White-chinned petrel population estimate, Disappointment Island (Auckland Islands)

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Summary

White-chinned petrels *Procellaria aequinoctialis* are one of the seabird species most affected by fisheries bycatch, yet some populations remain virtually unstudied. The size of the breeding population on the Auckland Islands, New Zealand, is unknown. We estimated the population size of white-chinned petrels on Disappointment Island, thought to be a key breeding site in the Auckland Islands, taking into account the detection probability of burrows via distance sampling and burrow occupancy. Eighty line transects were distributed over the island, with a total line length of 1 600 m. White-chinned petrel burrows occurred at a density of 644 (95% confidence intervals: 487–850) burrows/ha, with an overall burrow detection probability of 0.33 ± 0.03. We document an estimated total of 153 100 (115 900–202 200) breeding pairs of white-chinned petrels on Disappointment Island in mid incubation.

Introduction

White-chinned petrels *Procellaria aequinoctialis* breed at a number of sites around the Southern Ocean. In the Pacific sector, they breed on the subantarctic Auckland, Antipodes and Campbell groups. Very little is known about any aspect of these white-chinned petrel populations. Taylor (2000) suggested that the Auckland and Antipodes Islands may each support around 100 000 pairs, although these figures should be considered intuitive guesses. An initial quantitative estimate from Antipodes Island indicated that the breeding population was more likely to be 25 000–30 000 pairs (Sommer et al. 2010), considerably fewer than previously suggested. There has been no systematic estimate of the breeding population at any of the Auckland Islands.

White-chinned petrels are currently classed as 'vulnerable' by the IUCN (BirdLife International 2012), although there is ongoing discussion around whether this should be uplisted to 'endangered' (e.g., ACAP 2013). In New Zealand, white-chinned petrels are classed as 'at risk – declining' (Robertson et al. 2013), although it is unclear on what basis this assessment was made given the paucity of population data and therefore the complete lack of trend data for this species within New Zealand.

Importantly, white-chinned petrels remain a major component of commercial fisheries bycatch both globally and within New Zealand's EEZ (Bell 2014; BirdLife International 2014). Further, a risk assessment process that ranks New Zealand seabirds in terms of their risk from fisheries (Richard and Abraham 2013), which is used to inform mitigation of the effects of commercial fishing, is underpinned by the kind of population data that are currently completely lacking for white-chinned petrels at the Auckland Islands.

There is a clear need to quantify the population size of white-chinned petrels in the Auckland Islands, establishing a baseline for future monitoring and allowing the effects of current levels of fisheries bycatch within New Zealand's EEZ to be fully evaluated. Here, our aim was to estimate the breeding population of white-chinned petrels at Disappointment Island, which is thought to be the main breeding site in the Auckland Islands.

Methods

Disappointment Island lies 8 km off the western cliffs of main Auckland Island (50°45'S, 165°00'E), an island group 465 km south of New Zealand (Fig. 1). The island has a planar map area of ~330 ha and is well vegetated. The vegetation community is dominated by the tussocks *Poa foliosa* and *Poa litorosa*, and the megaherb *Anisotome latifolia*. Trees are almost entirely absent, with the exception of one small area of *Hebe elliptica*. Survey on Disappointment Island was conducted 1–11 January 2015 during the incubation period, six weeks after the expected time of peak laying 22 November (Hall 1987).

Strata and randomisation. Sampling site locations were randomised in ArcGIS to ensure representative sampling, using the Auckland Islands island polygon layer (Topo50 series, Land Information New Zealand). High-resolution photography of Disappointment Island (G.B. Baker 2014) was first inspected for habitat patterns to inform stratum boundaries. The strata were defined by vegetation and aspect: high-density white-chinned petrel aggregations were expected in areas where megaherbs and *Poa foliosa* appeared to be dominant, followed by south-facing slopes. This was based on previous fieldwork at Adams Island, the southernmost of the Auckland Islands group. Moderate densities of white-chinned petrels were expected in other, *Poa litorosa*-dominated regions (moderate-density stratum). A sampling goal of 120 points was generated at a minimum separation of 50 m; 70 random points in the high density stratum and 50 points in the moderate density stratum. A surplus of points was generated in the expectation that cliffs and bluffs would make some points unsafe to access.

