Antipodes Island grey petrels: assess and develop population estimate methodology

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Summary

Antipodes Island is thought to have by far the largest population globally of grey petrels *Procellaria cinerea*, but the trend in population size over time remains unknown. This work focuses on planning an updated estimate of population size and trend. We collate and assess resources from previous work, using these to develop recommendations for field work that will yield a robust population estimate.

Our focus here is the methods and findings of grey petrel studies on Antipodes in the early and late 2000s: the feasibility study in 2001 (Bell 2002) and population research in 2009–10 (Thompson 2019). A valuable record of observations underpinned those studies, so key observations on grey petrel behaviour and occurrence over trips since 1969 were extracted from notebooks by Bell and Burgin (Appendix A).

We first collated resources, then compared and contrasted methods and findings from previous work (section *Assess existing information*). Requirements for a robust, repeatable population size estimate and best-practise approaches are discussed in *Design a robust population estimate*. Taken together, previous work and requirements inform a range of options for population size estimation, with key pros and cons noted for each field strategy (*Ranked methodologies*).

Balancing effort, flexibility and precision of the population size estimate, the recommended field strategy is spatial coverage distance sampling. This approach uses distance sampling following a simple-random design that maximises spatial coverage. Several other good options suggest variations but with key things in common: timing (occupancy sampling should occur in second half April), accounting for habitat lost to landslips, and using true surface areas of grey petrel habitat in calculations. With broad sampling across the grey petrel range, an accurate, robust, repeatable population size estimate can be produced.

Contents

Introduction

New Zealand's subantarctic Antipodes Island is a key site for grey petrels *Procellaria cinerea*. The Antipodes population is thought to be by far the largest population globally of grey petrels (BirdLife 2020). However, the trend in population size over time remains essentially unknown.

Observations from visits since 1969 were the main source of information on grey petrels until the early 2000s. The 1969 University of Canterbury expedition to the Antipodes was too early in the year for grey petrels, as they are winter-breeding and the expedition was at the island 28 January to 12 March 1969 (Warham & Bell 1979). The team were present for grey petrels' pre-lay return to island, and recorded useful notes on where grey petrels were seen landing ("*Many were seen to alight on the slopes above Ringdove, Stack and Crater Bays, but we also found several nests on flat ground behind Reef Point only some 20 m a.s.1*".). In 1978 the BAAS expedition was on the Antipodes 20 November to 6 December, too late for grey petrels as just some grey petrel fledglings remained (Imber 1983). Trips in 1994 and 1995 also took place in the October to December period, focusing mainly on summer-breeding species. Key notes and observations from the 1969, 1978, 1994 and 1995 expeditions, extracted from the notebooks of Brian Bell and Mike Imber, are summarised in appendix here (Appendix A: Bell & Burgin 2020).

Although several sources refer to a grey petrel population size of 10–50,000 pairs (Robertson & Bell 1984; O'Brien 1990; Taylor 2000; Bell 2002), there had been no seabird work during autumn/winter when grey petrels are present at the Antipodes. The figure appears to be based on observations from 1969 and 1978 trips, and is described as "*..an educated guess following thorough ground surveys by experienced ornithologists during the 1969 and 1978 expeditions to the Antipodes"* by Bell *et al.* (2013).

In 2000, Graeme Taylor identified possible sites for the population monitoring needed at the Antipodes, suggested potential methods ("*Burrow density should be determined in quadrats or active burrows should be counted in a defined area"*), and proposed that counts be repeated every 10 years to determine trends (Taylor 2000). Obtaining a population size estimate requires survey to determine the distribution and extent of the target species, a census or estimate of burrow numbers, and an assessment of burrow occupancy (what proportion of burrows contains a breeding pair) (Workshop 2006; Parker & Rexer-Huber 2015). A pilot study is ideally conducted first to test methods and ensure good data can be acquired with the planned method.

The first study focused on the grey petrel population was a feasibility study undertaken for DOC CSP in 2001 (Bell 2002). Grey petrel population research in 2009 and 2010 was conducted for the then Ministry of Fisheries (Thompson 2019), with work to inform population size part of a broader remit. Journal articles and reports summarise much of the methods, data obtained and results from previous work, but some remain available only as raw data.

Here we focus on planning an updated estimate of population size and trend, building on the existing knowledge base. This work has three phases: collate, assess, and develop recommendations. We first collate all previous work, including any unpublished data available. Our focus here is on work in the early and late 2000s that yielded data on grey petrel populations. These data, summaries and publications are then assessed, comparing and contrasting methods and findings. Finally, recommendations on a population survey method suitable for obtaining a robust population estimate and assessing population trend are developed. Recommendations are based on findings from previous surveys and informed by the broader literature on grey petrels and burrowing petrel survey methods.

Methods

Reports, publications and primary data are collated from the feasibility work in 2001 and from the most recent research 2009–2010 (Table 1). We contacted key personnel involved in those studies to ensure our collated data pool was as complete as possible, and for clarification where questions arose about field methods and findings.

Resources relevant to grey petrel population size assessment were also obtained, including a workshop report discussing burrowing petrel work rationale (Workshop 2006), reports and data on Antipodes white-chinned petrel work (e.g. Sagar & Thompson 2008; Sommer *et al.* 2011; NIWA unpubl. data 2007–11), a digital elevation model for the Antipodes (DOC GIS unpubl. data 2015), GIS data layers for the Antipodes from LINZ Data Service, and the extent of landslips around the island (K. Walker and G. Elliott unpubl. data 2014; DigitalGlobe Inc).

A parallel project by Biz Bell and Dan Burgin extracted grey petrel observations from notebooks and logbooks (Appendix A: Bell & Burgin). Historical grey petrel records from the notebooks of Brian Bell and Mike Imber are complemented by unpublished notes from the 2001 project notebooks and logbook.

Table 1. Primary resources: Antipodes grey petrel population size work

	Resource	**Description**	**Type**
2001	Bell 2002	Primary grey petrel feasibility study report	Final report to DOC
	Imber *et al.* 2005	Some information from the feasibility study	Journal article Notornis
	Bell *et al.* 2013	Feasibility report condensed for wider readership	Journal article Notornis
	WMIL unpubl. data 2001	Raw data from 2001 feasibility study in .xls	Raw data in .xls
	WMIL unpubl. data 2013	GIS datafile of grey petrel distribution	.kml file
	Bell & Burgin 2020	Notes from feasibility study logbook, notebooks	Report with notebook extracts
2009/10	Sommer *et al.* 2009	Summary report on first season's grey petrel work	Progress report to MFish
	Sommer *et al.* 2010	Summary report on second season	Progress report to MFish
	Thompson 2019	Final report with summarised grey petrel findings	Final report to MPI
	NIWA unpubl. data 2009, 2010	Raw data for population estimate work in .xls, notebooks and hand-drawn maps	Raw data in xls, notebooks, maps
Other	K. Walker & G. Elliott unpubl. data 2014	Hand-drawn map of slips in Jan 2014, composite of satellite images showing slips' extent (imagery from DigitalGlobe)	Map, composite satellite image

Existing grey petrel population size work was then assessed, scrutinising existing data and methods for comparability and repeatability. We distinguish comparability (i.e. are methods underpinning population size estimates comparable) from repeatability, which considers how suitable methods are for long-term trend assessment (Parker & Rexer-Huber 2015).

The assessment is structured so that each aspect of a population size estimate is considered individually to compare the methods and the data obtained from those methods. For example, for burrow density we compare sampling method, extent and randomisation between studies, considering the implications for the data quantity and data quality obtained.

This evaluation is the basis of recommendations for field work to provide an updated estimate of population size, designed to enable assessment of population trend. Field work recommendations consider data on loss of grey petrel habitat due to landslips since grey petrels were last surveyed, to ensure field surveys provide comparable data. Suggested field methods are discussed in light of potential error sources arising from a given method and how to mitigate these error sources to improve estimate precision (Parker & Rexer-Huber 2015).

Assess existing information

Logistics and focus

The 2001 feasibility study was on Antipodes island 24 April–6 June, with a team of six people (Bell 2002). The primary focus was investigating the feasibility of a long-term study monitoring breeding success and population biology, and trialling a range of methods for population size assessment.

In 2009 and 2010, work on grey petrels took place throughout March until 20 April 2009 (grey petrel component of a longer trip), and 19 March–30 April 2010 with three-person teams. Population research focused primarily on adult survival via mark-recapture and tracking, but also collected data toward estimating population size.

Since the 2001 work was a feasibility study, and the 2009/10 work was focused on demographic study and tracking, neither study was set up to devote the time to acquiring all the data needed for a robust population size estimate. However, the work toward population size assessment that was possible provided a great deal of useful data to inform planning of a robust, repeatable population size estimate.

Survey for distribution

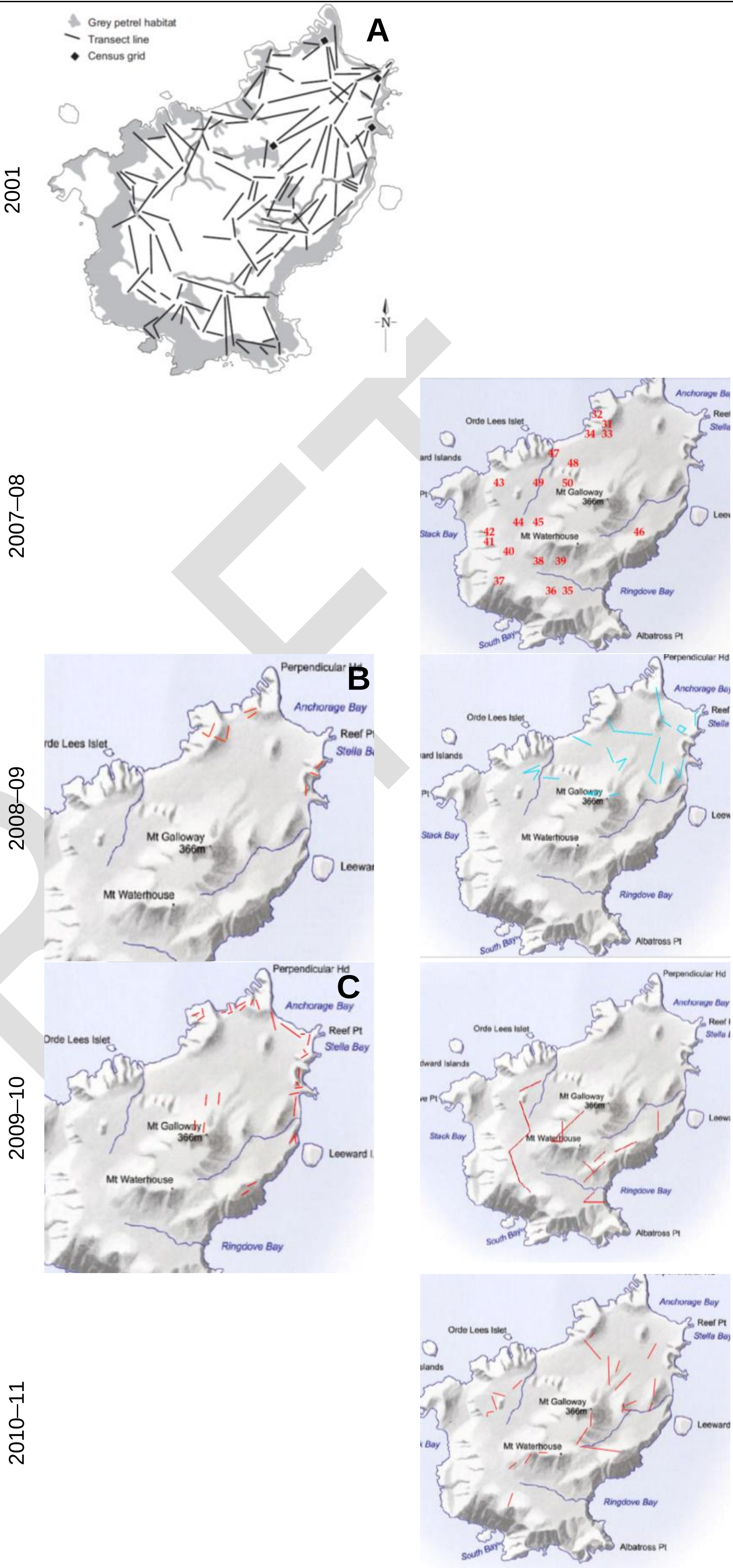
To identify the distribution of grey petrels around Antipodes, the feasibility study surveyed widely. Survey effort included transects as well as arrival/departure counts from high points. Transects were walked throughout the island in all habitats (Fig. 1A, top left, from Bell 2002). Imber *et al.* (2005) added that 110 transects of 1000m were walked, searching a 1m-wide strip, and Bell *et al.* (2013) mapped 10 sites for arrival counts. Only about half of transects encountered grey petrels (WMIL unpubl. data 2001) (Fig. 1A), so the grey petrel distribution map was also informed by observations from earlier trips, grey petrel skulls in skua middens (Appendix A: Bell & Burgin), landing sites observed during arrival counts, calls from burrows (Bell *et al*. 2013), and grey petrel-type habitat identified using aerial photographs and topographic maps (E. Bell pers. comm. 2020). Grey petrel habitat identified covered 510 ha (grey shading in Fig. 1A, from Bell 2002). Grey petrels were also found on Bollons Island in a "*very exclusive and dense colony*" in 1978 (Appendix A: Bell & Burgin). Grey petrels mostly used steep well-draining areas on coastal cliffs, along steep stream banks and high knobs along ridges. Grey petrels were typically found in dry vegetation areas dominated by *Poa litorosa*, areas of mixed *Poa* and *Polystichum vestitum* fern, and occasionally *Coprosma rugosa*.

