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ORIGINAL PAPER

The white-chinned petrel (*Procellaria aequinoctialis*) on South Georgia: population size, distribution and global significance

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Abstract More white-chinned petrels (*Procellaria aequinoctialis*) are accidentally killed in fisheries than probably any other seabird in the world, but the population impact of this mortality is poorly understood, partly because there have been no recent estimates of the species' abundance. The breeding aggregation on the sub-Antarctic island of South Georgia is believed to be larger than all others combined. We estimated the size of this population by calculating the area of suitable habitat and the density of occupied burrows within it. Some 670,000 occupied nests were estimated for the island at mid-incubation, representing 0.9 million pairs of breeding-age birds associated with South Georgia in the survey seasons (2005/06 and 06/07). This is 40–45% of the previous estimate, but still represents well over half of the global population. If the population is declining due to fishery bycatch, as is likely, the scale of annual mortality in this population alone is at least in the high tens of thousands, and plausibly hundreds of thousands.

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Introduction

Burrow-nesting seabird species are individually and collectively some of the most abundant wild birds on Earth, yet robust population estimates exist for only a handful of the more than 100 taxa that nest under ground. There are several reasons for this. First, the birds themselves are at the sea for most of the year, often spread over vast areas of ocean. Second, when ashore during the breeding season they spend little or no time above ground during daylight hours. Third, breeding colonies are usually on remote, inaccessible islands. Finally, the nests are visually and physically inaccessible, at the end of a long narrow burrow, usually a metre or more underground, and often with the entrance hidden in dense vegetation.

The white-chinned petrel (*Procellaria aequinoctialis*) is a long-lived, slow-reproducing, burrow-nesting seabird that occurs throughout the mid- and high-latitudes of the southern hemisphere (Brooke 2004). More white-chinned petrels (WCPs) than any other species of seabird are accidentally killed each year by fishing gear south of the equator (Weimerskirch et al. 1999; Robertson et al. 2006), and perhaps worldwide (Montevecchi 2001). The scale of the mortality is known to be at least high tens of thousands annually. But this excludes losses due to illegal and unregulated fishing, and to fisheries where observers are not present, so the total bycatch is certainly much greater than is currently quantified. The species is classified as *vulnerable* in the IUCN red list (Birdlife International 2007).

South Georgia has long been considered to hold the largest breeding population of WCPs in the world and, with an estimated 2 million pairs (Prince and Croxall 1983), that population could perhaps sustain high levels of fishery-linked mortality. However, the estimate on which that assumption was based is both out of date and subject to uncertainty because it was an extrapolation based on data from Bird Island, a relatively small and rat-free island off the extreme western end of South Georgia. With annual fishery-induced adult mortalities on such a scale, and a current population of unknown size, a thorough re-evaluation of the South Georgia WCP breeding population was long overdue. This paper presents the results of the first all-island survey of breeding WCPs on South Georgia. The objective of the study was to obtain an estimate of the breeding population in order to improve understanding of (a) the impact of fishery bycatch on the species, and (b) the impact of this petrel on the prey resources of the region in relation to fisheries.

The size, topography and climate of South Georgia, together with the subterranean nesting habits of the study species, presented scientific challenges that required solutions at geographical scales varying from metres to hundreds of kilometres. These were overcome using a variety of techniques from the investigation of individual burrows by hand to satellite-based estimation of vegetation cover of the whole island.

Study area and methods

South Georgia is an ice-cap dominated sub-Antarctic island situated south of the Polar Front at 54–55°S, 36–38°W. It is ca. 190 km long and has a land area of 3,900 km^2. Vegetation occurs only near the coast, much of it tussac (*Parodiochloa flabellata*), a stool-forming grass which occurs in dense stands up to 2 m high.

