and topography types recognisable on the images and which we thought were associated with different white-chinned petrel burrow densities.

We corrected the areas of habitat classes identifiable on the satellite imagery for slope using a digital elevation model derived from the contour map (LINZ ???).

Burrow density

We estimated burrow density along 20m long distance sampling (Buckland et al. 1993) transects. Transects were placed along predetermined "routes" chosen to sample representative white-chinned petrel habitat. Transect starting points along the routes were randomised by starting transects at predetermined intervals along the routes (either 20, 30 or 40m).

Transect lengths were measured accurately with a fibreglass tape, and burrow distance from the transects was measured using 1m long poles and distances or parts of distances less than 1m were estimated to the nearest 10cm.

White-chinned petrel burrows were distinguished from those of white-headed petrels using the following features:

1. Size.
2. Shape of entrance.
3. Presence of white (white-headed petrels) or grey (white-chinned petrel) feathers.
4. Wet burrows.

The burrow occupancy analysis was undertaken before assessing burrow density and during this work we became familiar with the differences between the burrows of the two species.

The dominant vegetation on each transect was classified into the same 10 classes used in previous estimates of white-chinned petrel abundance (Sommer et al. 2008).

Burrow occupancy

Burrow occupancy can be assessed reliably by digging into burrows or more quickly and less destructively using a burrow scope or by listening for responses to played-back calls. Burrow occupancy is estimated by dividing the number of burrows in which birds are found by the number of burrows inspected, but some burrows are too long, too crooked or too full or water and/or mud to be usefully assessed with a burrow scope and some birds don't respond to recorded calls.

There is no obvious simple correction for burrow occupancy assessed using playback, but burrow occupancy assessed using a burrow scope has sometimes been "corrected" by dividing the number of occupied burrows by the number of "scopeable" burrows – that is all burrows inspected minus those which the burrow scope operator judged could not be assessed (most often because the burrow was too long). This practice assumes that un-scopeable burrows have the same occupancy as scopeable ones. We could not make this assumption with the data we collected. Although we did not measure burrow length it was obvious that in short burrows, we could confidently identify both "occupied" and "unoccupied" burrows. In contrast in long burrows we were less confident, and long burrows in which birds were detected were judged "occupied", while long burrows in which we did not detect birds were mostly judged "unscopeable". We could not ignore unscopeable burrows without biasing our estimate of burrow occupancy.

To overcome this problem, we used a combination of both playback and burrowscope on 309 burrows and used this data to produce unbiased estimates of the efficiency of these tools and burrow occupancy

We estimated these three parameters by assuming that the likelihood of detecting a bird was related to burrow occupancy, and detection efficiency by:
When a bird is detected

$$likelihood = \beta_{bo} \times \left({\beta_{pb}}^{pb} \times \left(1-\beta_{pb}\right)^{1-pb}\right)^{pbused} \times \left({\beta_{bs}}^{bs} \times (1-\beta_{bs})^{1-bs}\right)^{bsused}$$

When no bird is detected

$$likelihood = 1-\beta_{bo} + \beta_{bo} \times \left(1-\beta_{pb}\right)^{pbused} \times (1-\beta_{bs})^{bsused}$$

Where
β_{bo} = burrow occupancy
β_{pb} = the efficiency of playback for detecting occupied burrows
β_{bs} = the efficiency of burrow scoping for detecting occupied burrows
pb = 1 when a bird is detected with playback and
= 0 when no bird is detected
bs = 1 when a bird is detected with burrow scope and
= 0 when no bird is detected
pbused = 1 when playback is used to detect birds and
= 0 when playback is not used
bsused = 1 when a burrow scope is used to detect birds and
= 0 when a burrow scope is not used

We estimated the parameters β_{bo}, β_{pb} and β_{bs} by maximising the product of these likelihoods using the function "optim" in program R and estimated standard errors from the hessian.

We sampled burrow occupancy on 21–23 Dec 2020 in 3 study blocks in which occupancy had previously (Thompson 2019) been assessed, and on 26, 27, 31 Dec 2020 and 2 Jan 2021 along walking transects through country we judged representative of the whole island. We found burrows using the same rules used for the distance sampling estimates of burrow density, i.e., we examined only burrows we could see from the transects. The burrow occupancy checks were timed to occur soon after laying was complete (Sommer et al 2010) to minimize chances of missing pairs who failed early.

