Aerial Census of Northern Royal Albatross (*Diomedea sanfordi*) fledglings on Rangitatahi (The Sisters) and Motuhara (Forty-Fours), July 2017


Northern royal albatross chicks, Middle Sister Island (photo credit: Sarah Matthew©)

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December 2017

(*amended and expanded 6 March 2018*)

Executive Summary

1. A mixed-method census of the northern royal albatross population nesting on The Sisters and Motuhara/Forty-Fours, conducted in November–December 2016, provided the opportunity to determine breeding success through a follow-up census of late-stage fledglings eight months later.

2. The census was carried out on 27 July 2017 by Department of Conservation staff who took a comprehensive set of aerial photographs that blanketed the islands at a range of scales. Sets of photographs were then demarcated to ensure no overlap or gaps in coverage, and the number of northern royal albatross chicks, adults and fresh carcasses counted. The numbers of northern giant petrels present on the islands prior to the start of breeding in August–September were also counted.

3. Overall, 2,116 royal albatross chicks were counted on the three islands: Big Sister, 574; Middle Sister, 539; and Motuhara, 1,003. Seventy-eight adult albatrosses and 17 carcasses of recently dead chicks were also recorded, along with at least 1,889 northern giant petrels, mostly concentrated on Motuhara (92 %).

4. If little or no further mortality occurred among these chicks before fledging, breeding (nesting) success for the 2016/17 breeding season would be around 48 % overall (The Sisters, 37 %; Motuhara, 58 %), considerably lower than the 64 % recorded at the small mainland colony on Taiaroa Head in the same season.

5. A statistically highly significant difference was found between The Sisters and Motuhara in the proportions of 'feathered downy' and 'well-feathered chicks', with greater than expected numbers of feathered downy chicks, and fewer than expected well-feathered chicks on Motuhara (and vice versa for The Sisters). The difference between chicks in these two categories is about 30 days developmentally. This disparity could be due to the peak of breeding on Motuhara being later than on The Sisters, despite the two island groups being only 90 km apart. Alternatively, if the peak of egg-laying on the two island groups was more-or-less synchronous, chick development on Motuhara could be slower, possibly reflecting largely segregated foraging areas for breeding adults from the two colonies and adverse foraging conditions in the areas used by birds from Motuhara.

6. If the differences are due to asynchrony in peak egg laying, for whatever reason, it may explain the 80 % increase in the number of northern royal albatross apparently occupying nest sites on Motuhara, as seen on super-high-resolution satellite imagery taken on 20 December 2016, over the number of active nests counted 12 days earlier on the ground, and the 48 % increase over the numbers counted on aerial photographs taken on 23 November. In contrast, counts of apparently occupied sites on The Sisters, determined from the same satellite imagery, were around 15 % lower than the number of pairs counted on aerial photographs taken in November, perhaps indicating that the number of breeding birds was more settled then. It may also explain the higher apparent breeding success on Motuhara, an artefact of the overall younger age of the chicks, with further mortality likely before the chicks fledge.

7. Despite the remoteness of these islands and the difficulties of access and habitation by researchers, regular monitoring of this population is needed, both through aerial photography of nesting pairs and chicks prior to fledging. Further marking and resighting known-aged birds are needed to refine parameter estimates of demographic variables. This could include using satellite tracking of birds from Motuhara that are feeding chicks, to determine if their foraging areas differ substantially from those known to be used by breeding adults on The Sisters. Tracking population trends in northern royal albatross could also benefit from further development and ongoing application of the existing integrated population model of the species.

1. Introduction

Northern royal albatross or toroa (*Diomedea sanfordi*) breeds only on three outlying islands in the Chatham Islands group—Motuhara (Forty-Fours), Big Sister (Rangitatahi) and Middle Sister (Te Awanui)—and on Taiaroa Head, Otago Peninsula. A couple of birds have been recorded hybridising with southern royal albatross (*Diomedea epomorphora*) on Enderby Island in the Auckland Islands group, just as a few southern royal albatrosses have hybridised with northern royal albatrosses at Taiaroa Head. Overall, >99% of the population breeds in the Chatham Islands.

An aerial photographic survey of The Sisters and Motuhara/Forty-Fours was conducted in late November 2016. Counts from these photographs, supplemented by ground counts made on Motuhara in early December 2016 and counts of birds visible in super-high-resolution satellite imagery taken late December 2016, produced an estimate of 4,406—4,772 nesting pairs for these islands, after adjusting for the presence of non-breeding birds (Baker *et al*. 2017; Bell *et al*. 2017). In addition, a further 36 pairs (two of which were female-female pairings) nested at Taiaroa Head during the 2016-17 breeding season (http://www.doc.govt.nz/nature/native-animals/birds/birds-a-z/albatrosses/royal-albatross-toroa/royal-cam/news/).

The northern royal albatross is a biennial breeder: birds that successfully rear a chick in one year only return to breed again two years later, but pairs that fail during incubation or the early nestling stage, while still guarding the chick, often re-nest the following year (Department of Conservation 2001). Annual counts will therefore encompass only around a half of the breeding population, depending on how successful nesting was the previous season and how many failed breeders then return. Moreover, because individuals only breed for the first time when 4–10 years old, there is a substantial population of immature and sub-adult birds, some of which come to the colonies a year or more before starting to breed, to prospect for mates and nest sites. Their presence also needs to be accounted for in any census of the actual breeding population. Together, these features all lead to considerable uncertainty in population estimates.

Modelling the population dynamics of this and other long-lived, slow-reproducing species, to predict the possible population responses to various scenarios of environmental change, requires detailed information on fecundity and survival. Because the three islands on which the albatrosses breed are relatively inaccessible, neither key components of fecundity (hatching success, fledging success), nor age-related survival, as reflected in the number and age of birds returning to breed, are well known. Much of what is known about the species comes from studies at the small Taiaroa Head colony, which may not be typical of the wider population.

The detailed censuses of nesting albatrosses carried out in November-December 2016 produced reasonably precise estimates of the number of nesting pairs at the end of egg laying/start of incubation. This provided an opportunity to undertake a follow-up census prior to the chicks fledging in mid- to late-September 2017, to get an estimate of breeding success. Accordingly, an aerial survey was carried out in late July 2017 in which blanket photographic coverage of all three islands was obtained. These photographs were then sorted, and the number of fledgling albatross chicks counted.