The island is sufficiently large and geographically complex such that it varies climatically from north to south and east to west. Some areas have been ecologically modified by introduced rats (*Rattus norvegicus*) and reindeer (*Rangifer tarandus*) (Headland 1984; Leader-Williams et al. 1987). The north coast has a milder climate than the south, more vegetation and deeper soils. It is more attractive to wildlife, but much of it also hosts the introduced mammals, which may have a negative impact on nesting seabirds (Jouventin et al. 2003).

Because these environmental factors are likely to influence the probability of a WCP choosing to nest at any site, the extrapolation of density estimates from one ecological zone to another could lead to error. For the purposes of this study, South Georgia was therefore stratified into eight eco-geographic zones, and the population size of WCPs estimated separately for each. These zones were dictated primarily by climate, vegetation and the presence of introduced mammals (Table 1; Fig. 1).

WCPs on South Georgia nest only in the vegetated coastal strip, and only in stands of pure tussac or where tussac is the dominant vegetation. Particular landscape features such as headlands and ridges are preferred. The basis of the current survey was to estimate the density of occupied white-chinned petrel nests per unit area of suitable habitat (i.e. tussac-dominated vegetation) within each of the eco-geographic zones, to multiply this by the surface area of the habitat within that zone, and then to sum across all zones to gain an all-island value.

This petrel nests in relatively small, discrete colonies of typically 50–200 burrows, patchily and sparsely distributed (authors' unpublished data). Methodology used to measure their abundance must therefore be robust to patchiness and avoid bias due to inappropriate extrapolation from high- to low-density areas or vice versa.

Density estimates were obtained by walking straight-line transects across areas of suitable habitat and stopping every ca. 10 m to closely examine the ground within a sampling plot of 3 m radius (using a stake and a rope of this length to swing an arc). This radius was the maximum that a single observer could reasonably cover in dense tussac without the possibility of missing or double-counting burrows. The location and altitude of each sampling plot was recorded using a GPS unit, and the angle of slope at that point was estimated by eye. Transects were always walked across the likely density gradient of WCP nests, usually from the coast to the upper limit of tussac or vice versa, and not parallel to the coast or along ridges (where many colonies occurred). Transects were spread around the coast of the island to give as representative a coverage as possible in the time available. Landings were made in areas of habitat suitable for WCP nesting (i.e. tussac-dominated vegetation), and at each site field personnel fanned out to cover as much ground as possible.

Very little of South Georgia is flat, so planimetric data substantially underestimate the surface area of habitats on the island, especially that of tussac which invariably occurs on slopes. Conversion from planimetric land area to contour area in each zone was made by dividing the zone into 50 × 50 m planimetric squares, then multiplying the area of each square by the reciprocal of the cosine of the slope of that square, taken from a digital map with 50 m contours.

WCPs are the largest burrow-nesting seabird on South Georgia by far. Their burrows are correspondingly of greater diameter than those of other species, and some burrow entrances are also characteristically part-filled with water, so that the risk of misidentifying the occupying species is negligible. Only burrows that appeared to be

Table 1 The eight eco-geographical zones into which South Georgia was divided for the purposes of this study (see Fig. 1)

Zone number	Zone name	Characteristics
1	Northwest	Moderately cold, rats, reindeer free
2	Nunez	Only site on south coast with considerable tussac areas, rat and reindeer free. North facing
3	Salisbury	North coast, moderately cold, rats, reindeer free
4	Stromness and Cumberland	Central north coast, warm, rats. Reindeer at Stromness.
5	Barff	North coast, moderately warm, rats and reindeer
6	Southeast	Cold, rats, reindeer free
7	South coast	Cold, South facing, rat and reindeer free
8	Offshore islands	Rat and reindeer free, attractive as islands