To estimate the proportion of birds occupying burrows that were breeding (as opposed to loafing) we classified all the birds seen by burrow scope as loafers if they were moving around and not sitting on an egg of if there was more than one bird in the burrow. Birds seen sitting on eggs, or obvious nests were classed as breeders.

Impact of slips

To assess the likely impact of the 2014 landslides on the Antipodes Island white-chinned petrel population we compared our estimate of the current population with what it might have been had the landslips not occurred. To do this we assumed that all the slipped land would have supported white-chinned petrels at the same density they occurred elsewhere in that habitat type.

Results

Area of land occupied by white-chinned petrels

The planar area of Antipodes Island is 2025 ha, but when corrected for slope is about 2212ha.

Our estimate of the area of land (corrected for slope) occupied by white chinned petrels (Fig. 1):

1. Excluded 716ha that was occupied by grey petrels (*Procellaria cinerea*) and which white-chinned petrels did not use (Bell et al. 2013).
2. Excluded 99ha seaward of the "grey petrel" country which comprised cliffs, coastal rocks, and penguin colonies.
3. Excluded 125ha of dense *Polystichum vestitum* fern which both we and Thompson (2019) found did not support white-chinned petrels. These stands were identified from satellite imagery and appear mostly to occur on old slips and in watercourses.
4. Excluded 112ha of old slips on which there was little or no *Polystichum vestitum* and there was insufficient vegetation and soil for petrels to burrow. Most of these slips occurred before 1995 – the earliest satellite photographs available on Google Earth.
5. Excluded 295ha affected by 2014 slips. We identified the area of slipped land from satellite imagery (source?????).
6. Excluded areas dominated by *Carex ternaria* (Fig. 2). There is about 59 ha of raised peat bogs which are dominated by *Carex ternaria* and have a smoother surface than most of the rest of the island's vegetation. During our assessment of burrow-density we found no white-chinned petrel burrows in this vegetation type *Carex ternaria* dominated vegetation was identifiable from satellite imagery.
7. Included 8.04 ha of high altitude herbfields (Fig. 2) which are smooth like the *Carex ternaria* dominated vegetation, but which are dominated by the megaherbs *Pleurophyllum criniferum* and *Anisotome antipoda* in which white-chinned petrels burrow. High altitude herb fields were identifiable on satellite imagery.

Although we distinguished 10 vegetation classes on the ground, we were unable to confidently identify vegetation classes other than *Carex ternaria* dominated vegetation and high altitude herbfields from the satellite imagery.