The 2009/10 grey petrel study used the grey petrel distribution identified in the feasibility work. Grey petrel work focussed on known grey petrel areas (Fig. 1B, C from Sommer *et al*. 2009, 2010), and density estimates were extrapolated to the 510 ha of grey petrel habitat. This seems reasonable since a longer-running project conducted by the same team 2007–11 conducted intensive survey effort for white-chinned petrels using randomised plots and transects across the rest of the island (i.e., areas not identified as grey petrel habitat) (Sagar & Thompson 2008; Sommer *et al.* 2008, 2009, 2010, 2011) (Table 2, Fig. 1 column at right). That work did not detect grey petrels in unexpected places (E. Sommer pers. comm. 2020), suggesting that the distribution remained essentially unchanged and no grey petrel areas missed in the initial work.

Grey petrel habitat appears to have only limited overlap with white-chinned petrel habitat. The two species overlap along some cliff-top edges (Bell 2002), at the top of Stella Bay (Imber *et al.* 2005), and at Banana Ridge in the white-chinned petrel study area (Sagar & Thompson 2008; Sommer *et al.* 2009). Grey and white-chinned petrel burrows are readily distinguished (e.g. Bell 2002), and if there is uncertainty, burrow contents checks can quickly resolve the question since white-chinned petrels are rearing chicks during the grey petrel incubation period.

Figure 1. Spatial coverage of sampling for grey petrels (left) and white-chinned petrels (right).

Grey petrel surveys	White-chinned petrel surveys



Inset figures from Bell 2002; Sommer *et al.* 2008, 2009, 2010, 2011.

Burrow density

The feasibility study determined burrow density in four 50x50m census grids, and extrapolated the density of active burrows (in pairs/ha) to the area of the grey petrel distribution. Grids were sited in known grey petrel habitat (small squares in Fig. 1A), selected to cover different aspect, and the position randomised via a random bearing off the primary pole for the first grid side (Bell 2002). Each grid took a day to set up and two days to check thoroughly. However, as Bell *et al.* (2013) pointed out, the four grids used for density (and occupancy) estimates in 2001 do not sample enough of the variability in grey petrel habitat to be confident in the accuracy of the estimate (Fig. 1).

Grey petrel work set up in the late 2000s did not repeat the 2001 census grids since the focus of that work was marking and monitoring study burrows for mark-recapture, not estimating burrow density. Since most burrows in the grids were too long to access birds for mark-recapture (Bell 2002; Sommer *et al.* 2009), study burrows were sited elsewhere. Grey petrel habitat was sampled via transects 2 m wide, with every grey petrel-type burrow checked for occupants. In 2009, 16 transects were completed in the final days of the trip, largely at the northern end of the island (Fig. 1B), but transects in 2010 covered more of the grey petrel distribution (38 transects over 13 days) (Fig. 1C) (Sommer *et al.* 2009; Sommer *et al.* 2010; NIWA unpubl. data 2009, 2010). Burrow density can be calculated from these occupancy transects, and sampling was more widespread and representative than in 2001.

Comparing density estimates from the three years of existing data shows substantial variability: 104 pairs/ha in 2001; 172–175 active burrows/ha in 2009; and 96 pairs/ha in 2010 (Bell 2002; NIWA unpubl. data 2009; Sommer *et al.* 2010). The variability could be an artefact of data limitations. The sample was likely too small in 200, as discussed above. Density calculations from 2009/10 data are inaccurate to an unknown extent because transect lengths were calculated from start- and end-waypoints, and GPS waypoints are of variable accuracy in the steeper terrain favoured by grey petrels (NIWA unpubl. data 2010). Even when positions of poor horizontal accuracy were flagged for exclusion (Sommer *et al.* 2010; NIWA unpubl. data 2010), some calculated transect distances are surprising (Table 2). Given the importance of accurate density estimates in a population size estimate, we suggest on-the-ground measurement of sampling unit area (transect length, plot diameter, quadrate sides) is needed.

In steep terrain planar or map areas are smaller than ground measures of surface area, since planar area does not account for slope. Since it is the surface area that animals use, a density estimate extrapolated to planar area of habitat will underestimate animal numbers (Parker & Rexer-Huber 2015). To date a mix of planar and surface areas have been used for petrel work on Antipodes (Table 3). In the feasibility study density was calculated using surface area (grids measured on the ground), but density was extrapolated to planar area of habitat (estimated in GIS) (Bell 2002). Sommer *et al.* (2009, 2010) calculated density based on planar area (estimated from GPS), then also extrapolated to planar area. The most accurate population size estimate will be surface area density sampling, from accurate measures on the ground, extrapolated to the surface area of grey petrel habitat. The planar/map area can be slope-corrected using a digital elevation model (DEM) (e.g. Barbraud *et al.* 2020), or by sampling slope measurements across grey petrel habitat (Barbraud *et al.* 2009; Rexer-Huber *et al.* 2020). A DEM is available for the Antipodes at 10m resolution (DOC GIS unpubl. data 2015).

To obtain a more sound population size estimate, Bell *et al.* (2013) suggested using more grids, line-transect surveys or distance sampling. Increasing the number of randomised grids or transects across the island is attainable with reasonable effort (Table 2; Fig. 1). For example, transects through the island's northern grey petrel habitat took 13 days in 2010 (36 transects; Fig. 1C) (Sommer *et al.* 2010), but small 10x10m sampling quadrates over most of the island took 4.5–9 days for white-chinned petrels (20–30 quadrates) (Table 2, Fig. 1 column at right) (Sommer *et al.* 2008; NIWA unpubl. data 2007). As many 36 transects were covered in just 1.5d, given short transects and little travel time between transects (Sommer *et al.* 2008). Accounting for weather days and the need for a suitable weather window for trips to more distant sampling locations, we note that 13d of transects required a 20-d period, and 4.5d of quadrates required a 10-d period (NIWA unpubl. data 2008, 2010). Across all the sampling effort data available for large burrowers at the Antipodes, it seems that work days should be scaled by 1.5 to 2 times (season with most grey petrel effort, and average over all WCP and grey petrel seasons, respectively). That is, sampling effort requiring for example 10 working days should allow for a 15 to 20-day window.

Table 2. Sampling effort for grey petrels and white-chinned petrels on Antipodes

		N	type	Effort days	Area/length		Focus	Source
2001	greys	4	quadrates	12 d	50x50m grid	measured	Density, occupancy	[1]
2006–07	wcp	30	quadrates	9 d	10x10m grid	measured	Density	[2]
2007–08	wcp	20	quadrates	4.5 d	10x10m grid	measured	Density	[3]
	wcp	36	transects	1.5 d	50m	measured	Occupancy	[3]
2008–09	wcp	29	transects	10 d	62–955m	calculated from wpt	Occupancy	[4]
	greys	16	transects	4 d	17–130m	calculated from wpt	Occupancy	[4]
2009–10	wcp	20	transects	6 d	152–1112m	calculated from wpt	Occupancy	[5]
	greys	38	transects	13 d	25–253m	calculated from wpt	Occupancy	[5]
2010–11	wcp	31	transects	5 d	43–875 m	calculated from wpt	Occupancy	[6]

Sources: 1 (Bell 2002); 2 (NIWA unpubl. data 2007); 3 (Sommer *et al.* 2008; NIWA unpubl. data 2008); 4 (Sommer *et al.* 2009; NIWA unpubl. data 2009); 5 (Sommer *et al.* 2010; NIWA unpubl. data 2010); 6 (Sommer *et al.* 2011; NIWA unpubl. data 2011)

For trend assessment, a new population size estimate should be compared with the most accurate figures available from existing data. We suggest the following two corrections should be applied if population size figures are to be compared:

- More accurate transect lengths could potentially be extracted from the raw data (NIWA unpubl. data 2009, 2010). Currently, transect length is the straight line distance from start- to end-waypoint (Sommer *et al.* 2010; Thompson 2019), but data sheets also contain waypoints for all burrows found along a transect. Plotting transect length via burrow positions may refine the length estimate, as suggested by Sommer *et al.* (2009), or it may simply compound the GPS error. Some transects highlighted as having poor GPS quality also need to be checked to ensure those data are excluded.
- More accurate breeding pair numbers could be calculated if the 2001 and 2009/10 density estimates are extrapolated to the surface area of grey petrel habitat, using the available DEM (DOC GIS unpubl. data 2015), rather than the planar or map area used for calculations to date (Bell 2002; Sommer *et al.* 2010).

Burrow occupancy

In the feasibility study, all census grid burrows were checked using a mix of methods (visual, bird removal, playback, scope). Burrows were mostly straight so a bird present could often be seen, but only a quarter had a nest that could be reached by hand (Bell 2002). Burrow contents were also checked along two randomly placed 300m transects, with the added observation that activity sign were not useful because "*unoccupied burrows nearly all showed signs of occupancy; typically moulted contour and coverts feathers of grey petrels, freshly added nest material and often fleas*" (Imber *et al.* 2005).