Distance sampling. Burrow densities and their variances were estimated with line-transect distance sampling, which uses the distance between burrow and line to correct for detectability decreasing with distance (Buckland et al. 2001). Random start points were found using GPS and map. At each start point, a 20 m transect was marked using a tape measure run directly downhill (perpendicular to the contours). Note that transect length was decided using trials starting at length 50 m, but where white-chinned petrels were present 20 m was long enough to detect burrows. Any random point that could not be safely accessed was excluded. Points where part of the transect would fall off the cliff were moved uphill until the entire transect could be accessed safely.

Transect features recorded were: aspect (e.g., WNW), slope (using a clinometer, Silva and Suunto, to nearest degree), dominant vegetation species (in descending order of dominance if >1 species), substrate moisture (scale 1–3 from dry and well-drained to saturated where pressure brings water to surface), whether the substrate was rocky, and whether white-capped albatrosses *Thalassarche steadi* were nesting at the site. Each transect was then searched thoroughly, moving uphill and looking for burrows under vegetation on the line and in both directions. White-chinned petrel burrows were identified by their size and their entrance moat. Burrows of other species were markedly different from white-chinned petrel burrows, being smaller and dryer. Any white-chinned petrel burrow seen from the line was marked by GPS and its distance to the line measured, using a pre-marked walking pole or tape measure to measure from the center of the burrow entrance to the line. Burrows seen only when away from the line (e.g., while measuring distance) were not counted, to ensure burrow detections were independent events. To minimise observer bias in burrow detections and distance measurement, four transects at the start and five transects at the end were checked by all three and by two observers, respectively

The three major assumptions of distance sampling are that (i) objects on the line are always detected; (ii) objects are detected at their initial location; and (iii) measurements are exact (Buckland et al. 2001). To test the assumption that burrows on the line are always detected, a sample of five transects were examined by paired observers. The first observer detected burrows and indicated their positions to the second observer. The second observer recorded whether any additional burrows occurred on the line. No additional burrows were found by the second observer, so we consider the probability of detection on the line $g(0)=1$. Since burrows are immobile, the second assumption was fulfilled. The third assumption can be considered satisfied since we measured distance to ±5 cm and burrows were detected >5 m away.

Burrow occupancy. Burrow occupancy was assessed at four sites within an area known to contain white-chinned petrels. Burrow occupancy sites were randomised using a random numbers table to obtain a bearing on which to move 100 paces, initially from the first burrow density transect, then from the latest site. At each random site, all burrows in the nearest cluster of entrances were checked using a burrowscope (Sextant Technologies, Wellington), ensuring that the burrow was thoroughly inspected. We recorded whether or not the burrow was occupied, and if occupied, whether the bird was incubating or 'loafing' (bird present without an egg). Burrows with loafers and empty burrows were checked for signs of a failed breeding attempt, particularly egg fragments. Some burrows which superficially appeared to be white-chinned petrel proved to be erosion cavities or old collapses, so we recorded these as entrance-not-burrow (ENB). One worker conducted all burrowscoping to avoid introducing observer bias. White-chinned petrel burrows are relatively large and can be inspected fully, with confidence that an occupant will be detected, so it was considered unnecessary to quantify occupant detection rates. To avoid introducing a detection bias, we recorded the few cases where a burrow could not be fully inspected ('unscopable') and excluded these from occupancy estimates.