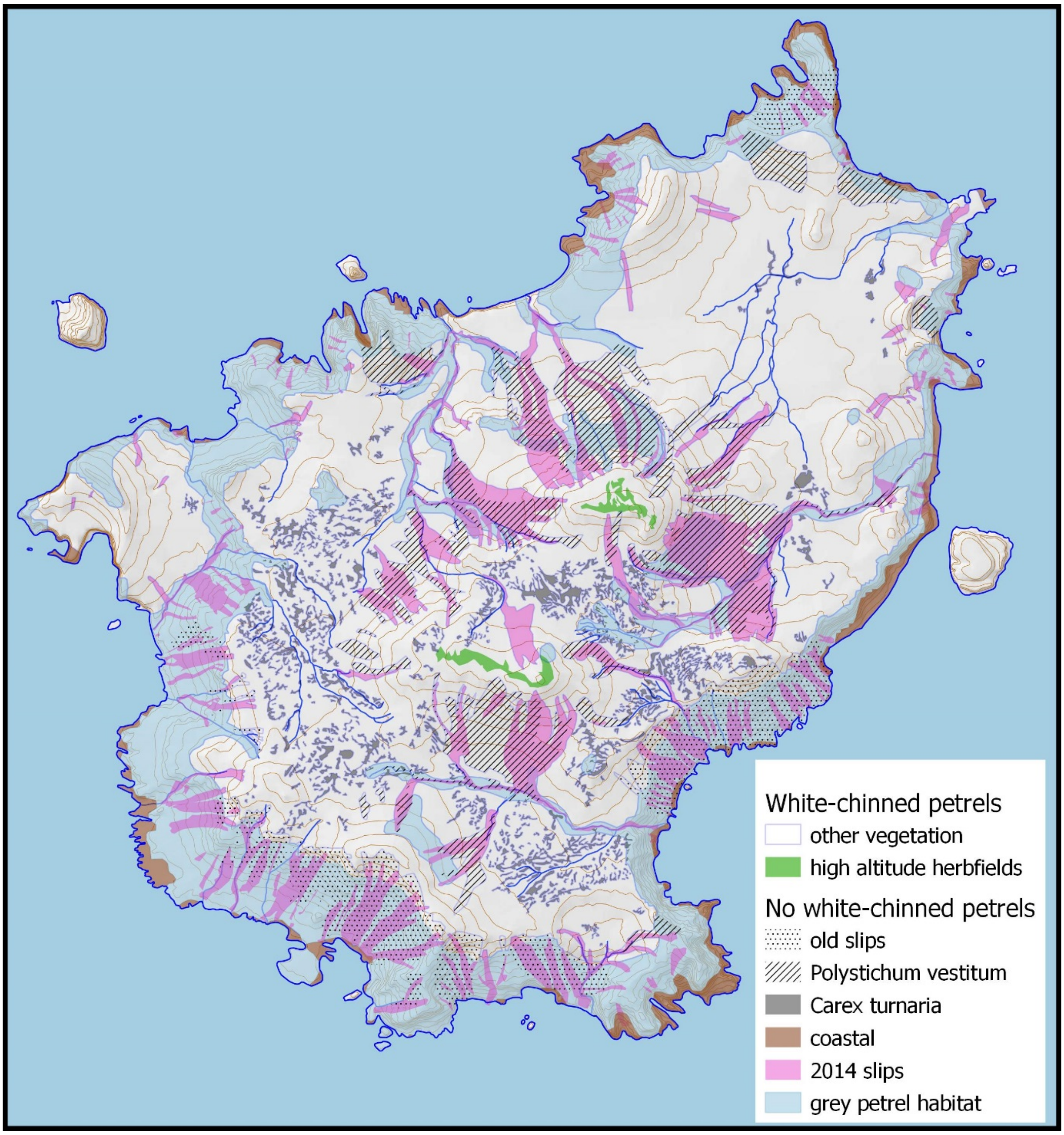

Figure 1. Areas with and without white-chinned petrel burrows on Antipodes Island.

Figure 1 shows the two identifiable vegetation strata in which white-chinned petrels burrows were found and the areas in which we assumed no white-chinned petrels nested. When corrected for slope white chinned petrel habitat covered 1073.5 ha including 8.04ha of high altitude herbfield. Most of the white-chinned nesting country was relatively flat so the slope correction increased the estimated land area by only 1.2% for high altitude herbfield and 2.9% for the rest of the white-chinned petrel habitat.

Burrow density

Burrow density was assessed along 155 transects in mid-late Jan 2021 (Fig 2).