In 2009 and 2010, all grey petrel-type burrows were checked for an occupant, by hand or with a burrowscope, along occupancy transects throughout grey petrel habitat (Sommer *et al.* 2009; Sommer *et al.* 2010). Any burrow whose end could not be reached with the burrowscope was excluded from occupancy calculation. Good occupancy data were also obtained from study burrows, with 257 grey petrel-sized burrows marked and monitored in 2009. Study burrows used for breeding in 2009 were again monitored in 2010. Occupancy can also consider the probability that some of the empty grey petrel-sized burrows belong to other species (white-headed petrel in particular) and apply a correction, as done in Thompson (2019). However, Table 4 shows the simple occupancy figure (n breeding pairs/ n grey petrel-type burrows checked) for direct comparison with Bell (2002).

Table 3. Grey petrel population size work on Antipodes, comparing 2001, 2009/10 and potential next steps

	2001	**2009/10**	**Next**
Field team size	5	3	
Timing	On island 24 April–6 June Occupancy work 9–21 May	Grey petrels ~1 Mar–20 Apr and 19 Mar–30 Apr; Occupancy transects from 15–20 Apr and 9–30 Apr	- Occupancy work from 2nd week April - Can be preceded or followed by density work (less timing-sensitive)
Distribution	Grey petrel distribution thoroughly defined from field effort, maps and photos	Used 2001 grey area, plus noted areas with grey-WCP overlap	Use 2001 grey petrel distribution area (Appendix B)
Density	From 4 grids. Sites selected, exact placement randomised	Not explicitly sampled but can derive from occupancy transects. Transects randomised	- Transects (comparable method) - Comprehensive sampling through whole grey petrel range (more representative)
Density sampling coverage	4 grids not representative coverage of greys habitat	Coverage OK (if deriving from occupancy transects), but little sampling in southern half	- Need coverage right around greys range - Randomise sampling positions in greys area in GIS
Stratification	None	Data on variables like veg, slope and aspect collected but not used	Collect data on veg, slope, aspect in case needed for post-stratification
Area surface or planar	Density based on surface area (measured grid) extrapolated to planar (GIS)	Density based on planar (estimated from GPS), extrapolated to planar	- Use surface area for density sampling (accurate ground measure), extrapolate to surface area using DEM. - Extrapolate 2001 and 2010 density estimates to surface area for comparison.
Burrow detectability	Systematic searches. No mention detectability check	Not mentioned	Consider distance sampling to explicitly account for detection. If not, conduct double-counts
Occupancy	From grids using range of methods. Timing bit late cf. peak lay.	From study burrows and transects (2009) and transects (2010). Mostly used burrowscope. Timing cf. lay about right although a bit early in 2010.	- Occupancy by burrowscope in representative sites - Consider including 2001 grids and/or 2009/10 study burrow areas for comparison
Occupant detection	Not discussed	Excludes not inspected in full	Consider testing occupant detection probability
Availability: areas not sampled	Extrapolated just to grey petrel habitat (as sampled in plots). Named some areas too steep to access, but limited sampling so representativeness unknown.	Extrapolated just to grey petrel habitat. Lack of coverage to south not discussed but may not be important	Get coverage right around island, then consider if areas not accessed were represented in existing sampling
Availability: slips			- Digitise slipped area in GIS - Survey slips to identify areas of habitat lost (i.e. scoured to rock) - Subtract surface area of habitat lost for new estimate of grey petrel habitat area
Observer bias	Not mentioned	Not mentioned	Test, multiple counts. Standard measures. Field team working together initially until metrics consistent.

Occupancy data from both studies seem robust, with good numbers of burrows checked and wide sampling across areas (Table 3, 4). Burrow occupancy was 47% in 2001, and it is not clear why this is substantially higher than in the late 2000s (22.5–32.3%) (Table 4). The methods and sampling seemed similarly thorough and comprehensive, and both studies excluded non-breeding occupants. Grey petrel burrow occupancy was substantially higher on Campbell Island (63%) even though the colonies are very small and burrow checks were late in the season (large chick stage, 13 July–6 August) (Parker *et al.* 2017).

Neither study tested for occupant detection, or the probability of missing a bird present (Parker & Rexer-Huber 2015) (Table 3). In theory, this is redundant if observers only record a bird present in the burrow if they are certain that the burrow has been inspected in full, and exclude burrows where contents are not certain. However, grey petrel burrows are long, with as little as a quarter reachable by hand (Bell 2002), call playback requires a response rate test (e.g. Barbraud *et al.* 2009), and burrowscope inspection can miss birds in long burrows or around corners. Occupant detection rates could potentially be extracted from the repeat-visit data at study burrows (Sommer *et al.* 2009).

Table 4. Occupancy by breeding grey petrels of grey petrel-sized burrows

	Occupancy	N grey-sized burrows checked	Sampling coverage	Timing
2001	47.1%	221	4 census grids	mid–late incubation (9–21 May)
2009	26.8%	257	study burrows 2 areas	during lay (Mar–mid-Apr)
	28.6%	105	16 transects	just after lay (last half Apr)
2010	32.3%	133	study burrows	during and after lay (21 Mar–28 Apr)
	22.5%	360	38 transects	egg laying near end but not yet complete (9–30 Apr)

Timing relative to breeding

Timing surveys as close to the main lay period as possible can reduce the number of assumptions and corrections required (Parker & Rexer-Huber 2015). Burrow occupancy, in particular, is sensitive to the timing relative to egg lay, with the number of pairs underestimated if occupancy sampling is too early (e.g. 8.5% occupancy at the start of grey petrel laying) (Barbraud *et al.* 2009). Sampling should preferably be conducted once most eggs have been laid, before there has yet been much chance for breeding failure, to avoid the need for failure-rate correction of the breeding pair estimate.

In the 2001 feasibility study, occupancy data were collected 9–21 May (Table 3). The 2009 and 2010 seasons involved occupancy work from 15–20 April and 9–30 April, respectively.

Grey petrels start returning to the island 1–9 February but are back en masse from mid- to late February (Warham & Bell 1979; Sommer *et al.* 2009; Appendix A: Bell & Burgin). Data from monitored study burrows recorded egg lay 21 March–9 April (Sommer *et al.* 2009), in line with the 20 March–8 April recorded on Kerguelen (Zotier 1990). Although egg lay is known to start before and continue after those dates (Imber 1983; Bell 2002; Appendix A: Bell & Burgin), the peak of egg laying occurred around the beginning of April, and 5 April was already past the egg-laying peak (Sommer *et al.* 2009). Data from Antipodes on hatching corroborate these lay dates. Bell (2002) showed peak hatch was 25 May–1 June and "*even proportions of eggs and chicks around 31 May, indicating that hatching peaked then*" (Imber *et al.* 2005). In notebooks, the implications for lay dates were considered: "*suggests now [30 May] that we are at peak of hatching and therefore laying peaks around 1st April*" and "*seems that there is a pronounced peak of laying around 25 March to 3 April*" (Appendix A: Bell & Burgin). Peak lay calculated back from the observed hatching dates (25 March–3 April) thus aligns with the 2009 lay data (21 March–9 April) (Sommer *et al.* 2009).

Ideal timing for occupancy work would therefore be in the second half April, once lay is largely complete, to estimate the proportion of burrows containing breeding pairs. Taylor (2000) pointed out that surveys to map burrow locations and assess numbers could be undertaken earlier, in February to March.

The 2001 feasibility study collected occupancy data a bit late relative to peak lay. Burrow contents were checked 9–21 May, which corresponds to late incubation: some early breeders already had chicks hatching 6 May while the peak of hatching started 25 May (Bell 2002). Burrow checks will not have accounted those pairs that had failed early, so breeding numbers will have been underestimated in the feasibility study (to unknown extent since failure rate data are not available). Occupancy work from 15–20 April 2009 and 9–30 April 2010 was timed well relative to peak lay, with the majority of eggs laid by 9 April (Sommer *et al.* 2009). At Kerguelen, work showed that grey petrel surveys March–April were too early, recording only 8.5% occupancy (Barbraud *et al.* 2009).

Design a robust population estimate

In light of findings from existing field surveys for grey petrels on Antipodes, this section proposes several options for field methods to provide an updated estimate of population size. We discuss the advantages and disadvantages of these options, informed by the broader literature on burrowing petrel population size estimation.

Population size study or trend study?

Obtaining a population size estimate requires

a) an initial pilot study to ensure good data can be acquired with the planned method;
b) survey to determine the distribution and extent of the target species;
c) an estimate of burrow numbers that is accurate via sampling that is representative; and
d) an accurate estimate of burrow occupancy from the end-of-lay stage.

In contrast, population trend study design can be simpler, involving as little as burrow numbers and occupancy (c, d) monitored over time in a sub-sample of permanent repeatedly-visited plots (as recommended in Workshop 2006). For trend monitoring, we can leave off the initial steps of a pilot data-quality study and survey of distribution because these have already been determined in a preceding population size estimate. In other words, a population size estimate provides the confidence that the subsampled monitored for trends is informative, representative, but manageable (time- and cost-effective).

We suggest that for grey petrels at Antipodes, a robust population size estimate is needed. The effort to obtain an accurate, precise, spatially detailed estimate, is greater than needed for monitoring a smaller trend study (Workshop 2006), but is justified being a ‘one-off’ or baseline figure that informs selection of representative, smaller sample for trend monitoring over time. This is generally acknowledged in the literature on seabird monitoring, with population size estimates recommended at ~10 yearly intervals while trend monitoring work is conducted annually (e.g. Taylor 2000; Wolfaardt & Phillips 2011; Moore *et al.* 2012).

Part of the work toward an updated population size estimate for grey petrels at the Antipodes has already been done. More than enough information is available from work in the early and late 2000s to ensure good data can be acquired with a planned method, making a pilot study redundant. Survey to identify grey petrel distribution on the island does not need to be revisited: surveys to identify distribution and habitat were conducted thoroughly in 2001 (Bell 2002), building on occurrence observations from earlier trips (Appendix A: Bell & Burgin). Later work confirmed the distribution with no sign of range change (grey petrel and white-chinned petrel surveys; Sommer *et al.* 2008, 2010, 2011). Therefore, work to obtain a robust, accurate population size estimate can focus on broad representative sampling of burrow numbers across the grey petrel range, with a thorough estimate of burrow occupancy.

Sampling burrow density

Grey petrel burrows are widespread in suitable habitat on the Antipodes (Bell 2002; Sommer *et al.* 2010). It would be implausible to identify every colony and count burrows (Ryan & Ronconi 2011; Parker *et al.* 2017), so burrow numbers must be sampled then extrapolated to the grey petrel habitat available. We discuss what is needed to ensure that a sample of burrow density will be accurate, precise enough and repeatable.

Randomisation and replication

To get the most accurate and precise density estimates—and thus population size estimates—sampling design should be tailored to the specifics of species and site (Parker & Rexer-Huber 2015). In grey petrel habitat, the distribution is more dispersed than densely clustered (E. Bell and E. Sommer pers. comm. 2020), suggesting a simple randomised sampling design is more suitable than, for example, targeted or systematic sampling approaches (Dilley *et al.* 2019).