The number of northern giant petrels (*Macronectes halli*), hereafter simply giant petrels, were also counted. These birds were gathering ahead of the start of their breeding season from August onwards. The size of the breeding population on these islands is poorly known. When breeding, giant petrels are difficult to census by aerial photography because in many places their dark colour blends into the background, especially when they are nesting among rocks or under vegetation.

2. Methods

2.1 Sites

The Sisters (43° 33′ 51″ S, 176° 48′ 27″ W) are three islands situated 20 km due north of Cape Pattison on Chatham I. (Rēkohu). The largest island, Big Sister (Rangitatahi), has a 3.8 ha undulating plateau at about 60 m elevation surrounded by 40–60-m high vertical cliffs, a total area of 7.3 ha (all areas measured on Google Earth). The highest point is around 90 m. Middle or Little Sister (Te Awanui), 4.8 ha, comprises a 2.3-ha plateau lying about 40 m above sea level and a 0.6 ha, 65-m high rounded hill with steep 20–30-m high slopes. A third island, apparently unnamed, is a 6.9 ha rocky reef, lying <20 m above sea level. There are also several bare rocky stacks. The main islands consist of massive limburgitic basalt with allied breccia, scoria and tuff deposits (Campbell *et al*. 1988). The soils are generally thin and support only sparse vegetation except in basins on the plateaus, where the Chatham Island button daisy (*Leptinella featherstonii*) and groundsel (*Senecio radiolatus*) are well established.

Motuhara (Forty-Fours or Bertier, 43° 57′ 44″ S, 175° 50′ 5″ W) lie 42 km east of Owenga on Chatham I. They comprise an 11.5 ha, 60-m high main island with a relatively flat 7.8 ha plateau, and four large and two smaller stacks that together cover a further 1.4 ha. In contrast to the volcanic origin of The Sisters, Motuhara consist of predominantly of hard, fine- to medium-grained, partly recrystallised quartzo-feldspathic sandstones or feldsarenites, and represent the most easterly exposure of Mesozoic basement rocks in the New Zealand region (Andrews *et al*. 1978). The soils are patchy and thin in places and support a mixture of open herb-fields and low-growing shrublands dominated by the Chatham Island button daisy, a species that apparently thrives on nutrient inputs from nesting seabirds. Vegetation cover on Motuhara is generally more extensive than on The Sisters.

Northern royal albatross breed on the plateaus of all three islands, including a few pairs on the rounded hill on Middle Sister, where they nest in gently sloping, soil-filled fissures. They do not nest on the steep slopes and cliffs of any of these islands.

2.2 Aerial survey

Department of Conservation staff flew to The Sisters and Motuhara on 27 July 2017 in a Cessna 207, photographing the islands and their bird colonies. The flight track was recorded on a Garmin GPSMAP 62s, which not only provided the geolocation of the airplane at 3 s intervals, but also the altitude and, by extrapolation from the distance travelled between track points and time, the airspeed. Unrealistically high airspeeds were recorded when the airplane was turning, so calculations of the mean and spread of airspeeds are based here only on those portions of the tracklog where the change in direction was less than 15° on either side. These and other operational details of the flight around the islands are summarised in Table 1.

Table 1. Operational details of the flights over The Sisters and Forty-Fours while photographing the northern royal albatross chicks and adult northern giant petrels, 27 July 2017.

Island	Start time	End time	Total time (min)	Circuits	Average speed (km/hr)	Range	Average altitude (m)	Range
Big Sister	10:52	10:58	5:57	6	148	111-194	206	168-265
Middle Sister	10:59	11:02	3:09	4	158	115-211	196	178-211
Big & Middle Sister	11:03	11.10	7:48	6	158	101-245	286	135-506
Motuhara	11:32	11:54	22:12	14	152	106-227	262	127-441

The relatively high altitude from which the photographs were taken must be seen in relation to the height of the islands themselves. The plateaus where most of the birds occurred range from 40–60 m above sea level, with the highest point being around 90 m on Big Sister Island. The presence of birds flying around the colony also required keeping a safe height above them. Track data were imported from the GPS *.gpx file to OziExplorer® and from there to Excel, where the time was corrected from UTC to local time. The data were then exported to both Google Earth (as a *.kml file) and QGIS (as a shape file). The flight paths around the islands are shown in Figures 1–2.

Photographs were taken with two cameras, a Canon EOS 77D with an EF 18–135 mm f/3.5-5.6 IS USM lens, used mainly to take wide-angle and medium-scale photographs, and a Canon EOS 700D with a EF 75–300 mm f/4-5.6 lens, used to take medium-scale and close-up images. Images from these cameras complemented each other and both sets were used interchangeably during analysis.

2.3 Photo analysis

A total of 1,179 photographs were taken (Sisters, 529; Forty-Fours, 650) at a range of focal lengths from 18 to 300 mm. These photographs fell into three groups:

- **wide-angle images**, 18–59 mm focal length (FL), covering large sections of the islands and used to help locate those areas photographed in more detail;
- **medium-scale images**, 70–135 mm FL, each overlapping considerably with adjacent images and showing sizeable areas at sufficient resolution for individual birds to be distinguished and counted; and
- **close-up images**, 190-300 mm FL, concentrated on parts of the colonies where the status of individual birds could be determined more accurately.

Medium-scale images made up the bulk of the photographs taken (Sisters 83%, Forty-Fours 68%) and covered all areas where birds were nesting or loafing on each island. These photographs were the main ones used when counting birds. If there were any doubts about either the numbers or status of birds visible in these photographs, or if there were small areas where birds were obscured, then these were resolved by looking at other medium-scale images of the same area or by finding that area in a complementary close-up image. The close-up images sampled the main nesting areas rather than producing blanket coverage.