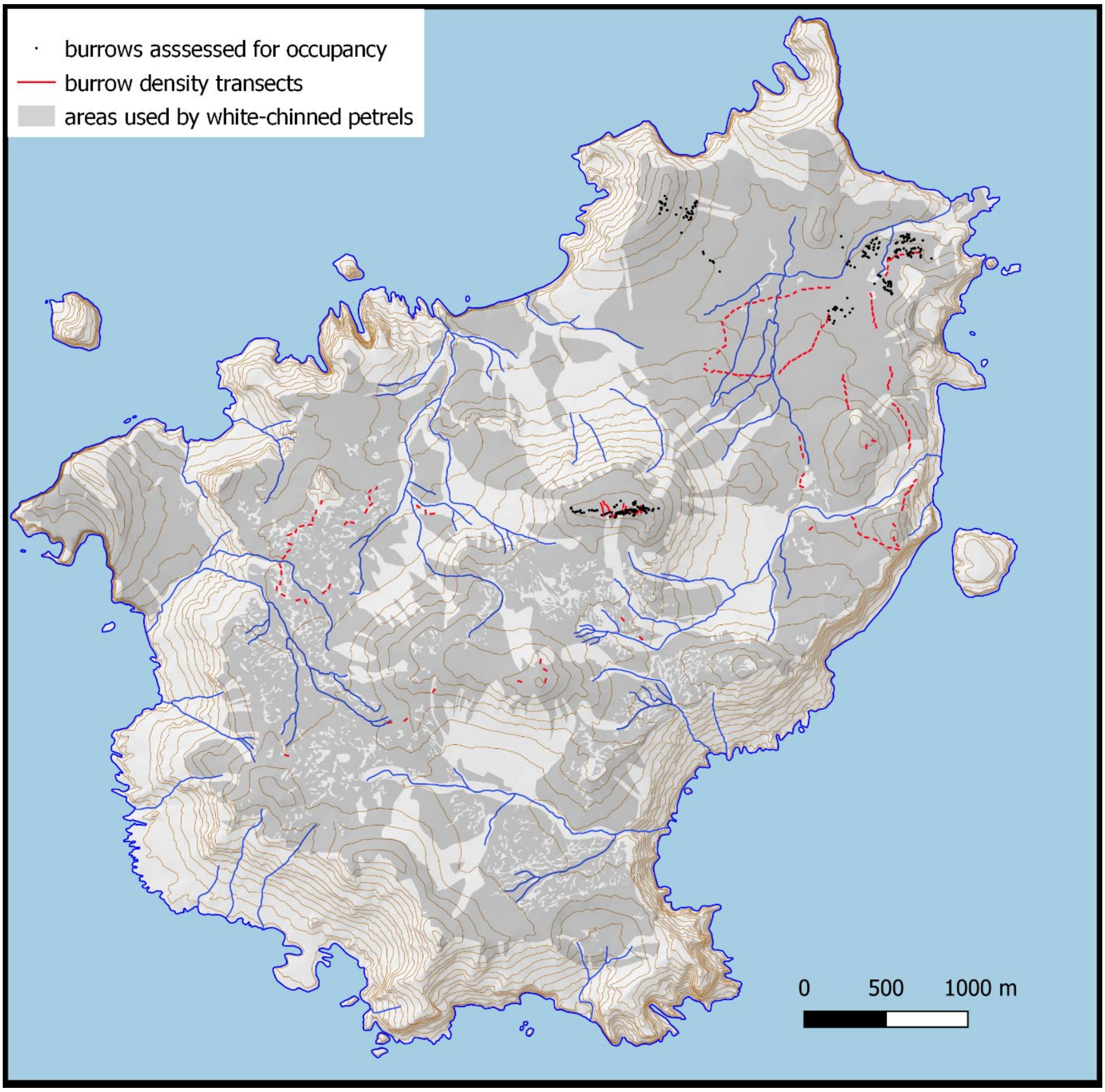

Figure 2. Burrows assessed for occupancy of white-chinned petrels, and distance sampling transects used to assess burrow density.

The best and most plausible detection function identified by distance sampling was half normal with cosine(2) adjustments (Miller et al. 2019). Burrows were detected up to 14m from the transects and the distance sampling model estimated that we detected 26% of the burrows within this distance.

Although we classified the burrow density transects into 10 vegetation classes, only 2 (high altitude herbfield and *Carex ternaria* dominated vegetation) were identifiable from satellite imagery, so we reduced the classification to 3 classes (high altitude herbfield, *Carex ternaria* and all the rest). We found no white-chinned petrel burrows in *Carex ternaria* dominated vegetation, and burrow density in high altitude herbfield was higher than in the remaining white-chinned petrel habitat (Table 1).