Random sampling must balance strict randomisation against the need to actually encounter burrows in a landscape. Random long walking transects largely did not find grey petrels (Bell 2002), but smaller random transects within the grey petrel habitats encountered burrows (Sommer *et al.* 2009, 2010). Large census quadrates limit the number of replicates possible in a given period (Bell 2002) and wider, more representative sampling was identified as a key requirement for improving existing data (Bell *et al.* 2013). Much more replication was possible within feasible timeframes using small, randomised plots (white-chinned petrels) and transects (grey petrels, white-chinned petrels) within target species habitats (e.g. Sommer *et al.* 2008, 2010) (Table 2). More replicates also help deal with variance in burrow encounter rates, which is expected since we anticipate grey petrel burrows to be somewhat aggregated, rather than truly random (Rexer-Huber *et al.* 2017).

We suggest GIS-based randomisation of sampling locations within the grey petrel distribution. Several relevant data layers are already available; this is discussed in Appendix B. If landslip areas are incorporated into GIS too, planning can ensure that randomised sampling also has adequate coverage of slipped and non-slipped habitat (Appendix B).

Sampling unit size, type

Bell (2002) identified transect sampling as problematic in some of the steep terrain occupied by grey petrels. In very steep or irregular terrain, smaller sampling units may be needed to ensure accurate data are acquired safely. For example, sampling plots can in some cases be safer than transects in steep clifftop terrain (e.g. Rexer-Huber *et al.* 2020). Transects were later used widely 2009–11 on Antipodes in both white-chinned and grey petrel habitat types (Sommer *et al.* 2009, 2010, 2011) so there appears to be no need for small plots. Making transects shorter (but more numerous) may be more appropriate in the steep terrain used by grey petrels on Antipodes than the fewer, longer transects sometimes used for grey petrels (Barbraud *et al.* 2009; Sommer *et al.* 2010). We suggest testing transect length onsite to establish a workable length that can still encounter burrows (e.g. Rexer-Huber *et al.* 2017).

Precision

A carefully set up sampling design can increase the precision of a population size estimate (Parker & Rexer-Huber 2015). Precision can be improved if transects are set up so they all span a known density gradient (e.g. from high density at island edge to low density inland; systematic sampling; Fewster *et al.* 2009). Stratified random estimates can also improve precision if burrows occur in useful pattern relative to e.g. vegetation and slope, or by geographic area (Barbraud *et al.* 2009). Pre-identified strata sometimes have too few burrows to be useful, though, so data that may allow post-stratification should be collected (Barbraud *et al.* 2009; Rexer-Huber *et al.* 2017). Given a known grey petrel distribution (Bell 2002), we expect the most precise estimate could be obtained by sampling within the known grey petrel-habitat 'stratum' (Barbraud *et al.* 2020), collecting local habitat data with which to post-stratify if e.g. vegetation type explains burrow distributions at a finer scale.

Burrow count accuracy

Burrow count accuracy is affected by burrow detectability, and burrows are much easier to detect in some vegetation types than others (e.g. Workshop 2006; Dilley *et al.* 2019). In dense vegetation like that in grey petrel habitat on Antipodes (Bell 2002; Workshop 2006), burrow count accuracy can be optimised by using smaller plots, narrower transects, and moving upslope, all of which reduce the risk of missing a burrow (Parker & Rexer-Huber 2015). Burrow detection rates should be tested, using for example double-observer counts where the first observer pointing out all burrows seen to a following observer, who notes anything else detected (e.g. Barbraud *et al.* 2009).

Ideally, burrow detection probability is included explicitly in the study via distance sampling (Lawton *et al.* 2006; Rexer-Huber *et al.* 2017). Burrow numbers from distance sampling were tested against exhaustive counts in the same area, and showed that distance sampling gave a highly accurate estimate (Barbraud *et al.* 2009). For distance sampling to be appropriate, a minimum number of burrows must be detected (Buckland *et al.* 2001; Buckland *et al.* 2004). Grey petrel burrow numbers along transects (Imber *et al.* 2005; Sommer *et al.* 2009; NIWA unpubl. data 2010) comfortably exceeded that threshold required for distance sampling with as little as 16 short transects, so we are confident that distance sampling is feasible.

Area accuracy

Whether measuring the distance from transect to burrow for distance sampling, or measuring the diameter of a sampling plot, measurement error is a known issue. Observers can also vary in their perception of distance, so physical aids like marked poles, cords or tapes can reduce another source of inaccuracy. More profound impacts on population size accuracy can occur if transect lengths or plot diameters are estimated in error. Area and thus density estimates errors compound as they are extrapolated to whole-island estimates of numbers. Distance measured by GPS proved problematic in the steep terrain like that favoured by grey petrels, with sometimes poor horizontal accuracy of the GPS resulting in variably reliable distance measures (Sommer *et al.* 2009, 2010). On-ground measures of length/diameter are thus highly recommended.

On-ground measures have the advantage of providing measures of surface area, or the true area sampled for petrels, rather than the planar or map area. This is valuable because the true surface area available for petrels is typically larger than the planar area, particularly for species that favour steeper habitats. Population densities extrapolated to planar map area will be inaccurate, likely underestimating the true population size. Slope-correction of planar map area to estimate the true surface area ideally uses a suitable digital elevation model (DEM) (e.g. Barbraud *et al.* 2020), but could use repeated slope measurements from density sampling sites (e.g. Rexer-Huber *et al.* 2017). As discussed in Appendix B, the DEM available for the Antipodes (DOC GIS unpubl. data 2015) should be part of the resources used for survey planning and analyses.

Habitat availability

This refers to the proportion of habitat that could not be accessed for sampling. Best-laid field plans for perfect sampling coverage can be waylaid for all sorts of reasons, most commonly the interface of weather, logistics and time. Once a sampling dataset is as complete as it can be, availability should be considered carefully to decide what proportion of habitat could not be accessed for sampling. If information is available to confirm that grey petrels are present in that area, are there variables that suggest the unsampled habitat is reasonably represented by sampling elsewhere, in other similar but available habitat? If not, consider excluding the unavailable area from extrapolations. For example, Barbraud *et al.* (2009) only extrapolated density estimates to the area surveyed and areas where grey petrels are known to breed, rather than extrapolating to a generalised 'grey petrel habitat'.

Habitat may also become unavailable to grey petrels over time, particularly if habitat is lost due to landslips. In January 2014 an unusually large number of slips occurred around the island in the steeper country favoured by grey petrels (Fig. 2). While burrowing petrels can dig new burrows again once slip material has settled (Disappointment Isl white-chinned petrels, authors' unpubl. data), this is not possible if slips have entirely removed soil to the bedrock. The area of substrate stripped to rock should be subtracted from the grey petrel habitat available.

The composite of satellite images showing areas that slipped in 2014 should be digitised in GIS using the map of slips as reference (Fig. 2). These GIS layers would inform planning to ensure that grey petrel sampling coverage includes slipped areas (Appendix B, Fig. B2), to capture consequences (e.g. potentially lower density in recolonised slips) and to determine the area of habitat no longer available to grey petrels.

Sampling burrow occupancy

Methods

Assessing the contents of burrows is crucial to confirm what proportion of burrows is occupied by a breeding pair. Burrowscope inspection is preferred so that the breeding status of birds can be seen. Other methods (looking with a torch, reaching by hand, using a probe to feel for birds, call playback) can sometimes be faster than a thorough burrowscope inspection, but lack the information on breeding status. Hand and probe inspection also cannot confirm species present, which is an issue given the regular presence of white-headed petrels in grey petrel-type burrows (e.g. Sommer *et al.* 2009).

Separating density and occupancy samples

We suggest that instead of spending time checking every burrow in every density sampling unit (Bell 2002; Sommer *et al.* 2010), it is better to get high-quality occupancy data from a representative sample of burrows. Checking every burrow on every transect is slower than when just searching for and counting burrows, reducing the spatial coverage that can be attained for density sampling. Density sampling is also less time-sensitive than occupancy sampling, which ideally occurs once egg laying is largely complete (in the second half of April). Combining occupancy with density sampling would narrow the time window available for density work, further limiting the spatial coverage possible. Spatial coverage is crucial for density but less important for occupancy estimation, where the sample unit of interest is the burrow numbers checked.

By separating occupancy sampling from density sampling, occupancy work could occur at the optimal time for occupancy, maximising the burrows-checked sample size. Occupancy sites should cover the broad types of grey petrel habitat already identified in preceding density sampling work. We suggest sites used for occupancy sampling should include the two study-burrow sites established in 2009/10, to allow for resighting of any banded birds still present.

Accuracy

Occupancy work to date suggests that the contents of grey petrel-type burrows can be determined with confidence using a burrowscope (e.g. Sommer *et al.* 2010), as for other *Procellaria* petrels that have large, structurally simple burrows (Waugh *et al.* 2003; Rexer-Huber *et al.* 2020). On the Antipodes, burrows that could not be inspected in full were rare so could reasonably be excluded (NIWA unpubl. data 2009, 2010). Error in burrow contents, however, could scale up quickly when extrapolated into a population size assessment, so it is worth considering methods to test the accuracy of burrow content assignment (Parker & Rexer-Huber 2015). The assumption that occupants are always detected, or occupant detection probability, is most commonly assessed by resampling methods: two observers checking the same sub-sample of burrows for occupants (e.g. Whitehead *et al.* 2014), or via repeated checks of the same burrows over a time period (Baker *et al.* 2008; Rayner *et al.* 2009). Since white-headed petrels are often found in grey petrel-type burrows (e.g. Sommer *et al.* 2009), species identification accuracy could also be assessed via the above resampling approaches.