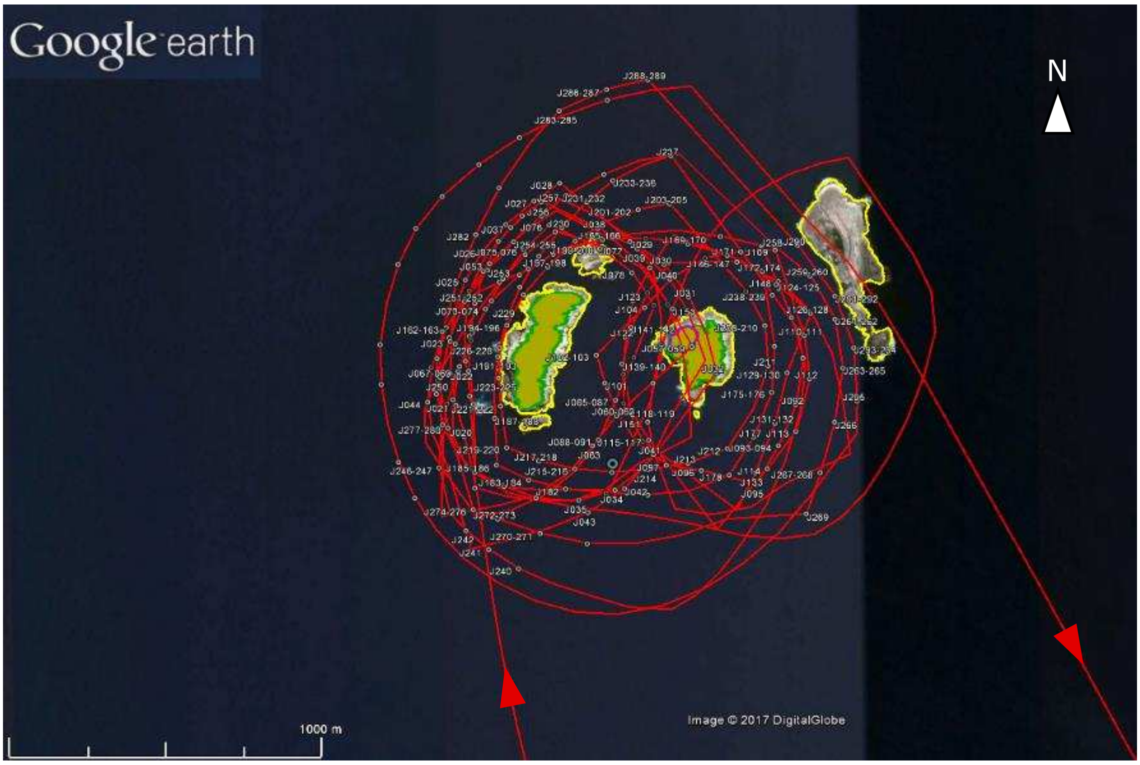

Figure 1. Flight track (red) and Canon EOS 700D photo points (numbered) around The Sisters, 27 July 2017. The plateaus on Big Sister (left) and Middle Sister (centre) are outlined in green and shaded olive.

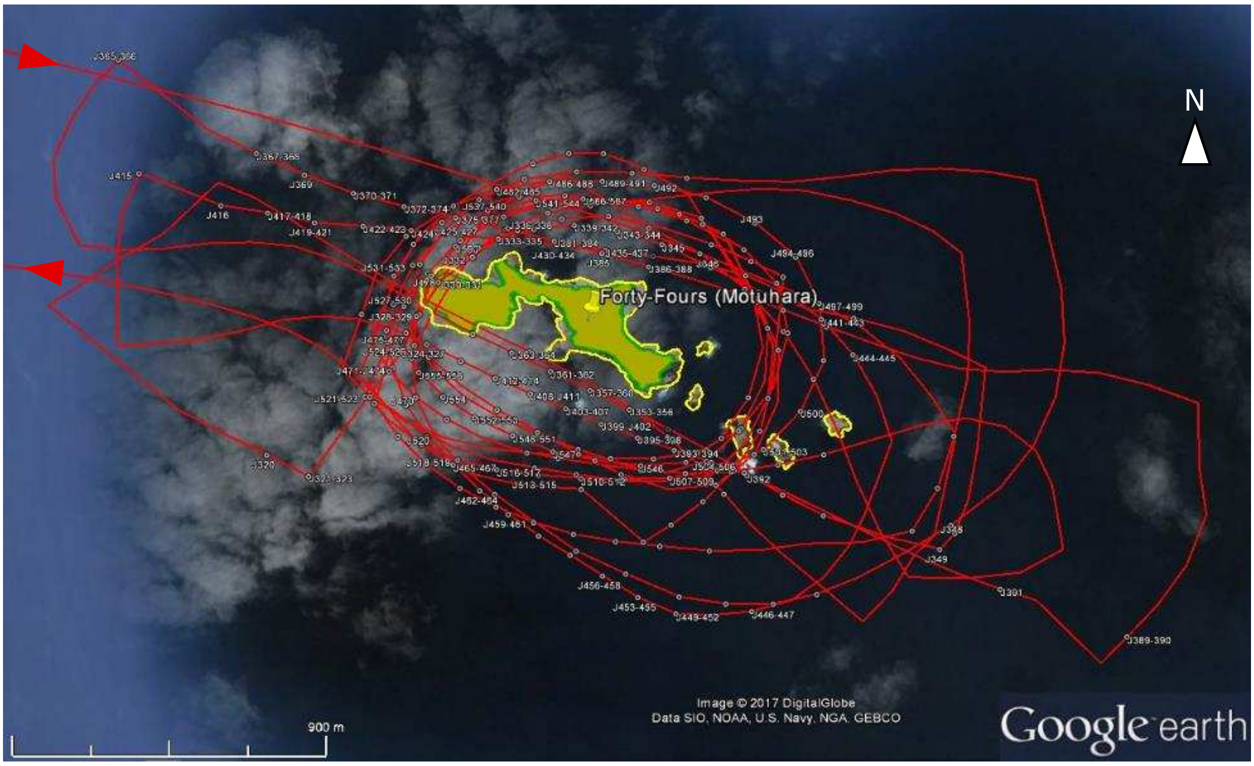

Figure 2. Flight track (red) and Canon EOS 700D photo points (numbered) around Motuhara, 27 July 2017. The plateau on which royal albatrosses breed is outlined in green and shaded olive.

The Exif data for each camera (camera make and model, date and time of each image, shutter speed, ISO rating and lens focal length) were extracted for each image (bulk extraction done using Picture Information Extractor 6.99.10.61, Picmeta Systems, http://www.picmeta.com). In the notes accompanying the images, the time stamp on EOS 700D was stated to be 60 s less than GPS time, when the latter was converted to local time, but difference turned out to be 11 hr 59 min difference because the camera time was set to a 12-hr clock and happened to be running during the PM cycle. The appropriate adjustment was made so that points from where the photographs were taken could be reasonably accurately calculated by correlating the image time stamps with the corresponding time stamp and position recorded by the GPS. As it was, this positional information was useful only in a general sense because many of the photographs were taken at oblique angles to the islands, rather than at right angles, which meant that the fields of view of the images varied and could not be deduced simply from where the photographs were taken.