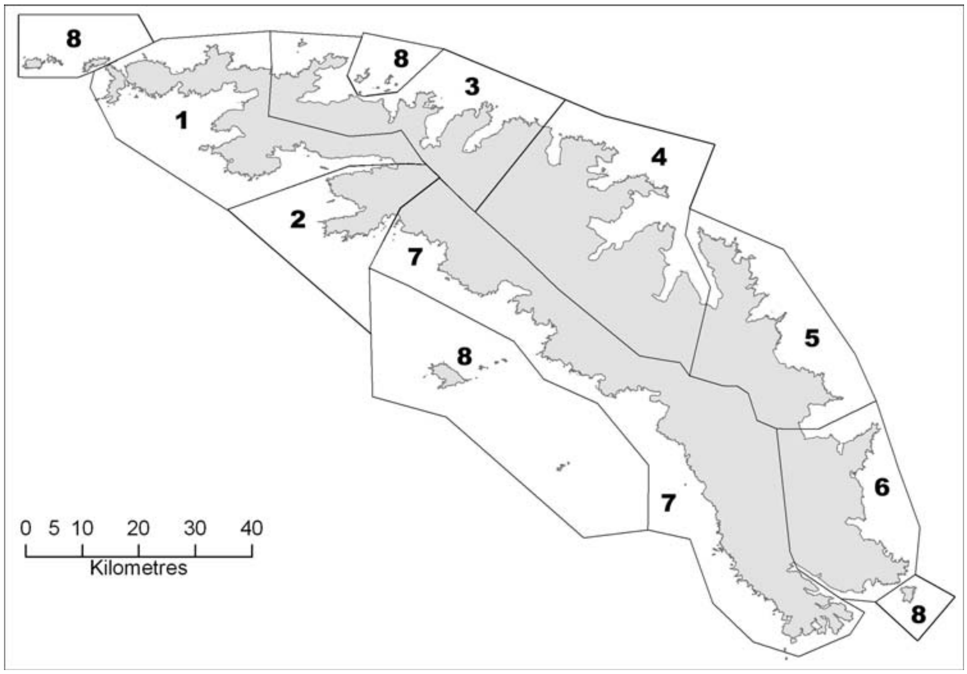

Fig. 1 Outline of South Georgia showing the eight eco-geographical zones within which the numbers of nesting white-chinned petrels were calculated independently. They are *1* Northwest, *2* Nunez, *3* Salisbury, *4* Stromness and Cumberland, *5* Barff, *6* Southeast, *7* South coast, and *8* offshore islands

potentially occupied by WCPs were counted. Any burrows that were too small to be those of WCPs, too short to be occupied or which were obviously unused (e.g. not cleaned out or with vegetation growing inside the burrow) were ignored, as were tunnels that only led to another entrance. A recording of WCP burrow-calls (both sexes combined) was played down each potentially occupied burrow with a digital voice recorder for 15 s or until a response was heard, whichever was the shorter (see Berrow 2000).

To calibrate the effectiveness of the playback technique in determining whether a burrow was occupied or not, a sample of burrows from which no response was heard was then examined using an infra-red illuminated scope (Sandpiper Technologies, CA, USA). This sample was obtained from numerous sites at different times during the study.

The total number of pairs of WCPs that occupied a burrow during the incubation period (and were therefore assumed to have laid an egg) on South Georgia was, therefore, estimated to be:

$$\sum_{\text{zones}} vt\left[\frac{\{o + (np)\}}{g}\right]$$

where

- v total vegetated area in the zone corrected for slope
- t proportion of vegetation that is tussac-dominated in that zone
- o no. of occupied burrows in all transects in that zone (i.e. no. of vocal responses)
- n no. of non-responsive burrows
- p proportion of the sample of scoped non-responsive burrows that were occupied
- g area of ground searched for burrows in zone (= no. plots × 28.274 m^2).

Due to the anticipated patchiness of WCP colony distribution, and the fact that more than one sampling plot would likely be in a colony if it was crossed by a transect, consecutive plots could not be considered entirely independent of each other—there would be a degree of autocorrelation. Consequently the transect, rather than the sampling plot, was used as the unit from which to calculate sample variance and thereby the confidence interval around the population estimate. The analysis follows that for a stratified random sampling scheme with zones as strata and transects as sampling units, using ratio estimates of density for each zone (Cochran 1977).