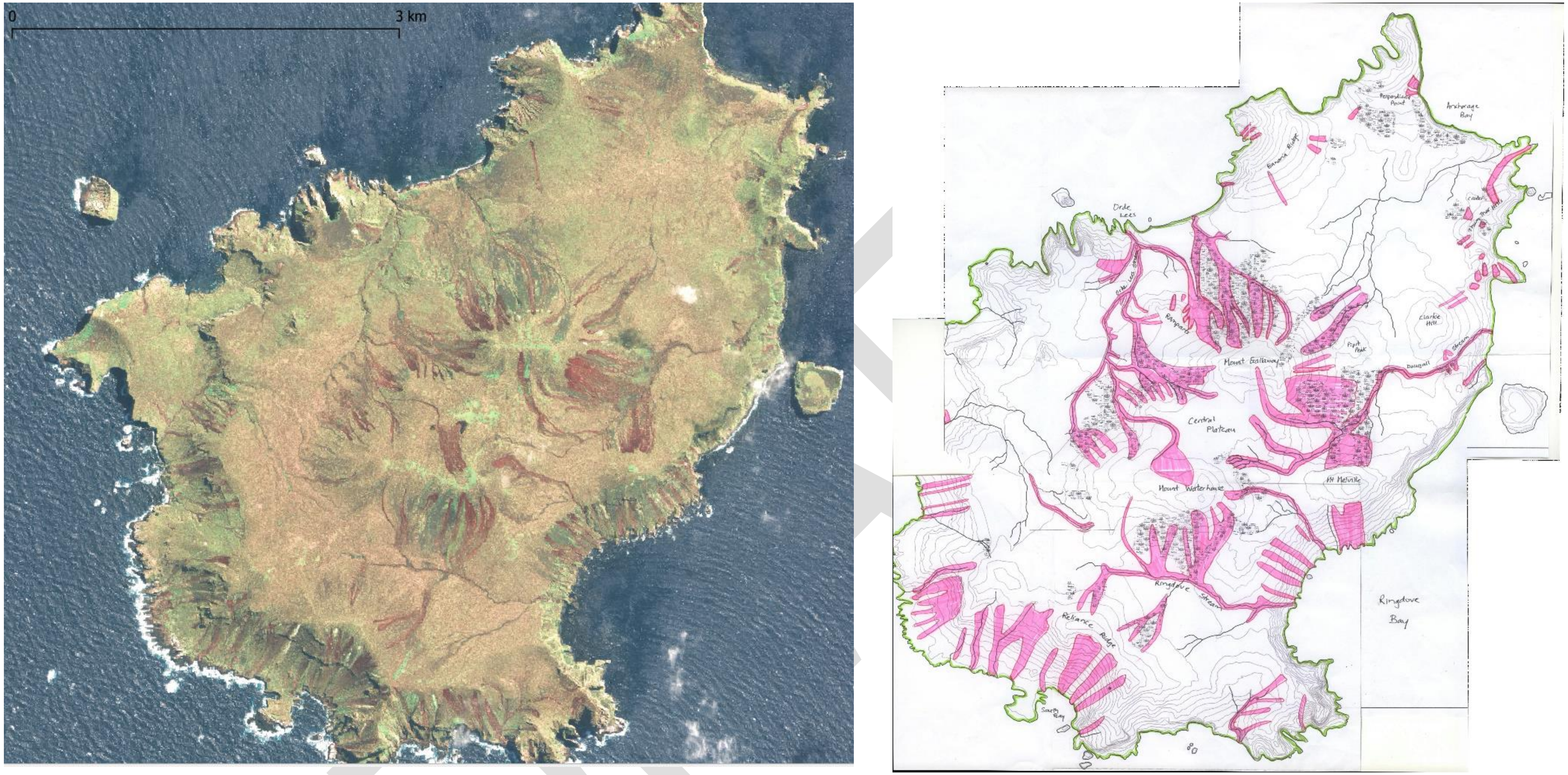


Figure 2. Antipodes slips in January 2014 shown in a composite of satellite images (left) and mapped shortly after slips occurred (right). Composite satellite image by G. Elliott with imagery from DigitalGlobe Inc; map by K. Walker and G. Elliott (unpubl. data 2014)

For the resulting estimate of the breeding population to be as accurate as possible, it is important that occupancy work is timed to best reflect the maximum number of breeding pairs; that is, early in the breeding season, just after laying has finished (Parker & Rexer-Huber 2015). For grey petrels at Antipodes occupancy work should be conducted the second half of April, once lay is largely complete (Sommer *et al.* 2009).

Revisit permanent plots

For a population size estimate, a single accurate estimate of burrow occupancy sampled from randomised locations across grey petrel habitats is all that is needed. However, where occupancy sites from previous work can be relocated (Bell 2002; Sommer *et al.* 2009), new occupancy checks at those sites could provide some insight into trend (Workshop 2006; Sagar & Thompson 2008). Bell (2002) calculated occupancy from four census grids, and recorded the positions of those grids.

Occupancy sampling by Sommer *et al.* (2009, 2010) (16–38 randomised locations around grey petrel habitat) was not set up for repeat monitoring. The grids from 2001 could be revisited to assess trend in burrow occupancy, although Sommer *et al.* (2009) noted that since it was difficult to exactly relocate grids they were not re-used, so there are no data from intermediate time points. Assuming grids could be relocated exactly, establishing the grids again and checking all burrows could take nine days (Bell 2002). With a population size estimate the primary focus of the planned work, revisiting permanent plots would have to be in addition to occupancy sampling as described above. This is largely because of timing: occupancy sampling should take place in the second half of April, to get the best picture of breeding pair numbers, while census grids should be checked in mid-May to properly replicate the 2001 data (Bell 2002).

Ranked methodologies

A. Spatial coverage, distance sampling

Burrow density estimated by conducting distance sampling to explicitly account for burrow detection probability. Distance sampling design simple random, for coverage across whole grey petrel habitat to get best possible replication and spatial detail. Environmental data collected to enable post-stratification if needed. Burrow occupancy determined by burrowscope at sampling sites in representative habitats, including the two study-burrow sites established in 2009/10. Density timing can be March-April, while occupancy best sampled in the second half of April. Breeding population size would then be calculated using the known 510ha of grey petrel habitat, subtracting area lost to slips and slope-correcting to the true surface area using DEM.

These methods are expected to refine the accuracy of the resulting population size estimate (directly accounting for burrow detection probability, and using accurate measured areas rather than calculated from GPS, applied to the true surface area from DEM at 10m resolution). A resulting estimate would also be more precise than possible from sampling in 2001, given whole-island sampling and extensive replication (Bell *et al.* 2013).

Based on previous work at Antipodes, and our experience sampling difficult terrain elsewhere, we estimate a fieldwork time budget below:

Table 5. Projected/estimated fieldwork time budget for spatial coverage and distance sampling. Window is the period or time window required allowing for weather and daylight limitations

	window	timing
~16 days for two teams (2-pax) for good distance sampling coverage of grey petrel habitat	3 ½–4 weeks	March–April
occupancy sampling over 7 days	1 ½–2 weeks	April 15–30
Total field time	6 weeks	Mid-Mar to end Apr

B. Spatial coverage

Burrow density estimated from known-area transects, repeating sampling type from 2009/10 with more replication and better spatial coverage across whole grey petrel habitat (March–April). Other aspects similar to option A above: sampling design simple random within grey petrel habitat; ancillary data collected to allow post-stratification if needed; and separate estimate of occupancy, sampling from representative habitats in the second half of April. Similarly, the breeding population size would be calculated based on the true surface area of grey petrel habitat with lost habitat accounted for.

A resulting population size estimate is expected to be more accurate than previous estimates, being based on measured areas (cf. 2009/10) and applied to the true surface area (cf. 2001, 2009/10). Wider sampling and better replication is also expected to give a more precise estimate than possible from sampling in 2001 (Bell *et al.* 2013).

A similar time budget would be required as for the option above. Slightly less time is required for fixed-width transects than distance sampling. Time requirements are estimated below:

Table 6. Projected/estimated fieldwork time budget for spatial coverage. Window is the period/window required allowing for weather and daylight limitations

	window	timing
~14 days for two teams (2-pax) for good distance sampling coverage of grey petrel habitat	3–4 weeks	March–April
occupancy sampling over 7 days	1 ½–2 weeks	April 15–30
Total field time	6 weeks	Mid-Mar to end Apr

C. Systematic whole-island distance sampling

Using a systematic sampling design, distance sampling for density estimation would cover the whole island rather than just grey petrel distribution. Systematic sampling designs improve the precision of estimates when transects each transect spans high- to low-density gradients (Fewster *et al.* 2009). On Antipodes this would mean transects each running inland from the island edge, from high-density greys habitat to low density. Other aspects (occupancy, population size area calculations) would remain the same as for options A or B.

Systematic distance sampling should produce the most precise population size estimate of methods proposed, and does not involve the assumption that the grey petrel distribution has remained stable. By covering the whole island, rather than focusing within the grey petrel distribution, the method is less comparable with previous estimates. That said, estimates are not particularly comparable anyway. We expect sampling edge-to-inland around the whole island to be more time-consuming than conducting shorter transects, with less between-transect travel time.

Unlike other methods, there has been no comparable sampling previously so a time budget is difficult to estimate with confidence. Timings (below) are like that for short-transect distance sampling above, but with more time to account for longer transects and more travel time:

Table 7. Rough fieldwork time budget estimate for systematic whole-island distance sampling. Window is the period or time window required allowing for weather and daylight limitations

	window	timing
~20 days for two teams (2-pax) for good distance sampling coverage of grey petrel habitat	5–6 weeks	March–April
occupancy sampling over 7 days	1 ½–2 weeks	April 15–30
Total field time	6 ½–8 weeks	Mar to end Apr

D. Population size estimate AND trend

Extending a field visit into May would allow census grids from 2001 to be revisited at around the time they were originally checked (9–21 May) (Bell 2002). This would give directly comparable density and occupancy figures for some indication of trend. However, we suggest this would be of limited use given the intervening time with no trend data, and the issue that four grids are too few for monitoring over time. A better option for trend estimation would involve setting up around 30 permanent monitoring quadrats (small 10x10m) (Workshop 2006) that can then be revisited annually.

The timing required would be as for options A and B, but with the field visit extended until 21 May to replicate the 2001 census grid checks. A time estimate is below:

Table 8. Projected/estimated fieldwork time budget for population size and grid revisit. Window is the period/window required allowing for weather and daylight limitations

	window	timing
~16 days for two teams (2-pax) for good distance sampling coverage of grey petrel habitat	3 ½–4 weeks	March–April
occupancy sampling over 7 days	1 ½–2 weeks	15–30 April
Census grid checks over 12 days	2 weeks	9–21 May
Total field time	9 weeks	Mid-Mar to 21 May

E. Trend assessment alone

If population trend assessment is the only option, work could simply repeat 2001 grids in mid-May. This has the advantage of providing a repeat measure to assess trend from, involving less time than for sampling across the whole island. The problem is that it is not clear whether the four grids are representative of what is happening in grey petrel habitat across the island. This could be addressed via new permanent grids set up along the lines of the 10x10m grids proposed for trend monitoring (Workshop 2006). However, without an accurate population size estimate to judge monitoring design against, it would remain unclear how accurate, useful/representative this monitoring is, so trend assessment alone is quite low down a ranked list of options. Finding permanent plots again can also be challenging in steeper terrain, with most 'permanent' markers notably impermanent, particularly around burrowing petrels, and GPS coordinates having poor horizontal accuracy in steep terrain.

The timing required would as below:

Table 9. Projected/estimated fieldwork time budget for trend study establishment. Window refers to the period/window required allowing for weather and daylight limitations

	window	timing
Establish and check permanent monitoring grids ~14d for 30	3–4 weeks	15 April–8 May
Census grid checks over 12 days	2 weeks	9–21 May
Total field time	5 weeks	Mid-Apr to 21 May

Population estimate recommendations

A fieldwork plan for a robust population size estimate must balance the accuracy and precision of results against labour, comparability, and field strategy flexibility. We suggest that in balance, the best strategy for a grey petrel population size estimate on Antipodes is spatial coverage distance sampling; that is, distance sampling following a simple-random design that maximises spatial coverage.

Broad sampling across the whole range of grey petrel habitat will produce an accurate figure, particularly with distance sampling which explicitly accounts for varying burrow detection. 'Broad sampling' here means sampling locations are randomised within the established grey petrel distribution to get the best possible coverage, replication, and spatial detail. Although the most comparable estimate would be one that exactly repeats previous sampling methods (four grids; option E), this would be at the cost of an accurate, precise population size estimate. A simple-random sampling design is not the most precise option, with a more precise estimate expected from a systematic design (e.g. option C). Despite that, we propose a simple-random design as it is less time consuming, short transects are more flexible (easier to conduct) in difficult terrain than long coast-to-inland transects, and simple-random sampling is more comparable with previous approaches.

All fieldwork options for population size estimation suggested above (A–D) share key components to an accurate population size estimate. All involve randomisation in GIS to take advantage of grey petrel distribution and slip incidence data layers. All involve burrow occupancy work in the second half of April, sampled from representative habitat using a burrowscope to get the most accurate estimate of what proportion of burrows contain a breeding pair. During fieldwork transect length should be measured directly on the slope (thus measuring surface length rather than planar length). All involve calculating the breeding population size using habitat surface area, considering the slope of grey petrel habitat, and the potential loss of habitat from slip-scouring, to get the best possible estimate of the true surface area of grey petrel habitat.