Prior to analysis, the photographs were processed in Photoshop Elements 14, primarily adjusting the lighting, contrast, hue and saturation, to highlight the birds as best as possible. Photographs from the Canon EOS 77D were in RAW format and these were either processed first in that format, using Digital Photo Professional 4.6.30.0, or were converted to JPEG format with minimum compression. In most cases, the latter was done because of the significant increase in time needed to process images in RAW format.

To be useful for counting birds, an image must have a sufficiently discrete area that can be demarcated from neighbouring areas along a common boundary that is mappable in both images. This also extends to images that overlap above and below, where these cover other parts of a colony. The adjoining images in turn must have their own distinct areas that are distinguishable from the next image in the sequence, and so on until all areas in which albatross chicks and giant petrels occur have been covered without overlap or gaps.

Demarcating these count sections took considerable time because there are few suitably placed salient features that can be used as common points to form a dividing line that is visible in adjacent images, which are not seriously distorted by changes in the angle of view from the passing airplane. For instance, taking the 75 mm FL images used for counting albatross chicks on Big Sister as an example, where successive images were taken 3 sec. apart, 320–350 m away from the image centres, the field of view changes by 18–20°. This is sufficient for objects to look quite different from one image to the next (Figure 3).

The demarcated areas in which chicks were counted on all three islands are shown in Figures 4 and 5. These zones differ from those used in previous aerial surveys or during ground counts because the boundary markers and natural features used in those surveys were not clear. Other than a couple of experimental panoramas, no attempt was made to merge adjacent photographs into larger views. Aircraft speed, and the reality that few photographs of adjacent areas were taken close together, meant that adjacent fields of view were too distorted, relative to each other, to be merged digitally (Figure 3).

Figure 3. Coincident points in two adjacent images used to form a line demarcating discrete areas in the two images in which albatross chicks were counted. Note the considerable change in the positions of the birds, for example, in the areas of common view. The photographs were taken 3 s and 106 m apart.

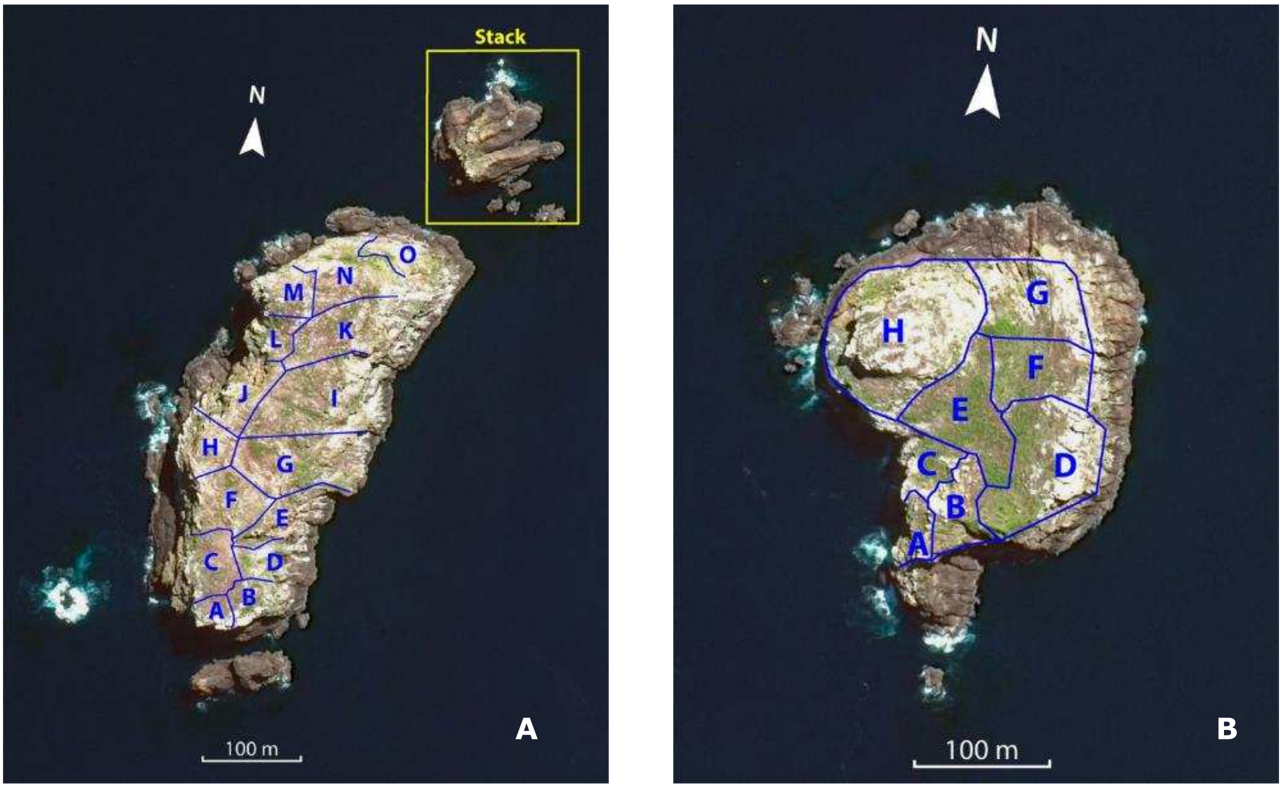

Figure 4. Demarcated zones used when counting northern royal albatross chicks and adult northern giant petrel on Big Sister/Rangitatahi (A) and Middle Sister/Te Awanui (B) from aerial photographs taken in July 2017.

Figure 5. Demarcated zones used when counting northern royal albatross chicks and adult northern giant petrel on Motuhara/The Forty-Fours from aerial photographs taken in July 2017.

For analysis, the selected photographs were first gridded digitally, using a grid size that usually encompassed no more than five albatross chicks. Each grid square was then searched systematically, row by row, and all birds seen were marked, using different coloured marks for the various species (northern royal albatross, giant petrel, others [labelled]) and age classes (chicks, adults). Once completed, the marked image was searched again, and the numbers of different coloured marks tallied separately. Any unmarked birds seen during this second search-and-tally were marked and counted but noted separately as these are a minimum measure of detection error (there could still be individuals present but not recorded).