The area of vegetation in each zone was calculated from spectral reflectance measurements acquired in the red and near-infrared wavelengths from satellite imagery, expressed as a normalized difference vegetation index (NDVI). The NDVI ratio identifies the presence of chlorophyll, so is a proxy for vegetation density within each pixel of the satellite image. Two Landsat ETM scenes were analysed, each with a cell size of 28.5 m. Landsat scene 206098 taken on 07/02/2003 was used to provide data for 99.1% of the area of South Georgia, and the remaining 0.9% was analysed using scene 207098 taken on 02/05/2002. The resulting NDVI values were compared with detailed ground-based vegetation mapping at 13 sites representing a variety of different landscapes (Scott and Poncet 2003). From this ground-truthing, NDVI ratios above 0.02 were interpreted as indicating the presence of vegetation above a threshold density.

The area of tussac-dominated vegetation in each zone was estimated from ground-based surveying and interpretation of aerial photography, the latter informed by comparison of ground-based surveys and photography at five large sites representing a variety of landscapes and vegetation types. Aerial photographs were georectified onto the Landsat ETM image of South Georgia using Arcmap and the areas of all vegetation types then calculated. The ratio of tussac-dominated vegetation to all vegetation in each zone was estimated by simply pooling the data for all images and all survey maps in that zone.

Fieldwork was carried out during the incubation period of two consecutive breeding seasons: 13–30 December 2005 and 05 December 2006–02 January 2007. No site was visited in both seasons.

Results

Over the two field seasons combined, landings were made at 44 different sites and 288 transects were walked. This yielded detailed coverage of 6,213 sampling plots, together covering 175,668 m^2 (17.3 ha). In all, 1,089 WCP burrows encountered in the sampling plots yielded a playback response and were therefore deemed to be occupied, giving an overall average of 63.1 occupied burrows per hectare. The frequency distribution of the count of occupied burrows per sampling plot is shown in Fig. 2. By far the majority of sampling plots 94% contained no burrows, but up to 12 were encountered in a single circle of radius 3 m.

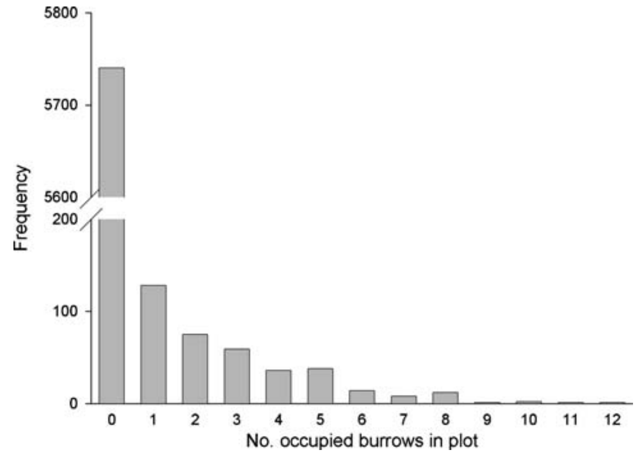

Fig. 2 Frequency distribution of the number of occupied white-chinned petrel burrows encountered per sampling plot

Results are given in Table 2. The total vegetated area of South Georgia was estimated to be 300.1 km^2, and tussac-dominated vegetation comprised between 14 and 77% of the eight different zones. The total number of occupied WCP nests on South Georgia mid-way through the incubation period was estimated to be 669,444 (95% CI = 445,485–893,403; CV = 17%) uncorrected for non-responsive birds.

Of the 58 non-responsive burrows examined by burrow-scope only one (1.7% of the sample) was found to have an incubating bird within. Correcting accordingly, the revised total of occupied nests becomes 681,189.