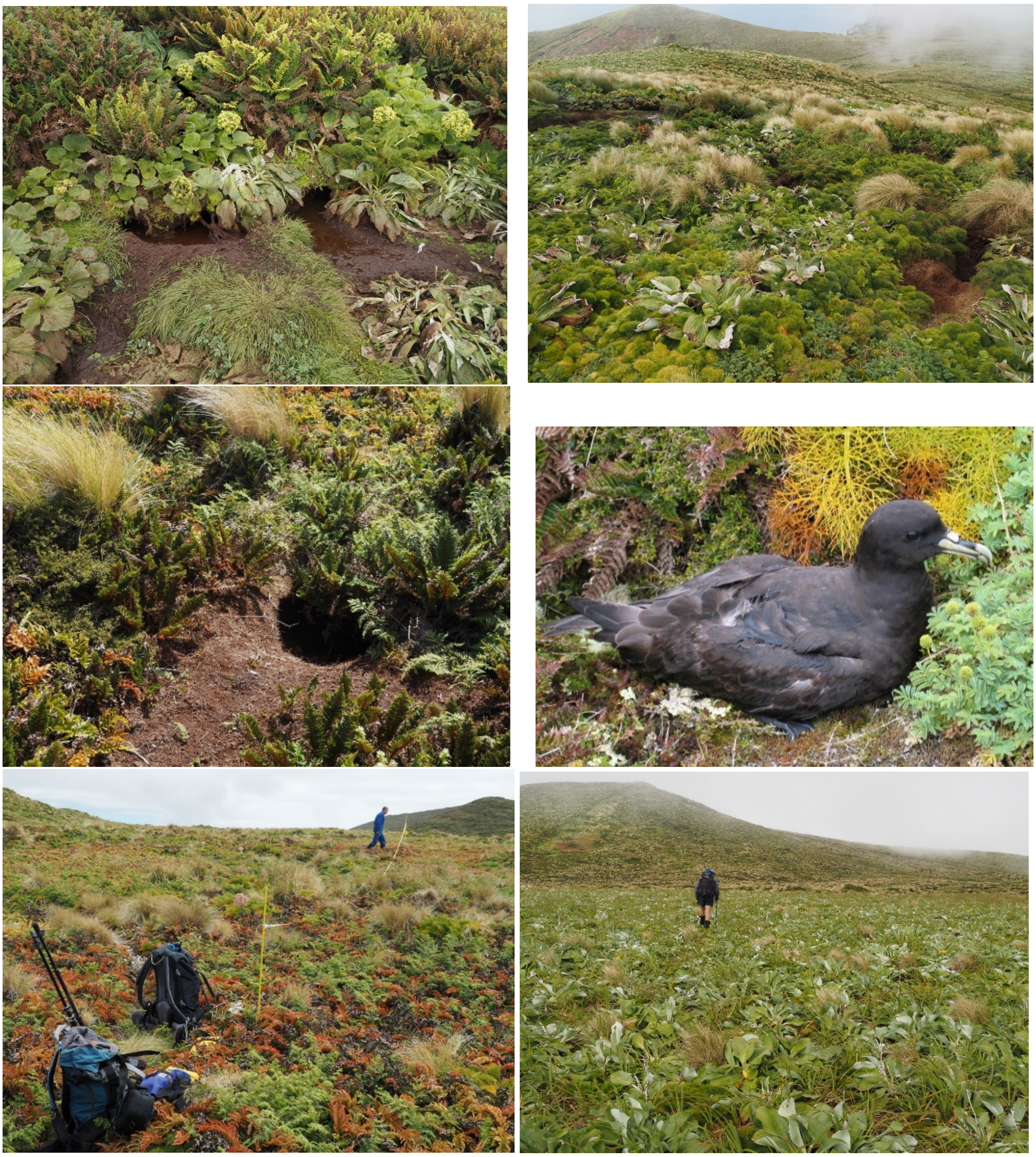

Figure 2. Differing environments on Antipodes I searched for white chinned petrel burrows: (top) soft wet soils supporting megaherbs on the summit of Mt Galloway densely burrowed by WCP (middle) a large open burrow with conspicuous dry "apron" more typical of the WCP burrows on Antipodes I (bottom left) 20 m long distance sampling transect on the North Plains where WCP burrows occur wherever there is a small mound (bottom right) raised peat wetland on Central Plateau dominated by *Carex ternaria* and megaherbs. WCP burrows are absent in these flat "clears".

Table 1. Burrow density of white-chinned petrels in two vegetation types on Antipodes Island.