When necessary, close-up images were studied to resolve uncertainties. These images were also used to determine the stage of development of a large sample of chicks. Because most of these images were not sharply focused, understandably so given airspeed and turbulence, only three broad categories were used: downy chicks; large downy chicks with emerging wing feathers; well-developed chicks, either still on a nest or not obviously associated with one (Figure 6).

Figure 6. Portraits of chicks used when classifying royal albatross chicks into size (age) classes: downy chick (A), predominantly white, showing little or no obvious wing-feather development; feathered downy chick (B), showing developing wing feathers but down still continuous across the lower back (arrowed); and well-feathered chick (C), with down restricted largely to scapulars and flanks, but not extending across the lower back (arrowed). For chicks seen head-on, comparative size and the amount of down visible on the head were used to distinguish younger from older chicks.

3. Results

3.1 Northern royal albatross

In total, 2,116 royal albatross chicks were counted on the three islands, along with 78 adults, most of which were either feeding or standing next to chicks (Table 2, Appendices 1–3). Seventeen relatively recent carcasses of chicks were also recorded and several fragmented, presumed older remains were noted. In relation to the areas of the plateaus of the three islands (excluding the hill on Middle Sister, area H), chick densities varied from 129 chicks/ha on Motuhara to 216 chicks/ha on Middle Sister. (Chick density on the Middle Sister hill was only 72 chicks/ha, a reflection of the bareness of environment there.)

Table 2. The number of chicks and adult northern royal albatrosses and giant petrels of all ages present on The Sisters and Forty-Fours, and overall, on 27 July 2017.

	Northern royal albatross			Northern Giant Petrel
Island	Chick	Adult	Carcass	(all ages)
Big Sister/Rangitatahi	574	35	2	59
Middle Sister/Te Awanui	539	14	1	92
Motuhara/Forty-Fours	1,003	29	14	1,738
Total	2,116	78	17	1,889

Detection error was relatively low, 0.9%, and was usually associated with birds being shielded by vegetation or rocks, or being confused initially with similarly-sized, partly obscured, pale boulders (Appendices 1–3).

Most chicks were well-feathered (Table 3), although primary development was still only in its early stages, as seen in birds exercising their wings. The numbers of chicks in each category were in similar proportions on Big and Little Sister ($X^2 = 4.968$, $p = 0.8339$), but there was a statistically highly significant difference in the observed numbers on Motuhara compared with the Sisters (treated as one population, $X^2 = 69.247$, $p < 0.0001$). Significantly more 'feathered downy' chicks and fewer 'well-feathered' chicks than expected were present on Motuhara, with fewer 'feathered downy' chicks than expected on The Sisters (X^2 with Bonferroni correction).

Table 3. Percentage of chicks in different plumage-development categories on the three islands, obtained by sampling 7-11 randomly selected close-up photographs on each island.

	Percent of chicks in size category			Number of chicks sampled	Adults present
Island	Downy	Feathered downy	Well-feathered		
Big Sister	4.0	16.2	79.8	371	17
Middle Sister	2.3	12.0	85.7	391	15
Forty-Fours	6.1	31.8	62.1	506	13
Total	4.3	21.1	74.5	1268	45

3.2 Northern giant petrel

Overall, 1,889 northern giant petrels were counted on the three islands (Table 2). This is likely to be a substantial undercount. Apart from the difficulty of distinguishing the petrels from similarly coloured rocks (often the only distinguishing feature was the birds' pale faces), many birds took flight as the survey airplane circled the islands and so were not all captured in the photographs. Because of this disturbance, it was not possible to determine consistently which birds were guarding nest sites and which were part of large social groups. Detection error in the counts was estimated to be 3.5–6.5 % (Appendices 1–3), but that is probably conservative.

Motuhara supported most of the birds. Their density there (222.8 birds/ha: Table 2 and Appendix 3) was almost an order of magnitude higher than on Big Sister, 15.3 birds/ha, and Middle Sister, 31.7 birds/ha (Table 2 and Appendices 1, 2). Two instances of giant petrels apparently harassing downy chicks were seen. In a third case, a well-feathered chick was seen lunging at a giant petrel, but this could just have been one that came too close rather than was harassing the albatross chick.

3.3 Other species

Other species were noted only in passing because the photographs were not sharp enough to allow birds much smaller than giant petrels to be easily detected. Just two Sub-Antarctic skua (*Catharacta antarctica*) were recorded, both in sector D4 on Motuhara. Others were almost certainly missed, given the species' dark colouration and small size relative to albatrosses and giant petrels. Two, possibly three, southern black-backed gulls (*Larus dominicanus*) were seen on the stacks off Motuhara. Four probable red-billed gulls (*Larus novaehollandiae*) were seen on the cliffs of Motuhara in sector B2.

4. Discussion

Northern royal albatross

An estimated 4,406–4,772 breeding pairs of northern royal albatross (toroa) were recorded on The Sisters and Forty-Fours at the egg-laying/early incubation stage of the 2016/17 breeding season (Baker *et al*. 2017). These estimates were derived from counts of birds in aerial photographs taken on 23 November 2016, variously adjusted for the presence of loafing birds, as seen in close-up photographs taken at the same time, and ground counts on Motuhara two weeks later. The total of 2,116 toroa chicks counted on aerial photographs of The Sisters and Forty-Fours islands therefore represents an apparent nesting success of 48%. This contrasts with 64 % reported for the small mainland colony on Taiaroa Head in the same season (23 chicks fledged from 36 nests: Department of Conservation, 2017).

If all 1,003 toroa chicks present on Motuhara in late July 2017 eventually fledged successful, nesting success for the 2016/17 breeding season will have been 58 %, based on 1,726 nesting pairs counted on aerial photographs taken there on 23 November 2016 (adjusted for the number of loafing birds: Baker *et al*. 2017). On 8 December 2016, 1,400 birds were recorded incubating eggs during a ground count of all nesting albatrosses on Motuhara (Bell *et al*. 2017; but see the substantially higher count derived from satellite imagery taken on 20 December, discussed below). The ground count is almost 19 % lower than that made from aerial photographs taken 15 days earlier (Baker *et al*. 2017), which might suggest considerable failure during the first quarter of the incubation period. From then on to July 2017, a further 23 % of nests apparently failed, but at what stage is unclear. Fourteen relatively intact carcasses were present in July 2017, all of them seemingly large downy chicks. The scattered remains of other chicks were visible in close-up photographs, reflecting earlier mortality. Given that the complete carcasses all looked intact, these birds had probably died recently of starvation or disease, rather than predation. Nevertheless, a couple of instances of giant petrels apparently harassing chicks suggests that some mortality could arise from this source, at least among young chicks.