For the most accurate estimate, sampling to estimate burrow occupancy is best conducted in the second half of April from representative habitats. Burrow density sampling is less timing-sensitive, so density sampling could take place March–April.

These methods are expected to refine the accuracy of the resulting population size estimate: sampling widely and comprehensively throughout the grey petrel range; directly accounting for burrow detection probability; and using accurate measured areas applied to the true surface area of grey petrel habitat.

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Appendix A

Historical data review for grey petrels *Procellaria cinerea* on Antipodes Island

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1. Background

Antipodes Island holds the main population of grey petrels (*Procellaria cinerea*) in New Zealand, being recorded on the island from mid-February to November, and population estimates have ranged from 10,000 to 53,000 (Warham & Bell, 1979; Imber, 1983; Robertson & Bell, 1984; Bell, 2002; Sommer, *et al*., 2010; Bell, *et al*., 2013; Thompson, 2019). The Department of Conservation (DOC) commissioned work to investigate the requirements needed for updating the population estimate and trends for grey petrels on Antipodes Island (CSP2020-04 - Grey petrel population estimate methodology, Antipodes Island).

Wildlife Management International Ltd. (WMIL) hold, and have permission to use, the field notebooks of the late Brian Bell and the late Mike Imber from Antipodes Island expeditions between 1969 and 2001. In addition to this historic data, WMIL led the 2001 Antipodes Island expedition to investigate the feasibility of establishing a long-term field programme to determine the current population size and monitor the population trend of grey petrels for DOC Conservation Services Programme (CSP). The results from this work were published in an internal DOC series (Bell, 2002) as well as in Notornis (Bell, *et al*., 2013). Data on other bird species sighted to, from and during this expedition were also published in Notornis (Imber, *et al*., 2005).

As part of this CSP2020-04 investigative work, DOC contracted WMIL to collate the historic data from the 1969, 1978, 1994 and 1995 trips from the field notebooks of Bell & Imber and 2001 expedition data. Electronic copies of the 2001 data and GIS shapefiles have been provided to DOC.

2. Data

Expeditions to Antipodes Island include: 28 January to 12 March 1969 (Brian Bell, BDB); 8 November to 3 December 1978 (BDB and Mike Imber, MI); 13-30 December 1994 (MI), 27 October to 29 November 1995 (MI) and 23 April to 10 June 2001 (WMIL, including EAB, BDB and MI).

The information collected in the 1969, 1978, 1994 and 1995 expeditions varied depending on the aim of each trip. The 1969 University of Canterbury expedition was focused on collecting general information about the island as well as separate research projects including general bird counts (focusing mainly on albatross, giant petrels and penguins with additional petrel and shearwater species presence or absence data collected as well) and collecting bird specimens for museums. Much of this research was covered in Warham & Johns (1975) and the bird work separately covered by Warham & Bell (1979). The 1978 expedition was a multi-agency trip to assess birds, invertebrates, mammals, and vegetation of the island. Department of International Affairs and New Zealand Wildlife Service internal reports were produced following this expedition and these are stored in National Archives. The 1994 and 1995 expeditions were focused on identifying whether taiko (*Pterodroma magentae*) were present on the island, although surveys of white-chinned petrels (*Procellaria aequinoctialis*), Antipodean albatross (*Diomedea antipodensis*) and other albatross species were also completed. The 2001 expedition was specifically focussed on grey petrels, although other bird observations were made. The outcomes of this research is covered in Bell (2002), Imber, *et al*. (2005) and Bell, *et al*. (2013).

The data has been separated into Historical Observations taken directly from field notebooks (Section 2.1), 2001 Expedition as summary of data collected (Section 2.2), Banding Data from all expeditions (Section 2.3) and a Summary of key information (Section 2.4).

2.1 Historical observations

2.1.1 1969 Observations on grey petrels

6 January 1969 - due to "the wind still in the north and coming in on the landing beaches - the worst direction possible and very unusually for these seas" the expedition left Antipodes and "steamed onto Campbell, followed by many grey petrels" and other seabirds.

1 February 1969 - "Freshly killed grey petrel on Plateau." "Found in midden of southern skua"

9 February 1969 – "One grey petrel in burrow – recorded calls."

10 February 1969 - "John (*Warham*) caught a grey petrel during the day so I (*Brian Bell*) saw my first live specimen and banded it – Z-band (Z-1010).

12 February 1969 – **"**Several seen over the island from about 7 pm."

14 February 1969 – "At night we went up onto this end of the North Plain but failed to catch any petrels. Although we saw many and heard greys"

15 February 1969 - Orde Lees camp site, at night: "The grey petrels were most numerous in the fading light, but the shoemakers were not so numerous." "Grey petrels were very noisy everywhere" "Over Western Plain and to the south of Cave Point, grey petrel seems to be the most common early arrival."

16 February 1969 - "grey a close second to the white-headed petrel in being the most numerous species, with grey petrel replacing white-headed petrel during winter."

Latter half of February 1969 - "now very common petrel in the evening sky"

22 February 1969 - "managed to get him a grey petrel (specimen for Canterbury Museum) which completes most of his requirements"

23 February 1969 – "Later I helped Rowley (*Taylor*) photograph a grey petrel with his flash."

2.1.2 1978 Observations on grey petrels

8 November 1978 (BDB) - "Grey petrels coming over late at night."

21 November 1978 (MI) - "apparent grey petrel burrows deserted; chicks have left. Possibly those full of fleas. Chicks may have left about 3 weeks ago. Few killed by skuas."

23 November 1978 (MI) - North Plains "Also 2 grey petrels, one adult, one chick with stunted wings and small skull, an undernourished runt." "At skua territory on hill opposite Mt Galloway remains of grey petrel fledgling with many squid beaks. This fledgling possibly 2-3 weeks dead." "Others banding *D. exulans* gave me foot of a grey petrel, obviously a chick with very sharp clean claw points. This still fresh and supple indicating death within last 3 days. Thus, chicks may leave up to as late as 23 November."

29 November 1978 (MI) – Bollons Island – "At top along the leading ridge, fair number of large burrows. Took a fully feathered grey petrel fledgling from one of those. Also found only little shearwater and grey petrels in skua kills so assume that nearly all those high burrows belong to grey petrels. A very exclusive and dense colony with skuas almost entirely dependent on them. Possible that there are really mor breeding on the main island."

30 November 1978 (MI) "Skua middens from Bollons Island: 10 *Procellaria cinerea*."

1 December 1978 (MI) – "Possible odd *P. cinerea* skulls but none positively identified until remains of 2 fledglings found not far below the fly-camp in upper Ringdove Creek. One of those had been killed last night or the previous one and was still somewhat downy on wing feather tips so was completing fledging and possibly would not have departed till first few days of December. Late."

3 December 1978 (MI) gorge mouth of stream opposite Orde Lees Island – "Nests of white-headed petrels, white-chinned petrels and grey petrels everywhere" "Grey petrel remains in skua middens – Bollons nest (3), Anchorage Bay/near Perpendicular Head (5), North Plains (1), Bollons Island (1), Ringdove Valley (7), Orde Lees Stream (6)"

2.1.3 1994 Observations on grey petrels

14 December 1994 – at sea sailing to Antipodes "*Procellaria cinerea* seen in evening"

16 December 1994 – at sea sailing to Antipodes "No grey petrels seen"

20 December 1994 – North Plain's skua middens "3 *Procellaria cinerea* skulls"

2.1.4 1995 Observations on grey petrels

29 October 1995 – at sea sailing to Antipodes "plenty of grey petrels about and accompanying"

3 November 1995 – "Conical Hill appears to be dominated by grey petrels with lesser numbers of white-chinned petrels. Three skua kills of fledglings (feathers only) but not all seem to have gone."

6 November 1995 – "skulls from North Plains – 6 grey petrel" "analysed another lot of skulls from North Plains – 6 grey petrel"

9 November 1995 – "Grey petrel skulls: North plains (12), Mt Galloway (2), Pothole Country (4) and Area 3 (6)"

10 November 1995 – Lower Crater (floodlight site) "Caught a fully-fledged, but fat (1.23 kg) grey petrel by the light – not clear which burrow it came from – seemed to be a long way from home."

11 November 1995 – Camp Station Gully "No adult grey petrels, but two more fledglings caught near Hut, 1 nearly fully feathered (1.1 kg) and 1 quite downy (c 750 g only)."

12 November 1995 – "1 grey petrel fledgling caught on track in soft-plumaged petrel area, fully feathered, banded Z-23089."

13 November 1995 – "Grey petrel skulls: northern North Plains (1), east of Mt Galloway/head of Dougall Stream (4), Mt Galloway saddle (2), Hill 208 (1), central North Plains (3), Dougall Stream Basin (2) and North Plains/Conical Hill (1)"

14 November 1995 – "Grey petrel chicks not seen, so may have already departed safely." "grey petrel skulls: top of Mt Galloway (1)"

20 November 1995 – above Alert Bay and on top of GP Hill "at least 7 grey petrel chicks in the colony on this hill."

22 November 1995 – Crater Bay – "5 grey petrel skulls"

27 November 1995 – at sea "one grey petrel seen"

28 November 1995 – at sea 90 nm SE of Otago Coats "No grey petrels seen."

2.2 2001 Expedition

During the 2001 expedition the island was surveyed to determine grey petrel distribution and trial methods to establish a long-term monitoring programme. The results are detailed in Bell (2002) and Bell, *et al*. (2013) with additional information on all birds in Imber, *et al*. (2005).

Over 140 transect surveys were completed across the island and four survey quadrats were established. The transects suggested that the distribution of grey petrels was restricted to steep, well-draining areas dominated by *Poa litorosa* tussock (approximately 510 ha of the 2025 ha island). Occupied burrow density within the 4 census grids ranged from 31 to 44 burrows (0.01 burrows per square metre). Extrapolating from the census grid density to the total grey petrel habitat resulted in a population estimate of 114,730 birds; 53,000 breeding pairs (range = 32,000-73,000) and 8,670 non-breeding-birds (range = 4,000-16,320) were present on Antipodes Island.

Additional observations regarding grey petrels from expedition members notebooks and the field log include:

22 April 2001 – Ringdove Bay "grey petrels coming in by 3 pm and flying along the slopes, some seen to land early, but others kept flying" "calling at night"

23 April 2001 – Ringdove Bay "grey petrels coming in again from 3 pm" "at night calls of grey petrels - a few only, though many flew around (breeders?) in later pm" "did not see any petrels circling over Leeward Island, so not a grey petrel breeding place probably"

25 April 2001 – Anchorage Bay "in pm, fair numbers of grey petrels came in"

26 April 2001 – "grey petrels active at camp in evening" Hut Creek 8-9 pm "a grey petrel displaying nearby – the only one heard in this valley"

28 April 2001 – "numerous grey petrels calling on the T.T. Hills around 6 am" "no grey petrels in grid on the ridge opposite hut. However, found 5 others on periphery of this ridge: 3 or 4 on eggs." "Pair in the cave where the white-chinned petrel had been in 1969.” “One very agitated adult on egg was banded newly.”