The estimate derived in this study is of the number of occupied nests at approximately the mid point of the incubation period. Missing from this figure are those birds that either (a) laid an egg and lost it before our visit, or (b) did not attempt to breed. Based on information in Chastel (1995) and Hall (1987), we estimate that these elements of the population are approximately 13.5 and 15% of the total, respectively. Consequently, we estimate that 773,150 nests were occupied, and that the population of WCPs breeding on South Georgia (but not necessarily every year) is 681,189 × 1.15 × 1.135 = 889,122 pairs. Allowing for error in the burrow density estimates and vegetation analyses, the 95% confidence interval about this estimate is approximately 591,671–1,186,572.

These figures are based on birds occupying burrows at mid-incubation. Their vocal defence of the burrow at this stage of the season implied that they were actually incubating eggs, and this was confirmed every time the burrow-scope was used to investigate a nest chamber. But it is certainly possible that a small proportion of birds located were not breeding, and that consequently the estimates of

Table 2 Summary results of the WCP survey of South Georgia, by zone, including the vegetational analysis on which it was partly based

Zone	Vegetated area (ha)	Tussac (%)	Area of tussac (ha)	Area searched (ha)	No. transects	No. occ. burrows	Density occ. burrows (ha^{-1})	Estimated no. occ. burrows	CV (%)	SG popn (%)
1	4,671	76.7	3583	1.9	44	76	40.9	146,545	55	21.9
2	2,924	62.6	1831	1.3	24	141	105.9	193,838	29	29.0
3	2,735	17.2	470	1.0	18	35	34.9	16,365	53	2.4
4	6,786	14.2	962	4.3	89	288	66.9	64,361	37	9.6
5	6,488	38.4	2490	1.2	32	58	48.0	119,594	37	17.9
6	2,671	60.6	1618	0.4	4	10	26.8	43,355	43	6.5
7	1,661	63.0	1046	0.7	10	0	0.0	0		0
8	2,078	57.9	1204	6.8	67	481	70.9	85,385	22	12.8
Σ	30,014		14,990	17.6	288	1089	63.1	669,444	17	100

Zone numbers refer to regions of South Georgia shown in Fig. 1. The vegetated area, calculated from planar satellite imagery (see text) has been corrected for slope. The percentage of tussac-dominated vegetation in each zone was estimated from visual interpretation of aerial photography. The number of occupied burrows shown is not corrected for non-responsive birds (see text)

breeding pairs given above may be slightly positively biased.

Discussion

The distribution of white-chinned petrel nests on South Georgia displays a marked geographical variation with lower densities on the south coast than elsewhere. This is likely due to the harsher climate in this zone, and to the consequent shallow soils and scarcity of suitable breeding habitat. Winter snow and ice melts later here than on the north coast, so prospecting birds would have to wait longer before attempting to excavate or clean out a nesting burrow. Our sampling in this area happened not to encounter any WCP nests at all, so the population estimate is necessarily zero. However, we know of some small colonies along this section of coast, and more extensive fieldwork would raise the nest density estimate slightly above zero for this zone, but the numbers here are so small as to make little difference to the all-island estimate.

The results for three zones appear, at first sight, to be anomalous. Zones three and four on the warmer north coast contributed relatively little to the all-island population estimate (Table 2), whereas the small zone two on the south coast contributed as much as 29%. A partial explanation for low numbers in zones three and four is that they had by far the lowest proportions of tussac-dominated vegetation, but zone three was also found to have a low density of burrows, for reasons unknown. The high numbers of petrels in zone two (Nunez) is likely due to the fact that, despite being on the cooler side of the island, much of it faces north—facilitating a coverage of dense tussac, the ideal WCP habitat. This peninsula is also free of potential negative impacts of rats and reindeer (McIntosh and Walton 2000) and is distant from glaciers compared to most other sites on the south side of the island, giving it a milder climate. It was also notable that zone eight, the offshore islands, did not have especially high burrow density in suitable habitat, and held just 12.8% of the South Georgia WCP breeding population. Burrow-nesting petrels normally favour island breeding sites, especially those with large areas of suitable habitat, as here. However, South Georgia itself is an island, albeit a large one, and it appears that the offshore satellites such as Albatross, Annenkov, Bird and Cooper islands are not greatly more attractive.