Veg class	Density	Se	area	Est number of burrows	Standard error
High altitude herbfield	231	59	8.0	1860	478
Other	86	11	1065.5	91762	11324
Total	87	11	1073.5	93623	11382

Burrow occupancy

Figure 2 shows the locations of burrows at which occupancy was assessed and Table 2 details the burrow occupancy tools used and outcome at all 309 burrows examined.

Table 2.White-chinned petrel burrows examined to determine occupancy.

		Burrow scope		
		Not used	No birds detected	Birds detected
Playback	Not used	0	36	11
	No birds detected	76	39	15
	Birds detected	82	10	39

Estimated burrow occupancy as well as the efficiency of playback and burrow scope at detecting occupied burrows are shown in Table 3.

Table 3. Estimated occupancy and the efficiency of playback and burrow scope at identifying occupied nests at 309 nests.

Parameter	Estimate	Standard error
Burrow occupancy	0.636	0.033
Playback detection efficiency	0.758	0.036
Burrow scope detection efficiency	0.712	0.047

Amongst the 65 burrows in which we detected birds with a burrow scope we judged 60 (92.7%) of them to be nesting rather than loafing (binomial standard error = 3.3%).

Applying this proportion to our estimate of occupancy we estimate breeding bird occupancy to be 58.7% (standard error = 3.7% using parametric bootstrap).

Population size

Combining the area of land occupied by white-chinned petrels, with burrow density and breeding occupancy leads to an estimate of 54957 breeding pairs (Table 3), and when this is compared with earlier counts suggests there has been 27% increase between 2011 and 2021 (Table 4) and this increase is nearly significant (Anova, F = 10.74 df = 1,2 p = 0.08).

Table 4.Burrow density, burrow occupancy and estimated breeding population size of white-chinned petrels on Antipodes Island during 4 summers.

	Burrow Density ha^{-1} (mean ± sd)	Burrow Occupancy % (mean ± sd)	Population Estimate	se	95% CI
2008–09	177.7 ± 144.4	19.2 ± 18.0	45135	6723	31957 - 58313
2009–10	115.3 ± 63.0	27.8 ± 15.8	44924	9979	25366 - 64482
2010–11	133.3 ± 76.0	24.7 ± 20.5	39670	7895	24195 - 55145
2020-21	87	58.7	54945	8458	38379 - 71535

Impact of slips

Although the area of slipped land (295ha) comprised 13% of the island's surface area, it affected only 5.4% of the land white-chinned petrels burrow in and destroyed only 5.2% of the burrows. Much of the land that slipped in 2014 was used by grey but not white-chinned petrels, was recovering from previous slips and still did not support white-chinned petrels, or it was covered in dense *Polystichum vestitum* which was also not used by white-chinned petrels.

The slips would have destroyed all the eggs and small chicks in burrows at the time and thus reduced productivity that year by 5.2%. Many incubating adults were also killed, comprising up to 2.6% of the breeding population.

The impact of slips is likely to have been greater on grey petrels as 21 % of their habitat was lost to slips, though they were not in their burrows when the slips occurred.

Discussion

Five differences in the methods used to estimate white-chinned petrel population size between 2008-2011 and 2021 might have confounded estimates of population change:

1. Burrow density in 2008-2011 was estimated by rigorously searching a series of 10 x 10m plots, whereas in 2020-21 we used distance sampling protocols and only counted burrows that could be seen from transect lines. Occupied and recently active burrows are easy to find as they have an area of recently excavated soil or mud at the burrow entrance or an area of clear ground caused by birds coming and going, whereas at older unused burrows any clear ground, as well as the burrow entrance, is usually overgrown. Distance sampling searches detect only obvious recently active burrows, whereas 10 x 10m plot searches will also detect old unused burrows. One would expect 10x10m plots to produce higher estimates of burrow density than distance sampling transects.
2. Burrow occupancy was assessed in 2008-2011 by inspecting burrows found in 10x10 plots whereas we examined burrows found along distance sampling transects. Since the burrows found in 10x10m plots include many more old unoccupied burrows, burrow occupancy measured in 10x10m plots will be lower than assessed along distance sampling transects.
3. We "corrected" burrow occupancy by combining play playback and burrowscope to estimate the proportion of occupied burrows that neither method detected, whereas in 2008-11 burrow occupancy was "corrected" by excluding burrows which the burrowscope operator

judged “unscopeable”. We have argued that excluding unscopeable burrows will lead to an over-estimate of burrow occupancy.