Estimation of area. Planar surface area was calculated in ArcGIS from the Disappointment Island polygon and from polygons delineating high- and moderate-density strata. Slope-corrected surface areas were calculated as follows: isocline polygons were drawn around areas of similar slope after mapping n=80 slope measurements, and the planar/map area ap_i of each isocline i recorded. The total surface area A was calculated as:

$$A = \sum as_i$$

where:

$$as_i = ap_i \times (\sec(\theta_i))$$

and as_i is the slope-corrected area of each isocline, and θ_i is the mean angle of the slopes within each isocline. This slope correction does not account for the surface area of cliffs (~100 m high around the 16.5 km of coast) since the cliffs are mostly bare rock, unsuitable for burrowing petrels.

Analyses. Datasets were examined for observer effects and pooled since burrow detection rates did not differ. Data were checked for normality, then analyses of burrow counts among different vegetation types conducted using Kruskal-Wallis analysis of variance (ANOVA). Burrow densities were estimated in program Distance 6.2 (Thomas et al. 2010). We estimated burrow density for Disappointment Island as a whole and by stratum (high- and moderate expected density areas, 51 and 29 transects respectively). Histograms were inspected for heaping, and outliers truncated to improve model fit (Buckland et al. 2001). The probability of burrow detection was estimated with models using parametric key functions (uniform, half-normal and hazard-rate) and adjustment terms (cosine, simple polynomial and hermite polynomial). Each model's fit to the perpendicular distances was assessed by quantile-quantile plots, Kolmogorov-Smirnov and chi-square goodness-of-fit statistics, and only included if the detection probability coefficient of variation was <20% (Buckland et al. 2001). The model with the lowest Akaike's Information Criterion (AIC) value was selected for each stratum and globally (Burnham and Anderson 2002). Uncorrelated environmental covariates were added singly to the lowest-AIC model using the multiple-covariate distance sampling engine, followed by forward stepwise selection until AIC values no longer decreased (Marques et al. 2007). Analytic variance estimates were calculated based on Poisson-distributed encounter rate observations with an overdispersion factor of 3. Standard errors SE and 95% log-normal confidence intervals CI are given for density estimates.

For burrow occupancy analysis, burrows that could not be inspected in their entirety (unscopable) were first discarded. One burrow containing a bird with a broken egg was included in the breeding bird total. A correction factor (b) to account for entrances that did not lead to a burrow (ENB) was calculated by dividing the number of fully-inspected burrows by the inverse of ENB. Burrow occupancy was then calculated as the number of fully-inspected burrows with ENB subtracted, divided by the number that contained breeding birds.

An estimate of the number of white-chinned petrel burrows was calculated as:

$$\widehat{N}_{burr} = \widehat{D} \times A \times b$$

where $\widehat{N}_{burr}$ is the estimated number of white-chinned petrel burrows, $\widehat{D}$ is the estimated density of burrows, A is the slope-corrected surface area, and b is the correction factor to account for entrances that did not lead to burrows (ENB). The final island-wide estimate of breeding pairs was then calculated using:

$$\widehat{N}_{pairs} = \widehat{N}_{burr} \times c$$

where $\widehat{N}_{pairs}$ is the estimated number of breeding pairs of white-chinned petrels, and c is the burrow occupancy correction factor.

Results

A total of eighty 20 m transects were visited; 51 in the high-density stratum and 29 in the moderate-density stratum (Table 1). White-chinned petrel burrows were found along 35% of transects and were distributed primarily on the southern part of the island (Fig. 1). A mean of eight burrows (range 1–24) were detected along the 28 transects where white-chinned petrels were found. The abundance of white-chinned petrel burrows differed significantly between vegetation classes (Kruskal-Wallis, χ^2_4=19.6, p<0.001). Burrows were more abundant in areas with megaherbs (particularly *Anistome latifolia*) and *Poa foliosa* tussocks, and rare or absent in *Poa litorosa* tussock and in areas of snow tussock *Chionochloa antarctica* and the woody shrubs *Cassinia* and *Myrsine* spp. (Table 2). Burrow detection probabilities (±SE) were lower than one, at 0.33±0.03 (Table 3).