The only previous estimate of WCP population size on South Georgia was of ca. 2 million pairs in the late 1970s (Prince and Croxall 1983). This figure was an extrapolation from the estimated number of pairs on Bird Island, taking into account the area of suitable habitat on the main island (J.P. Croxall, personal communcation). On this basis, the WCP population of South Georgia has long been considered to be the largest in the world by far, representing more than half of the global total (e.g. Brooke 2004). Latest estimates of the size of other major breeding populations indicate that together they hold perhaps half a million pairs. The results of the current study indicate that the size of the South Georgia breeding population is currently some 40–45% of the former estimate, and this reduces the estimated world population by almost half. But even with a population much smaller than previously assumed, South Georgia still holds more white-chinned petrels than all other sites worldwide combined.

The basis of this new South Georgia figure is very different to that of Prince and Croxall (1983), so we cannot infer that the WCP population has diminished to this extent in the space of some 30 years. However, the scale of known and likely mortality of WCPs in fisheries is so great that a decline in the breeding population is very likely. Indeed Berrow et al. (2000a) estimated that the population size of WCPs on Bird Island, South Georgia, had decreased by at least 28% over the period 1981–1998; an average annual decline of 1.9%.

The total number of birds of all ages in the South Georgia WCP population cannot be calculated directly on the basis of existing knowledge, but it is certainly much greater than just the breeders. This petrel, like most others, takes several years to reach sexual maturity, so a large proportion of the population comprises immatures that will spend little or no time at the colony. Few studies of Procellariiformes have attempted to calculate the ratio of breeders to non-breeders, but the most relevant to the current work is that of Simons (1984) who estimated that, at stability, about 48% of a Hawaiian Petrel (*Pterodroma sandwichensis)* population would be of breeding age. Applying this ratio to our estimate of breeding pairs of WCPs on South Georgia yields an all-age estimate of some 3.7 million birds.

With an average body mass of 1.31 kg (Hall 1987), this population has an estimated combined biomass in excess of 4,800 tonnes and must consequently be one of the most important marine predators of the region. Berrow and Croxall (1999) examined the diet of WCPs in the late 1990s during the breeding season, when most foraging is carried out around South Georgia and in the Scotia Sea (Berrow et al. 2000b; Phillips et al. 2006), and found that Antarctic krill (*Euphausia superba*) was the dominant prey, comprising some 42% by mass. Croxall et al. (1984) estimated that a breeding population of just over twice the current size consumed some 770,000 t of prey annually, comprising squid (366,000 t), krill (210,000 t) and fish (187,000 t). These authors did not attempt to estimate the quantity of food consumed by pre-breeders, but if they are approximately equal in number to the breeders then the figure of 770,000 t may be similar to the consumption of the all-age South Georgia population today. Based on data in Berrow and Croxall (1999), overlap between the WCPs and commercial fisheries for nekton in the Scotia Sea is probably not substantial, but the scale of krill removal may be twice that of the fishery (CCAMLR 2007).

WCPs from this population principally winter on and near the highly productive Patagonian shelf (Phillips et al. 2006) where there are large-scale fisheries for both fin-fish and cephalopods (FAO 2008; Sea Around Us Project 2008) and where most of the known and likely by-catch mortality occurs (Favero et al. 2003; Laich and Favero 2007; Phillips et al. 2006). There must be a high probability of competition with fisheries for resources here, where squid landings are of the same magnitude as the estimated consumption by WCPs (Berrow and Croxall 1999; FAO 2008; Sea Around Us Project 2008).