4. Thompson (2019) estimated population size by multiplying the burrow density and occupancy by the area occupied by white-chinned petrels, and he assumed, like we did, that white-chinned petrels do not nest in dense *Polystichum* nor where grey petrels nest. Thompson used the same area of grey petrel nesting habitat that we used (from Bell et al. 2013) but his estimate of the area of dense *Polystichum* fern was derived from Land Information New Zealand’s 1:50,000 digital map of Antipodes which is turn derived from a map published in 1972. Our areas of *Polystichum* vegetation were digitised from satellite imagery from 2015.
5. We excluded burrow density transects through areas dominated by *Carex ternaria* from our, burrow density estimates as we found no burrows in this vegetation. We also excluded areas dominated by *Carex ternaria* from our estimate of the area of land occupied by white-chinned petrels.

In an attempt to account for these differences in methodology we recalculated burrow occupancy for the 2020-21 data using the same rules used in 2008-11, i.e., we used only the burrowscoped burrows and excluded “unscopeable” burrows from estimates of burrow occupancy. We also reanalysed our burrow density transects after including transects through vegetation dominated by *Carex ternaria,* and we compared the product of burrow density and burrow occupancy (occupied burrow density) in 2008-2011 and 2020-21 without regard to the area of land that might be occupied by white-chinned petrels (Table 5).

Table 5. Occupied burrow density of white-chinned petrels on Antipodes Island estimated using comparable methodology.

	Burrow Density ha^{-1} (mean ± sd)	Burrow Occupancy % (mean ± sd)	Occupied burrow density
2008–09	177.7 ± 144.4	19.2 ± 18.0	34.1
2009–10	115.3 ± 63.0	27.8 ± 15.8	32.1
2010–11	133.3 ± 76.0	24.7 ± 20.5	32.9
2020-21	83.1	58.25	48.4

This analysis suggests there was a 46.5% increase in burrow density between 2008-11 and 2020-21 and a simple analysis of variance suggests this difference is significant (F = 174.377 df = 1,2 p=0.006). This difference is greater than difference between the population size estimates (Table 4) primarily because the density estimates are not confounded by differences between the two studies in the amount of land judged unsuitable for white-chinned petrels.

We conclude that there were approximately 55,000 pairs of white-chinned petrels nesting on Antipodes Island in 2020-21 and that this about 46.5% more than in 2008-11. This increase results from a dramatic increase in occupied burrow density and a small decrease (5.2%) in land occupied by white-chinned petrels.

Other conclusions about methodology include:

1. apparent changes in burrow density and occupancy between 2008-11 and 2020-21 are mostly artefacts of methodology, but
2. changes in the density of occupied burrows reflect real change.

3. burrow occupancy estimated by excluding "unscopeable" burrows, produces a very similar occupancy estimate to that estimated by combining playback and burrowscoping.
4. burrow density estimated using distance sampling transects is easier and quicker than 10x 10m plots and enables estimates of burrow density to be based on larger samples of burrows.

Why has the white-chinned petrel population changed?

Clearly the landslides of 2014 had little effect on white-chinned petrels as their population increased substantially despite the area of useable land decreasing by about 5.4%, and approximately 2.6% of the breeding birds being killed.

Perhaps the increase in white-chinned petrels is attributable to the eradication of mice from Antipodes Island. There is good evidence that mice have reduced the abundance of burrow nesting petrels on Gough (Refs?) and Marion Islands (Refs?), and that they also threaten the survival of albatrosses on Gough by eating their chicks (Refs?). Unfortunately however, we have no measure of rates of mouse predation of white-chinned petrels and nesting success before and after the mouse eradication. We cannot conclude that the increase we observed in white-chinned petrel abundance was caused by the eradication of mice, only that it was coincident with it.

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