Apparent nesting success on The Sisters was much lower, 37 %, based on 3,047 nesting pairs counted on 23 November 2016 (Baker *et al*. 2017), assuming little or no further mortality between July 2017, where the colonies were censused, and when the birds would have fledged (September). There were no ground counts during the incubation period, so it is not clear when most of the mortality occurred. Only three carcasses were noted, all downy chicks. As a percentage of all chicks on The Sisters, 0.3 %, this mortality is markedly lower than the 1.4 % recorded on Motuhara. If the higher proportion of well-feathered chicks on The Sisters signifies differences in age rather than growth rate (Table 3), then perhaps the population of chicks there would having been subject to losses for longer, which might account for the lower breeding success. Given the apparent younger average development age of chicks on Motuhara, further mortality might therefore be expected, so that the number which eventually fledged could be lower than the 1,003 chicks counted in July 2017.

Why there is a difference in the size-class distribution of chicks on the two island groups only 90 km apart is not known. Chicks classed as 'well-feathered' are about 30 days older developmentally than ones in the 'feathered downy' category (Junichi Sugishita, *pers. comm.*), like that described by Sorensen (1950) for 21- and 24-week old southern royal albatross chicks on Campbell Island. This could mean either that peak egg laying on Motuhara, at least in 2016/17, was later than on The Sisters, or that chick development on Motuhara was slower, for some or other reason. If the disparity in the proportions of chicks in the 'feathered downy' and 'well-feathered' categories in the two island groups is age-related, it presumably reflects a difference in the timing of peak egg laying on the two island groups. This could explain some of the 80 % increase in the numbers of birds apparently occupying nesting sites on Motuhara between 8 December 2016, when 1,400 nesting pairs were counted on the ground (Bell *et al*. 2017), and 20 December 2016, when super-high-resolution satellite imagery was taken, from which 2,632 apparently occupied sites were counted (Fretwell *et al*. 2017). The satellite-based count is also nearly 48 % higher than the 1,726 nesting birds (adjusted for the number of 'loafers'), counted from aerial photographs of Motuhara taken 23 November 2016 (Baker *et al*. 2017). In contrast, the count of 2,578 apparently occupied sites on The Sisters, seen on the satellite imagery, was around 15 % lower than the 3,047 pairs counted on aerial photographs taken 27 days earlier (Baker *et al*. 2017). These differences are consistent with the hypothesis that most birds on Motuhara started nesting a few weeks later than on The Sisters, for whatever reason. If the number of pairs that eventually bred on Motuhara was higher than the 1,400 pairs counted by Bell *et al*. (2017), then breeding success could be lower than the projected 58 %.

Conversely, if the peak of egg-laying was more-or-less synchronous, the disparity could be related to differences in the development rates of chicks on The Sisters and Motuhara. Fledging periods in northern royal albatross chicks can vary by as much as 41 days (Robertson & Wright 1973), presumably reflecting variations in chick provisioning. Growth and development of albatross and other procellariform chicks is generally variable, depending on meal size, food quality and the frequency with which the adults provision them (Berrow *et al*. 1999; Huin *et al*. 2000; Weimerskirch *et al*. 2000, 2001; Welch 2014). At least in yellow-nosed albatross (*Thalassarche chlororhynchos*), adults can regulate the rate at which they provision their chick, to adjust for the chick's nutritional status, but only when the environment is favourable. Otherwise, they apparently favour their own future by maintaining their body condition rather than provisioning their chick (Weimerskirch *et al*. 2000, 2001). Welch (2014), studying a much smaller procellariform, the grey-faced petrel (*Pterodroma macroptera gouldi*) has shown that chicks reared at a site on the west coast of the North Island, grew faster, fledged earlier and were in better condition than those reared 76 km away on the east coast in the same season. The fledging period was almost 20% longer at the east-coast site than on the west. Welch (2014) suggested that adults provisioning chicks at the east-coast site might have experienced different foraging conditions, including having to bear a higher energetic cost of flying further to their preferred feeding grounds beyond the continental shelf (110 km vs 50 km away for birds nesting on the west coast).

If the differences noted in the proportions of toroa chicks in the 'feathered downy' and 'well-feathered' classes reflect variations in development rate rather than age, then the question becomes: why is chick development on Motuhara slower than that on The Sisters? Perhaps the adults in the two populations feed over different ocean zones, with birds on Motuhara foraging in less productive areas, at least in 2016/17. But little is known about where northern royal albatross at these colonies forage during the breeding season. Nicholls *et al*. (2002), using data from four breeding

Northern Royal Albatross (two females, two males) fitted with satellite tags ((platform transmitter terminals: PTTs) during the early chick-rearing period on The Sisters, showed that almost 78% of 112 first satellite-determined locations per day were from outer continental shelf areas along the Chatham Rise, in waters < 1000 m deep; a further 16% of these records were from the upper slopes of the continental shelf-break zone where the sea is < 2000 m deep (Figure 7).

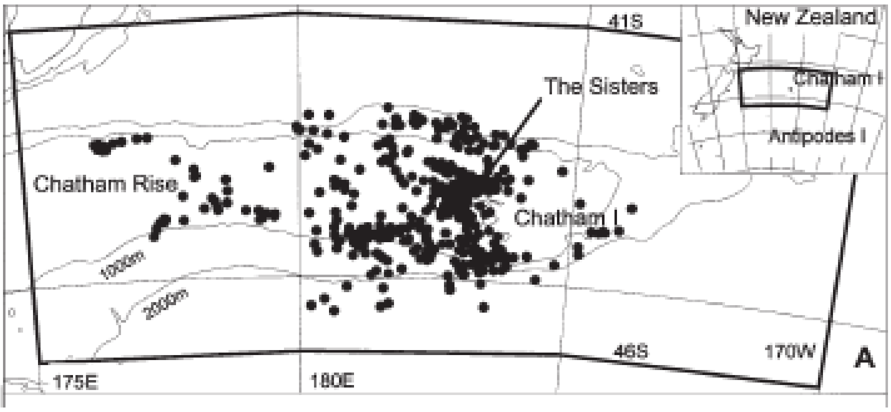

Figure 7. Distribution of first daily satellite-determined locations of four breeding Northern Royal Albatross nesting on The Sisters, February–March 1996, showing the concentration of the birds along the continental shelf and upper shelf-break zones on the Chatham Rise (reproduced from Nicholls *et al*. 2002, Fig. 1).