The number of South Georgia breeding WCPs killed by fishing operations cannot be measured directly, because few of the ships involved make any attempt to observe, record or report such captures. However, we can now estimate the likely scale of this mortality. We first assume that the rate of population decrease measured at Bird Island by Berrow et al. (2000a) represents that of South Georgia as a whole. In the most conservative scenario, we assume that the population would be in equilibrium without the bycatch, and that the 1.9% annual population decrease applies across all age classes. Then the kill will be 0.019 × (breeding population + pre-breeders) = ca. 70,000. A more likely scenario is that the population would be increasing without the bycatch (at, say, 3% p.a.), and that the inexperienced pre-breeders suffer twice the mortality rate of the breeders. In this case the anthropogenic removals would be (0.049 × breeding population) + (0.098 × pre-breeders) = ca. 276,000.

These figures are considerably greater than estimates of minimum fishery-related losses for this population, and may give a more realistic idea of the scale of the un-quantified catch. Phillips et al. (2006) concluded that in excess of 10,000 WCPs are killed each year off South America, and recognised that records are not available for the majority of fisheries involved. Because of a likely male bias in such deaths (Ryan and Boix-Hinzen 1999; Nel et al. 2002) and that this species is very likely to maintain pair-bonds over many years (Warham 1996), the number of breeding pairs impacted by fishery by-catch will be considerably greater than simply half the total removals.

The frequency distribution of occupied burrows per sampling plot (Fig. 2) demonstrates the patchiness of WCP colonies. Typically an observer would walk hundreds of metres without encountering a single burrow, but would then enter a colony and find burrows in several consecutive sampling plots.

The measurement of nest density using circular sampling plots along linear transects worked well statistically and suited both the landscape of South Georgia and the logistical circumstances of the field team. An obvious alternative—distance sampling—has been used with burrowing Procellariids elsewhere (Lawton et al. 2006), but was impractical in dense tussac. A more structured sampling regime, perhaps using plots placed according to randomised coordinates, may have further reduced the chance of introducing inadvertent bias. However, such methodology would dramatically increase the amount of time required to examine a unit area of ground, resulting in greatly reduced geographical coverage. On balance, the decision to opt for more plots, perhaps at the cost of reduced randomisation, was the correct one given the size and complexity of the area to be surveyed.

This study was one of the largest of its kind hitherto attempted anywhere in the world. In the absence of any technology that allows burrowing seabirds to be detected and identified remotely, ultimately its accuracy and robustness were determined by the number of person-days of fieldwork allocated to it. The confidence interval around the all-island estimate is fairly wide, reflecting the geographical scale of South Georgia and the heterogeneity of WCP distribution and density around the 1,800 km coastline of the main island and its satellites. Nevertheless, the results of this study provide a much-improved understanding of the true status of this species, both locally and globally, and demonstrate that the drowning of WCPs in fishery gear may have twice the population impact previously assumed.

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References

Berrow SD (2000) The use of acoustics to monitor burrow-nesting white-chinned petrels *Procellaria aequinoctialis* at Bird Island, South Georgia. Polar Biol 23:575–579

Berrow S, Croxall J (1999) The diet of white-chinned petrels *Procellaria aequinoctialis*, Linnaeus 1758, in years of contrasting prey availability at South Georgia. Ant Sci 11:283–292

Berrow SD, Croxall JP, Grant SD (2000a) Status of white-chinned petrels *Procellaria aequinoctialis*, Linnaeus 1758, at Bird Island, South Georgia. Ant Sci 12:399–405

Berrow SD, Wood AG, Prince PA (2000b) Foraging location and range of white-chinned petrels *Procellaria aequinoctialis* breeding in the South Atlantic. J Avian Biol 31:303–311

Birdlife International (2007) Species factsheet: *Procellaria aequinoctialis*. http://www.birdlife.org. Accessed 30 March 2008

Brooke M (2004) Albatrosses and petrels across the world. Oxford University Press, Oxford

CCAMLR (2007) Statistical bulletin 19 (1976–2006) Hobart, Tasmania. Ccamlr.org/pu/e/e_pubs/sb/vol19.htm

Chastel O (1995) Influence of reproductive success on breeding frequency in four southern petrels. Ibis 137:360–363