29 April 2001 – “more grey petrel burrows searching on T.T. Hills. Found c. 12 burrows and caught 7 nice birds – banded all on R leg, eggs not measured.” “burrowscoped the burrows found yesterday – 3 incubating and 1 empty at Hut Cove – all with a 2 m radius” “above Stella Bay – 2 burrows: 1 empty and cleared out and nest added – probably non-breeding; other deserted egg – the bird caught yesterday (v. agitated)” lower Hutt Station alley “looked for grey petrel burrows – got 2 incubating, one adult caught and other out of reach (c. 1.8 m); brayed when disturbed; also found also 1 probably empty burrow”

30 April 2001 – MI banded and measured 14 grey petrels at Craters and Hut Cove (Z54234-54249), “checked 20 burrows, 3 with pairs (1 pair almost certainly had egg – felt with a stick). Pairs calling actively. Very long burrows at Craters, and many seemed empty. Biennial breeding?” “All burrows fairly simple and straight with occasional bend at end.”

1 May 2001 – “many grey petrels calling at 5 am on little T.T. Hills – calls receding into the distance. Indicates large numbers there.” “Tape calls at grey petrel burrows: male responded well” “another bird incubating, but not first one found. Been a change over there or at least bird out for a poo.” “Dead chick of last year found at mouth of a fourth burrow – no response to tape – so possibly unoccupied. Chick a fledgling but wings still short, so probably starved.” “Burrows on the ridge seen mainly white-headed petrel, white-chinned petrel and diving petrel in that order, with some grey petrel around the periphery.” “on Conical Hill, nests were mainly white-chinned petrels and white-headed petrels with possible odd diving petrel, but no grey petrels evident although one circled the hill at 5 pm.”

2 May 2001 – “hardly any grey petrels though, 1 or 2 near hut, and the TT Hills silent (compared to 2-3 nights ago). Calm weather and some moon (1/2) may be inhibiting non-breeder activity.”

3 May 2001 - Upper Dougall Stream “no grey petrel burrows until on way back along the cliff edge” “found about 4 beside Dougall Stream in dense *Poa/Polystichum*, not able to reach birds.”

4 May 2001 – “Some grey petrels again at dawn on TT Hills.”

6 May 2001 – Reliance Ridge (westward) “no grey petrel burrows seen” “grey petrel burrows on bluffs above South Bay; pair calling probably. One seen to land in midst of extensive area of *Polystichum* fern at 1 pm.” Heading down Ringdove Stream campsite “found grey petrels in mid-slope and right down to flats. One pair duetting. Four corpses, 1-3 months old, in same area with numerous burrows. All very long, big and dry. Several with incubation signs but only 1 incubating bird detected – nibbled stick; and fleas!” “In transect down from ridge c. 15-20 probable grey petrel burrows, but also some likely white-chinned petrel burrows close by. All grey petrel burrows quite dry. One pair lowest down in dense tussock but upper ones in quite open habitat more typical of white-chinned petrels” “large rectangular entrances, well cleaned and clear entrances”

7 May 2001 – Mt Waterhouse “one pair of grey petrels on Skua Ridge in damp muddy burrow, shallow chamber, caught and banded. Duetting. Possible several similar burrows nearby.” “grey petrels again found on mid-ridges of Mt Waterhouse: bird calling from burrow – probably male call as in response to tape recording. Responded to tape also. One old predation – c. 2-3 months in same area. A few burrows all very long, look like grey petrel, but no response to stick or tape, all in same area. Possible 8 or so burrows looked at, all could be grey petrels”. Central Plateau “at a Tor another grey petrel in burrow calling – male? Call and responding to our activity at first and then to tape. A fairly short burrow with two entrances.” “No certain grey petrel burrows seen on way up southern side of Mt Galloway and down the eastern side of hill.” “hardly any calling petrels at night, just a few grey petrels near the Hut" "grey burrows found on sloping ground – never on flat or top of hills, usually on ridges, sloping faces or cliffs, if on gentle slopes burrows seem to be on knobs"

8 May 2001 – "no grey petrels in the Petrel Cave" "good numbers of grey petrels came in late pm." "All day one can see a few grey petrels in flight"

9 May 2001 – Craters – "during transect work saw several grey petrels flying over in late pm" "2 incubating grey petrels responded to tape (? males) of the possible 6 occupied burrows including one outside the transect" "grey petrels on upper slopes of Craters" "grey petrels flying silently and a few calls, but only in early evening (5-8 pm) and especially towards dawn (3-6 am) especially on TT Hills."

10 May 2001 – Craters – "150 m cliff line transect – 1 white-chinned petrel (chick), 20 diving petrels, 24 whit-headed petrels, 4 grey petrels, 1 parakeet old nest site. Burrowscoped and tape/response at all grey petrel burrows." "The 4 grey petrel burrows – 2 unoccupied but apparently in use (fresh nest material) but one all mossy at mouth as if disused; 2 occupied: 1 no tape response but bird incubating (egg seen); other tape response (male incubation type call given) not burrowscoped; 1.4 m and 2 m long respectively." "Several grey petrels in area late pm" "grey petrels more active towards dawn – c. 4 am"

11 May 2001 – North Head grid "all 5 grey petrel-type burrows in use, nest material but empty; no poos" "ca. 28 grey petrel burrows but only half occupied" "1 chick in grid, c. 3 days old – ca. 10 March laying." "most incubating birds visible with torch via entrance, as all very long and facing straight." "grey petrels flying about all afternoon and 1 seen to land" "plenty of grey petrels calling on TT Hills in evening, but few in early am"

12 May 2001 - Craters – cliff line transect finished, only got 1 possible grey petrel burrow - empty and not in use at present. There were just 5 grey petrel burrows in the 300 m transect and only 2 occupied. The 3 others all somewhat doubtful in various ways."

13 May 2001 – Alert Bay "found a dead (killed?) sooty shearwater chick in one of the grey petrel burrows in a grid. At edge of nest chamber, as if killed after burrow competition. Recent death?" "Many grey petrel burrows in grid large and straight enough for birds to be seen with torch via entrance." "fair number of grey petrels on TT Hills"

14 May 2001 - Clark's Hills "2 transects, from Dougall Stream to Hill 270, grey petrels in first 60 m only (7 burrows; 2 incubating, 1 pair and 4 inactive" "Grey petrel calling (bray) about 20 m away across stream" "With the strong wind, many grey petrels coming in from noon, and especially from 3 pm"

15 May 2001 – "grey petrels flying over TT Hills and near Hut most of day" "a few grey petrels calling early evening then quiet"

16 May 2001 – "6 grey petrels flying over Alert Bay, 3 landed on small bluff at sea level, couldn't see if went into burrow, another landed on edge into tussock/*polystichum*"

19 May 2001 – "grey petrels around most of day, especially from 2 pm" "a few grey petrels calling at dusk"

20 May 2001 – "plenty of grey petrels around all day" "50+ grey petrels flying around and landing at Ringdove Bay Ridge, flopping onto tussocks and sliding into burrows" "large rock faces and ledges of Ringdove Bay had grey petrels landing on tussock ledges" "lots of singing from grey petrels in burrows along cliff edges" "grey petrels calling along banks of both Ringdove Stream and Skua Stream"

21 May 2001 – "grey petrels along steep faces and stream banks facing the sea at Unknown Valley and Albatross Point" "last creek towards Albatross Point had a burrows with two grey petrels and a newly hatched chick present. Several other grey petrels calling in same area. Fewer grey petrels calling, and grey petrel burrows, up to ridge. Grey petrels landing on ridge" "traversed slope below Albatross Point – several grey petrels calling and landing. Some using very long tunnels through the *Polystichum*"

22 May 2001 – "two grey petrels landed in Alert Bay grid at c. 4 pm" "grey petrel landed in low tussocks opposite Ringdove Stream campsite – flattest site yet" "South Bay – grey petrels calling on all ridges, calling in burrows down to coast and onto south peninsular, plenty flying around (50+), low over spurs all along the coast"

24 May 2001 – "grey petrels active along Ringdove Bay slopes" "at night a few grey petrels on Mt Waterhouse slopes and 1 pair duetting just up the Ringdove Stream from the camp"

26 May 2001 – Ringdove Bay "walked length of south coast from above Ringdove Bay to SW Cape area. Followed ridge, keeping to north side out of wind using albatross paths and trails, then venturing over edge to check on grey petrels. Grey petrels seen flying all way along south slopes but especially abundant at SW Cape around the steep ridge, tussock-covered ridge down there to coast. That was also later in day (2.30 pm) – which may have slightly influenced numbers. Although birds not flying along crest of south slopes, burrows found there at all points with birds calling from burrows at 2 places where we stopped and many other burrows of grey petrel size, in use, digging or inc. signs (poos, nest material taken in) but burrows too long or bent to see birds with light and none actively seen in burrows."

28 May 2001 – Stella Bay "local grey petrel burrow check: 12 of which 5 were non-breeding (4) or failed (1). The failed one where bird deserted after handling egg now gone but burrow been visited. 3 of 4 non-breeding burrows in use. Of other 7 burrows, 2 with chicks and 5 still incubating. One chick alone, and other brooded. All 5 eggs seen OK. Banded 1 adult – not measured."

29 May 2001 – Stella Bay "local grey petrel burrow check: adult (banded Z54235) with newly hatched chick, outer primaries still a bit short, still a bit of wing and tail covert moult, good weight - a lot of food for chick in tummy? Chick very small" "Cave cliff edge burrows – No. 1 burrowscoped again: grey petrel still incubating egg. Possible peeping heard, not apparent if pipping yet – deep nest? No. 2 burrowscoped again: grey petrel still incubating egg. No. 3 looked at egg, still 10-14 days to go probably" "Berserker Burrow – opposite hut on LHS hill of track to Stella Bay: egg disappeared, fleas and new nest material, 2 feathers, new pair prospecting?" "Track burrow to Stella Bay near cliff edge where track goes over tip of cliff: chick alone ~1 week old? Pecked and lunged aggressively in direction of the burrowscope"

30 May 2001 – "Looked for grey petrel burrows around Noticeboard Headland from ladder to stream. 5 possible grey petrel burrows, but all suspect or unusable. No birds" "1 burrow digging; 5 m, feathers – apparently has dug as enlargement of white-headed petrel burrow! Active." "surveyed burrows in and near TT Hills grid: 1 with egg, 3 had chick just hatched (<2 days) or hatching (1), 1 with male (?) that we banded with chick, 2 courting pairs in burrows outside grid (banded), checked c. 5 empty burrows in and outside grid – fleas in several. Thus, we now have 5 eggs to 5 chicks which suggests now that we are at peak of hatching and therefore laying peaks around 1st April."