Table 1. Physical features of zones surveyed by line transects for white-chinned petrel burrows on Disappointment Island, January 2015

	planar area ha	surface area ha	slope mean (range) °	transects	burrows
Global (unstratified)	332.3	395.4	27 (2–50)	80	229
High-density	93.6	111.4	31 (10–50)	51	189
Low-density	238.7	284.0	20 (2–45)	29	40

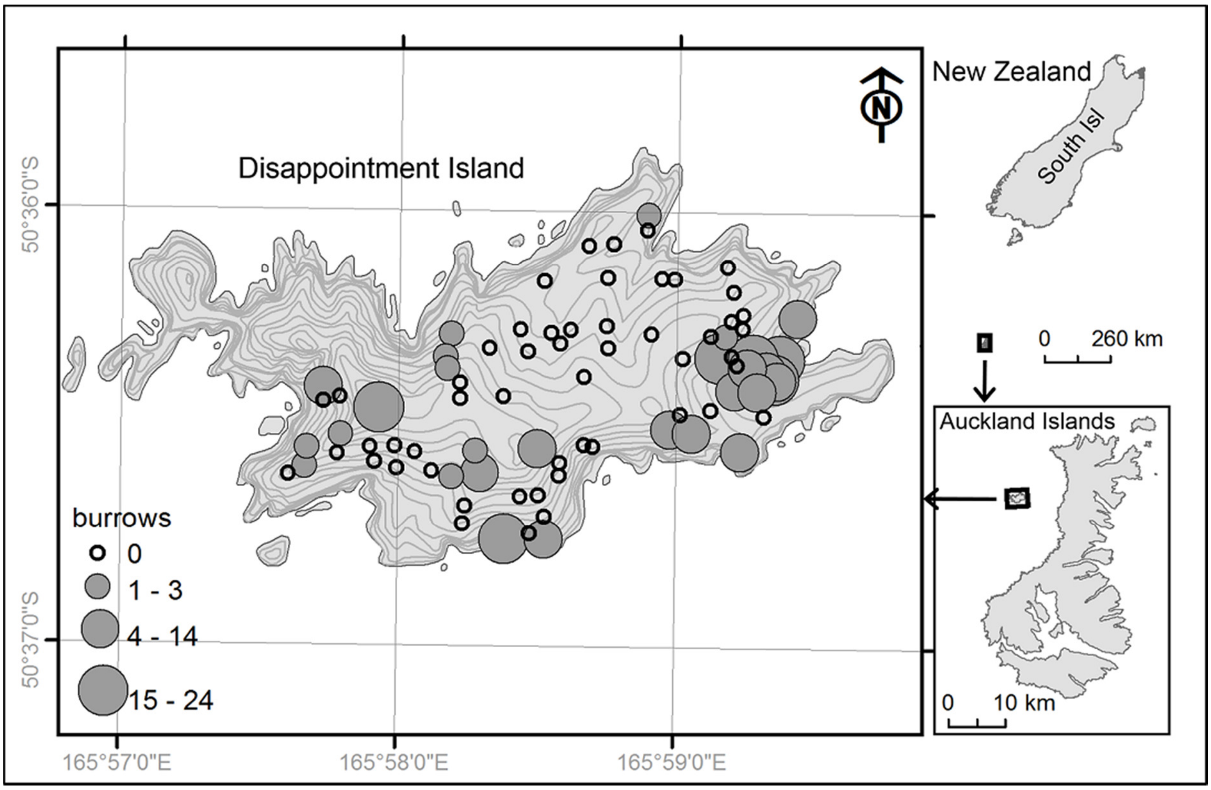

Figure 1. The Auckland Islands, New Zealand, showing white-chinned petrel burrow distribution on Disappointment Island. Burrow numbers along each line transect are indicated by the size of the point. Scale 1:30 000.