Cochran WG (1977) Sampling techniques. Wiley, New York

Croxall JP, Ricketts C, Prince P (1984) Impact of seabirds on marine resources, especially krill, of South Georgia waters. In: Whittow GC, Rahn H (eds) Seabird energetics. Plenum, New York, pp 285–317

FAO (2008) Regional fisheries statistics. http://faostat.fao.org/site/395/default.aspx

Favero M, Khatchikian CE, Arias A, Silva Rodriguez MP, Cañete G, Mariano-Jelicich R (2003) Estimates of seabird by-catch along the Patagonian Shelf by Argentine longline fishing vessels 1999–2001. Bird Conserv Int 13:273–281. doi:10.1017/S0959270903003204

Hall AJ (1987) The breeding biology of the white-chinned petrel *Procellaria aequinoctialis* at South Georgia. J Zool 212:605–617

Headland R (1984) The island of South Georgia. Cambridge University Press, Cambridge

Jouventin P, Bried J, Micol T (2003) Insular bird populations can be saved from rats: a long-term experimental study of white-chinned petrels *Procellaria aequinoctialis* on Ile de la Possession (Crozet archipelago). Polar Biol 26:371–378

Laich AG, Favero M (2007) Spatio-temporal variation in mortality rates of white-chinned petrels *Procellaria aequinoctialis* interacting with longliners in the south-west Atlantic. Bird Conserv Intern 17:359–366. doi:10.1017/S0959270907000895

Lawton K, Robertson G, Kirkwood R, Valencia J, Schlatter R, Smith D (2006) An estimate of population sizes of burrowing seabirds at the Diego Ramirez archipelago, Chile, using distance sampling and burrow-scoping. Polar Biol 29:229–238

Leader-Williams N, Smith RIL, Rothery P (1987) Influence of introduced Reindeer on the vegetation of South Georgia: results from a long-term exclusion experiment. J Appl Ecol 24:801–822

McIntosh E, Walton DWH (2000) Environmental management plan for South Georgia. British Antarctic Survey, Cambridge

Montevecchi WA (2001) Interactions between fisheries and seabirds. In: Schrieber EA, Burger J (eds) Biology of marine birds. CRC Books, Boca Raton

Nel DC, Ryan PG, Watkins BP (2002) Seabird mortality in the Patagonian toothfish longline fishery around the Prince Edward Islands, 1996–2000. Ant Sci 14:151–161

Phillips RA, Silk JRD, Croxall JP, Afanasyev V (2006) Year-round distribution of white-chinned petrels from South Georgia: relationships with oceanography and fisheries. Biol Conserv 129:336–347

Prince PA, Croxall JP (1983) Birds of South Georgia: new records and re-evaluation of status. Br Antarct Surv Bull 59:15–27

Robertson G, McNeill M, Smith N, Wienecke B, Candy S, Olivier F (2006) Fast sinking (integrated weight) longlines reduce mortality of white-chinned petrels (*Procellaria aequinoctialis*) and sooty shearwaters (*Puffinus griseus*) in demersal longline fisheries. Biol Conserv 132:458–471

Ryan PG, Boix-Hinzen C (1999) Consistent male-biased seabird mortality in the Patagonian toothfish longline fishery. Auk 116:851–854

Scott JJ, Poncet S (2003) South Georgia—environmental mapping. Technical Report No. EBS03/1 South Georgia Environmental Baseline Survey South Georgia Surveys, Stanley

Sea Around Us Project (2008) Landings from fisheries on the Patagonian Shelf. http://www.seaaroundus.org. Accessed 20 March 2008

Simons TR (1984) A population model of the endangered Hawaiian dark-rumped petrel. J Wildl Manag 48:1065–1076

Warham J (1996) The behaviour population biology and physiology of the petrels. Academic Press, London

Weimerskirch H, Catard A, Prince PA, Cherel Y, Croxall JP (1999) Foraging white-chinned petrels *Procellaria aequinoctialis* at risk: from the tropics to Antarctica. Biol Conserv 87:273–275