Likewise, most records in the global online bird-sighting database eBird (http://ebird.org/ebird/newzealand/map/royalb3), although perhaps reflecting more the presence of observers than of albatross distributions overall, show groupings close to the New Zealand mainland and south-eastern Australia during the main chick-rearing periods (Figure 8). (Those records along the west coast of South America are perhaps non-breeding birds.)

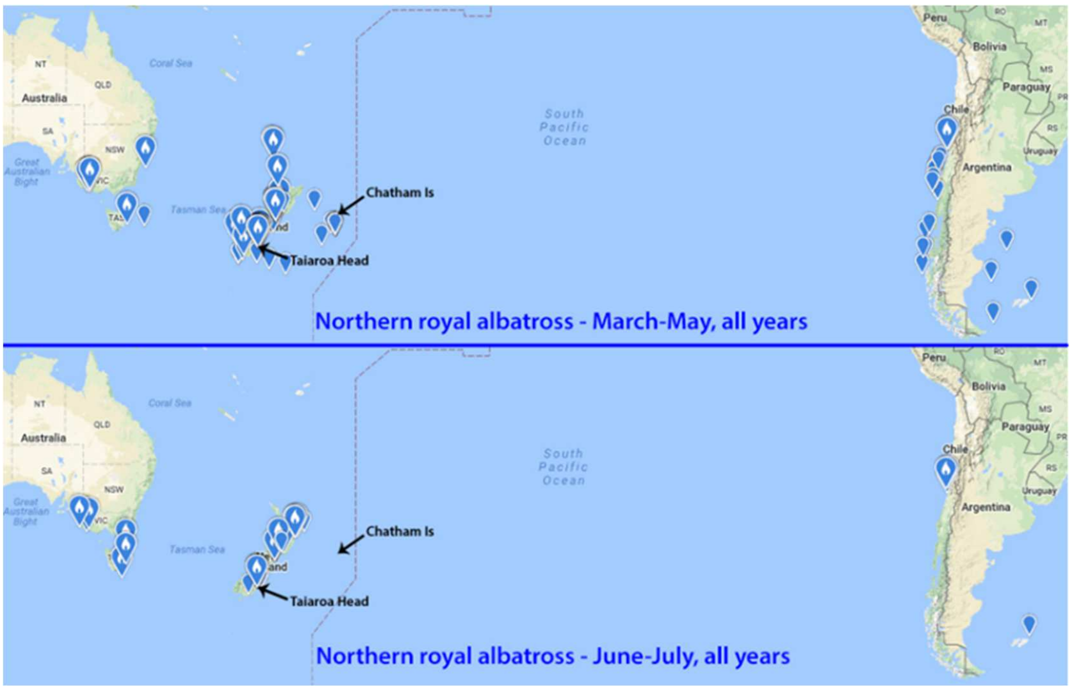

Figure 8. Sightings of northern royal albatross during the main periods of chick-rearing, March–July, as recorded in the global online database eBird (viewed 20/01/2018).

The satellite data refer only to birds nesting on The Sisters, but they show wide distribution along the Chatham Rise. If the birds nesting on Motuhara feed in the same region, then there is likely to be considerable overlap. Conversely, relatively few records of these birds were located over the extension of continental shelf to the east of the Chatham Islands. Is it possible that birds nesting on Motuhara feed preferentially there? It would be worth deploying satellite tags on a selection of breeding adults on Motuhara to answer this question.

The 1,003 toroa chicks counted on Motuhara in 2017 contrasts with the 1539–1829 chicks counted each August during 1973–1975, and the 115–719 counted the same month through 1989–1993 (Figure 9). The low nesting success recorded in 1989–1993 was apparently due to climate-related reductions in vegetation cover. As a result, the nests that the birds built were poorly developed, with eggs being laid directly onto rocky soil, amplifying the risks of failure through eggs being crushed, cracked or rolling out of the nest, or through dehydration of the eggs and chicks caused by the drier nest environment (Robertson & Sawyer 1994). This could explain the gradual reduction in toroa numbers on The Sisters and Motuhara from 6,500–7,000 breeding pairs counted on aerial photographs taken in 1972–1975 and 1989–1991, to 5,200 in 1995, 5,800 in 2002, and an average 5,545 pairs during 2006–2009 (Robertson 1998; Scofield 2011 cited by Bell *et al*. 2017; BirdLife International 2017), then to 4,406–4,772 nesting pairs in 2016/17 (Baker *et al*. 2017; Bell *et al*. 2017). It may also explain the smaller number of birds breeding on The Sisters, where vegetation is sparser and the soils more shallow and stony than on Motuhara. For Motuhara, the increase in the number of chicks recorded in 2017 over those recorded in 1989–1993 may reflect the marked improvement in vegetation cover noted by Bell *et al*. (2017). This could yet feed through to increase the future breeding population.

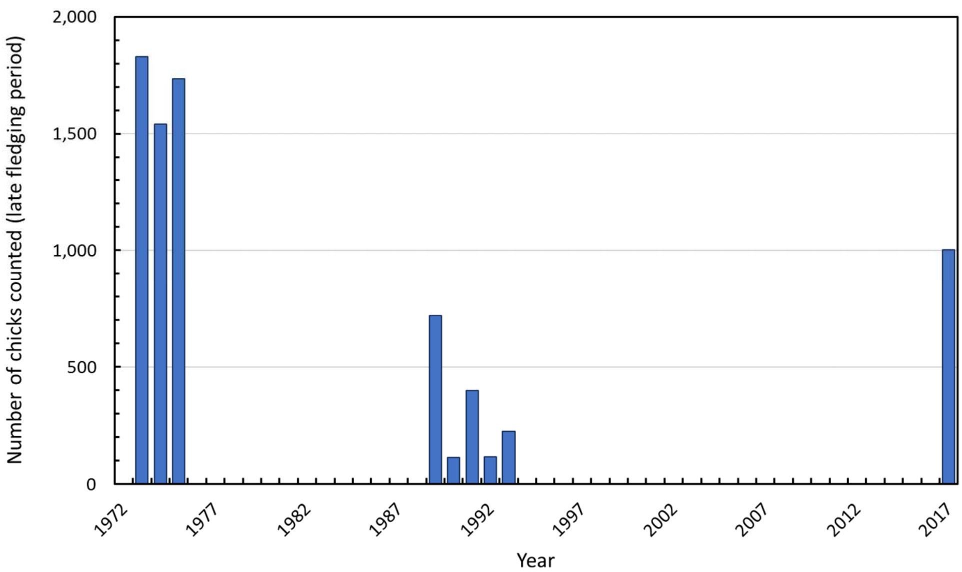

Figure 9. Counts of northern royal albatross chicks on Motuhara over time as determined from aerial photography taken during the late fledging phase, July–August (data for 1973–1975 and 1989–1993 from Robertson & Sawyer 1994; for 2017, this study).