Table 2. Mean number of white-chinned petrel burrows per transect in different habitats

Habitat	mean	SE	n
Megaherbs	5.88	1.87	16
Poa foliosa	4.88	1.40	24
Low open	0.83	0.61	12
Poa litorosa	0.32	0.20	22
Snow tuss scrub	-	-	6

Megaherbs, dominated by *Anisotome latifolia*; Low open, dominated by *Acaena* or *Leptinella* spp.; Snow tuss scrub, *Chionochloa antarctica* with woody shrubs *Cassinia* and *Myrsine* spp.

Distance sampling. Several competing models used to estimate burrow density were compared for each stratum and globally (Table 3); the best-fitting detection function for each case is shown with associated detection probability histograms in Fig. 2. Although 'vegetation' and 'rocky' covariates improved AIC, the shape of the detection functions differed among levels of each factor, violating a key assumption of the method (that covariates only affect the scale parameter). The global density estimate had tighter variance parameters than did summed strata (Table 3), so the best-fitting global model (hazard-rate with polynomial adjustment) was selected, giving burrow densities of 643.6 (487.2–850.1) burrows/ha (Table 3).

Burrow occupancy. Of 158 burrows that could be inspected fully (n=5 discarded as unscopable), 131 proved to be white-chinned petrel burrows while 27 had an entrance that did not lead to a burrow (ENB), being washed-out or collapsed. The correction factor b (proportion of the total inspected that were burrows, not ENB) was 0.8265±0.037 (mean±SE) (Table 4). The burrow occupancy rate c was 0.73±0.03, 0.04 contained birds without an egg (failed or non-breeders) (Table 4), and the ratio of empty white-chinned petrel burrows was 0.24.

Table 3. Competing models for estimating density of white-chinned petrel burrows on Disappointment Island

Area	Key function	Adj	Trunc	AIC	GOF	$\hat{p}$	SE ($\hat{p}$)	CV ($\hat{p}$)	$\hat{D}$	SE ($\hat{D}$)	95% CI ($\hat{D}$)
G	haz-rate	poly	2%	319.78	0.269	0.330	0.027	8.2	643.6	91.4	487.2–850.1
G	half-norm	cos	2%	320.76	0.111	0.323	0.019	6.0	657.5	85.6	509.2–849.0
G	uniform	cos	2%	323.07	0.044	0.332	0.018	5.5	638.2	81.8	496.3–820.7
HD	haz-rate	poly	4m	240.71	0.928	0.255	0.025	9.7	907.7	144.0	665.0–1238.9
HD	half-norm	cos	4m	242.06	0.959	0.240	0.020	8.4	964.6	145.8	717.2–1297.5
HD	uniform	cos	4m	245.35	0.594	0.278	0.014	5.1	833.0	106.1	596.7–1018.2
MD	half-norm	cos	10%	412.39	0.347	0.409	0.074	17.8	210.7	71.7	107.6–412.7
MD	haz-rate	poly	10%	412.37	0.330	0.420	0.128	30.6	205.5	86.4	90.5–466.4
MD	uniform	cos	10%	413.10	0.256	0.575	0.053	9.2	150.0	45.4	82.2–273.7

G, global; HD, high-density; MD, moderate-density; Adj, model adjustment term; Trunc, right truncation distance; AIC, Akaike's Information Criterion; GOF, detection function goodness-of-fit p value; $\hat{p}$, burrow detection probability (probability that a burrow situated between the line transect and the truncation distance is detected); SE, standard error; CV, % coefficient of variation; $\hat{D}$, estimated density burrows/ha; CI, confidence intervals.