31 May 2001 - Western slopes of Dougall stream below Mt Galloway - "found grey petrel burrows common and widespread in *Poa litorosa* and *Polystichum* as soon as left the sparser *Carex* tussock albatross areas." "14 burrows: (1) Adult caught and chick <2 days, (2) Unoccupied, active, digging, chamber, feathers; (3) Unoccupied, but active, (4) Bird out of reach, with egg or chick, (5) Unoccupied, being dug, chamber, no nest?, (6) Bird incubating egg, banded Z-54135, male, 1320 g (7) Unoccupied, (8) Failed breeders, pair calling out of reach, egg shell outside, cleaned out burrow,

(9) Non-breeders, pair duetting, not disturbed, (10) Adult brooding chick <2 days old, (11) adult out of reach, vocal, chick/egg/single bird?, (12) adult incubating, egg out of reach felt with stick, banded Z-54136, male, 1350 g (13) Visible with torch, adult and chick sitting side by side, chick up to 5 days old, not disturbed (14) swamp edge, adult incubating egg out of reach, seen with torch, banded Z-54137, male, 1380 g" "Total 3 chicks/3 eggs/1 failed egg: suggests that we are at peak of hatching now." "Good proportion of nests in use – 8 out of 14"

1 June 2001 – Check of burrows by camp and on TT Hills "(1) adult with chick, c. 2-3 days, banded Z-54204, (2) Courting pair under ledge, digging, gone, previously banded, (3) Nest being dug on track very fresh, well advanced, (4) adult (Z-54244) on egg, egg very well pipped and cheeping, (5) Chick, alone and active, (6) Bird out of reach, vocal, incubating egg/guarding chick?, (7) Empty, as before, (8) Empty, as before, (9) Bird alone, on nest, no egg, banded Z-54138, stroppy!, 1020 g, (10) Chick, alone and active, (11) Bird with chick, guarded, out of reach (12) Bird with chick, 3-4 days old being guarded, (13) Bird with egg or chick, out of reach and not seen (bird felt), (14) Bird with chick, out of reach, not seen (felt with stick), (15) Bird on pipped egg, not removed, (16) Bird with chick, not visible, probably guarding. Egg membranes/shell visible, (17) Chick, alone and active, (18) By track to Hut Cove, bird brooding new chick, burrowscoped, chick c. 1 day old, (19) Hut Cove, lidded, egg removed and candled (c. 7 days to go), (20) Hut Cove, bird incubating egg seen by burrowscope, bird seems proactive, ? pipped egg." "Therefore 9 chicks, 4 eggs, and 2 uncertain (egg or chick), 2 eggs well pipped. Seems that there is a pronounced peak of laying around 25 March to 5 April." "small bluff between Clark's Hill and Craters had grey petrel burrows"

2.3 Banding data

Table A1. Banding data from all 1969, 1978, 1994, 1995 and 2001 expeditions to Antipodes Island.

Expedition	1969	1978	1994	1995	2001
Number banded	6	Nil	Nil	1	78
Age class	adult	n/a	n/a	pullus	adult
Band numbers	Z1010-Z1015	n/a	n/a	Z-23089	Z54101-Z54138 Z54141-Z54142 Z54150 Z54201-Z54217 Z54222 Z54232-Z54250
Bander	Brian Bell	n/a	n/a	Mike Imber	Elizabeth Bell, Joanna Sim, and Mike Imber

2.4 Summary of key findings

Table A2. Key findings on grey petrels from all 1969, 1978, 1994, 1995 and 2001 expeditions to Antipodes Island.

	1969	1978	1994	1995	2001
First appearance at Antipodes	1 February (dead) 9 February (in burrow)	n/a	n/a	n/a	n/a
First egg recorded	n/a	n/a	n/a	n/a	n/a
Peak laying	n/a	n/a	n/a	n/a	25 March – 5 April
First chick recorded	n/a	n/a	n/a	n/a	9 May
Peak hatching	n/a	n/a	n/a	n/a	31 May
Chick fledging period	n/a	Up to 23 Nov (and 1 Dec)	n/a	Up to 20 November	n/a
Population estimate	10-50,000	n/a	n/a	10-50,000	53,000

3. Acknowledgement

WMIL thank the families of Dr. Mike Imber and Brian Bell for the permission to use their field notebooks to collate their recollections of grey petrel behaviour and occurrence on Antipodes Island.

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Appendix B

GIS-based mapping resources to inform planning of grey petrel survey

The grey petrel distribution defined in the feasibility study (Bell 2002) was confirmed over the course of subsequent burrowing petrel work 2007–11 (NIWA unpubl. data 2007–11). Figure B1 illustrates the grey petrel distribution, which was digitised by Kelvin Floyd for Bell *et al.* (2013), with several data layers from LINZ Data Service.

Landslips in January 2014 are seen clearly in a composite of satellite images by Graeme Elliott (imagery by DigitalGlobe). A map was drawn shortly after slips occurred to document their extent. Both slip resources are show in the main text, in Figure 2.

These resources will be valuable when planning a grey petrel population size estimate. Once the preferred method has been chosen, grey petrel study design can proceed using a GIS resource as shown in Figure B2, combining satellite imagery, the grey petrel distribution and LINZ layers for the Antipodes. Together with these layers, a digital elevation model (not shown; DOC GIS unpubl. data 2015) should be used to determine true surface areas of the areas of interest, particularly slips and the grey petrel distribution.

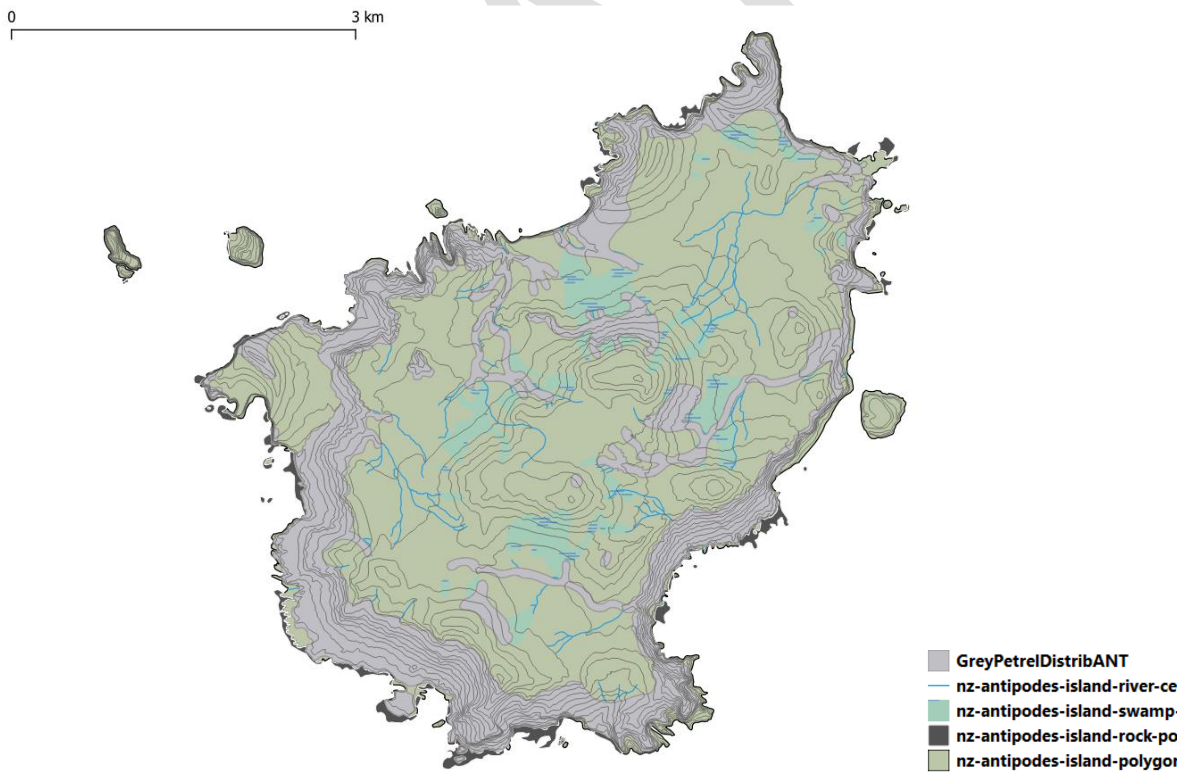

Figure B1. Grey petrel distribution (grey shading) with other Antipodes layers in GIS. Grey petrel distribution layer by Kelvin Floyd for Bell *et al.* (2013), other data layers all LINZ

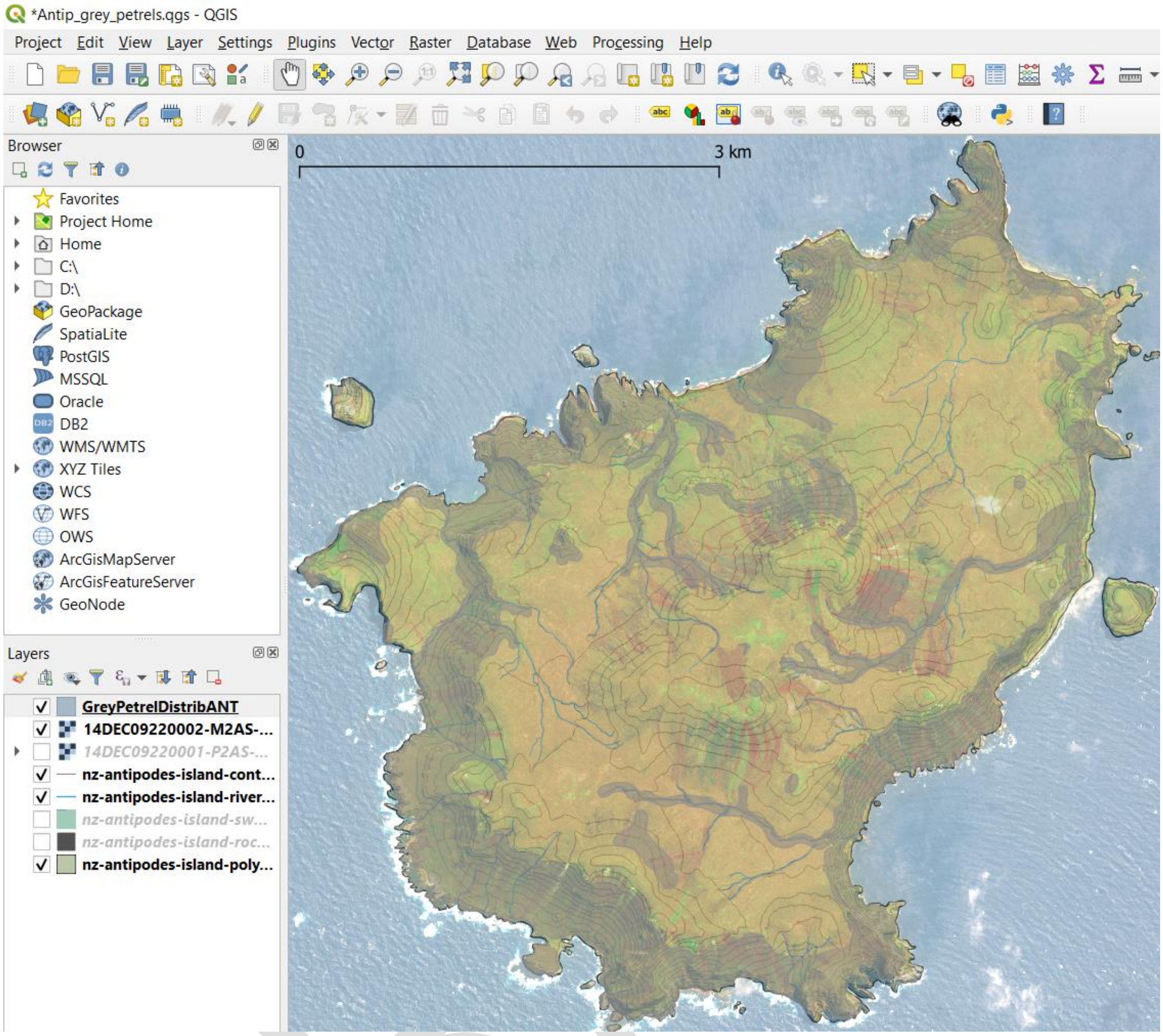

Figure B2. Example of GIS workspace for planning grey petrel survey. Data layers from Bell *et al.* (2013), LINZ Data Service and DigitalGlobe Inc