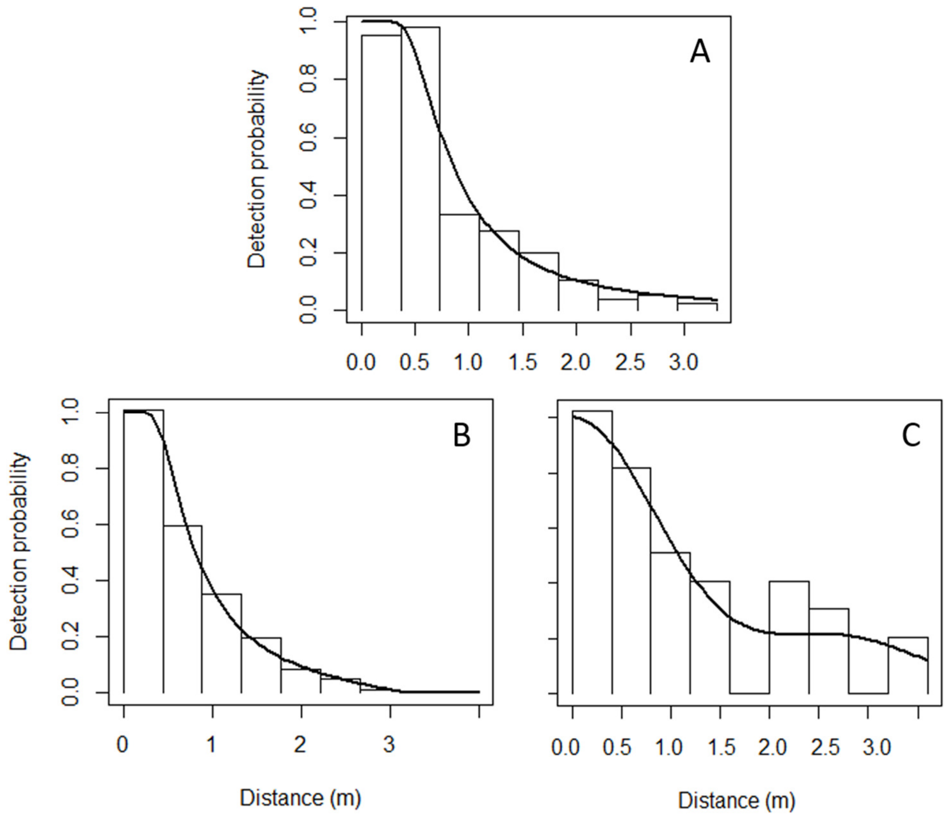

Figure 2. Estimated detection functions for white-chinned petrels, superimposed over histograms of observed distances. A: whole-island unstratified, hazard-rate with polynomial adjustment; B: high density stratum, hazard-rate with polynomial adjustment; C: moderate density stratum, half-normal with cosine adjustment.

Table 4. White-chinned petrel burrow status and occupancy, Disappointment Island, January 2015

site	inspected	ENB	burrows	*b*	occ no egg	occ incubating (*c*)
1	45	10	35	0.7778	0.0286	0.6571
2	37	8	29	0.7838	0	0.6897
3	44	3	41	0.9318	0.0488	0.8293
4	32	6	26	0.8125	0.0769	0.7308
Total	158	27	131	0.8265	0.0386	0.7267

ENB, entrance that did not lead to a burrow; burrows, the number of inspected burrows with ENB subtracted; *b*, the proportion of the total inspected that were burrows (not ENB); occ no egg, proportion of burrows containing bird without an egg; occ incubating (*c*), the proportion of burrows containing bird on egg

Breeding pair estimate. Disappointment Island had an estimated 210 600 (159 500–278 200) white-chinned petrel burrows within its 395 ha surface area, using the best-fitting global density estimate and a factor of 0.8265 to correct for entrances that did not lead to burrows. Taking into account burrow occupancy (0.7267), an estimated 153 100 (115 900–202 200) white-chinned petrel pairs were breeding on Disappointment Island in January 2015.

Discussion

The estimate of 153 000 white-chinned petrel pairs breeding on Disappointment Island suggests that the Auckland Island population is larger than was proposed by Taylor (1988). However, the New Zealand regional population size is likely to be around 200 000 pairs as suggested in 2000 (Taylor 2000), since the Antipodes Island population of ~ 23 000 breeding pairs (Sommer et al. 2010) was much smaller than previously estimated (Taylor 2000).

Our estimate of burrow density of 644 burrows/ha is an order of magnitude higher than most island-wide estimates for *Procellaria* petrels: 45 burrows/ha white-chinned petrels on Antipodes Island (Sommer et al. 2010), up to 26 active burrows/ha on Îles Kerguelen (Barbraud et al. 2009) and 62 active burrows/ha on South Georgia (Martin et al. 2009). Densities estimated from within colonies are often higher (Ryan et al. 2012; Waugh et al. 2015; but see Francis and Bell 2010), but are not comparable with randomised island-wide estimates. The burrow occupancy of 73% recorded on Disappointment Island was similar to that for white-chinned petrels on nearby Adams Island (69%, Rexer-Huber unpubl. data) and for spectacled petrels *Procellaria conspicillata* on Inaccessible Island (81%, Ryan and Ronconi 2011), but much higher than for white-chinned petrels (15–28%) and grey petrels *P. cinerea* (23%) on Antipodes Island (Sommer et al. 2010), and Westland petrels *P. westlandica* on the west coast of New Zealand's South Island (43%, Waugh et al. 2015).

Surprisingly, the density estimate from stratified data was less precise than from a global model using unstratified data. This may have resulted from the pronounced difference in burrow distribution across the island: few burrow observations from the moderate density stratum resulted in relatively poor model fit for that stratum, negating the good fit for the high-density stratum and inflating the precision of the overall stratified estimate.

The detection probability for burrows close to the line was high and relatively constant across habitat types, probably because burrows of this species are large and conspicuous. However, burrow detection declined sharply with distance from the line, with an overall detection probability of 0.33. This is similar to detection on other islands with dense subantarctic vegetation (e.g., Barbraud et al. 2009), but difficult to compare with forest-breeding *Procellaria*, such as Westland and black petrels *P. parkinsoni*. Survey coverage was broad and representative, with only one very steep section to the northwest of the island not sampled. However, similarly steep (45–50°) slopes in the southwest were sampled, so this steep habitat is represented in our estimate. The number of breeding pairs reported here underestimates the annual number of breeding pairs since burrow occupancy was estimated six weeks after the peak laying period, so breeding pairs that had experienced egg failures before the survey ('early' failures) were not included in the population estimate. Demographic data with which to correct for failed breeding attempts do not exist for this population, but it is reasonable to expect that some failures will have occurred since at other sites, 30–40% of breeding attempts fail during incubation (e.g., Berrow et al. 2000). Vegetation and the cup of what appeared to be this year's nest were found in the nesting chamber of many of the empty burrows. However, we are hesitant to introduce a potential source of error to the population estimate by using nest remains without concrete evidence of a breeding attempt (e.g., egg shells). This timing bias will be addressed in future surveys by conducting the survey as soon as possible after laying has finished.

White-chinned petrels breed on three other islands in the Auckland Islands group: Adams Island, Ewing Island and main Auckland Island. Adams Island is relatively large (11 300 ha), and white-chinned petrels breed primarily along the southern cliffs (Rexer-Huber unpubl. data). Main Auckland Island (53 700 ha) has feral cats *Felis catus*, pigs *Sus scrofa* and mice *Mus musculus*, and very few white-chinned petrel burrows have been found there. However, areas inaccessible to pigs may support petrels. Ewing Island (68 ha) had 20 white-chinned petrel burrows in 1988 (Taylor 1988), but has not been checked since. On this basis, main Auckland and Ewing islands may support tens to perhaps several hundred burrows. We suggest that Adams Island may have tens of thousands of white-chinned petrel burrows, and should be the focus of work to complete an overall Auckland Islands white-chinned petrel population estimate.

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