The estimate of no more than 48 % breeding success[1] overall in 2017 on the Chatham islands is well below that reported from the small mainland colony at Taiaroa Head. This has risen from 54% to 74% in recent decades (Richard *et al*. 2013) because of various management interventions (intensive predator control; transferring abandoned eggs to the nests of recently failed pairs; artificial incubation of abandoned eggs, then fostering the chicks to a just-failed nest; and protection against fly-strike and heat-stroke, among others: Robertson 2001). Without interventions, breeding success on this small colony would have been just over 32% (Robertson 2001), closer to the 37 % recorded for The Sisters in 2016/17.

Current demographic modelling of the northern royal albatross population is based primarily on data gathered at Taiaroa, which may not be representative of the larger population on the Chatham islands (Richard *et al*. 2013). Much of the uncertainty in population projections and the sensitivity of the global population to various natural and anthropogenic forces is due to uncertainty in the probabilities of adult and juvenile survival. The probability of breeding success or failure was not explicitly modelled because it is managed at Taiaroa, being subject to numerous interventions (Robertson 2001). It was instead incorporated as a covariate for each individual and calculated separately at each model time step.

Given the gradual growth in the Taiaroa Head colony, where breeding success has increased through intensive management, but where there is no evidence of any contemporary increase in adult or juvenile survival (Richard *et al*. 2017), and given also the decline in the numbers of birds nesting on the Chatham islands colonies between the mid-1970s and early 1990s, which has been attributed to breeding failure rather than to any massive rise in adult mortality, the question remains: how important are changes in breeding success in the long-term dynamics of northern royal albatross?

Some insights may come from the Department of Conservation's Seabird Modelling Tool (https://docnewzealand.shinyapps.io/seabirdmodelling/). A 1 % reduction in adult survival reduces annual population growth rate from the base-case rate of 0.49 % (95 % confidence limits [CL]: -2.85 %–4.61 %) to -0.33 % (95 % CL: -4.22 %–3.75 %). An equivalent reduction in juvenile survival has much less effect (mean growth rate reduced to 0.32 %; 95 % CL: -3.25–4.21), as does a 1 % reduction in breeding success (mean growth rate reduced to 0.33 %; 95 % CL: -3.20–4.20).

Under this model, adult annual survival is clearly the most sensitive parameter, but population growth rate is still vulnerable to declines in mean annual breeding success. A ~7% reduction in breeding success from the base-case mean of 43% is sufficient to generate a negative population growth rate (Figure 10), although the confidence limits around all these estimates are wide. Whatever the case, breeding success remains an important variable to measure.

[1] Because albatrosses lay a single egg, nesting success and breeding success, the percentage of known nests and eggs laid, respectively, that produce successfully fledged chicks, are synonymous. The terms are used as such here, in line with whatever term was used in the linked references.

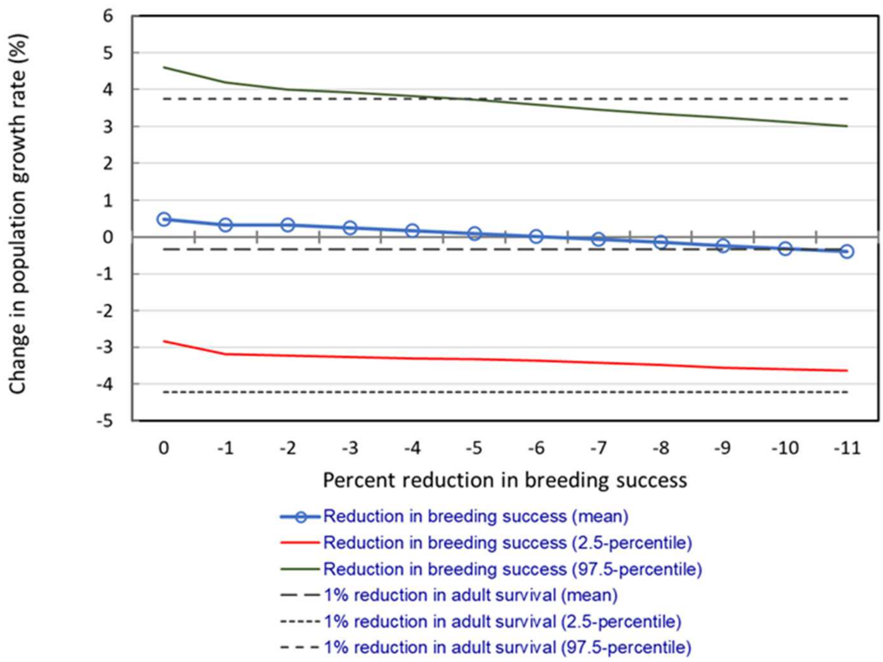

Figure 10. Modelled changes in population growth rate with increasing reductions in breeding success (see text for details). The mean and 95-percentile range for a 1 % reduction in adult survival are shown for comparison.

Monitoring changes in adult survival in a long-lived species such as northern royal albatross is complicated by the remoteness of the islands and, for researchers, by the difficulties of access and habitation for anything other short stays. Determining the age of individual northern royal albatrosses is only possible if they have been marked at a known early age, usually at the time of fledging, then tracked over time. That has been one of the merits of the study at Taiaroa Head, although questions remain about whether those results are applicable to the wider population. Furthermore, in such a long-lived species, the sample sizes of the oldest age classes are invariably small, and the lifespans of such individuals are usually much greater than the working lifespan of a researcher, or the financial support given to research and monitoring.

The option of studying changes in demographic structure, which should reflect changes in survival, albeit often with a lag, is also limited because northern royal albatrosses have few markers of age beyond the first few years of plumage development. As it is, one also cannot assume that the population is in steady-state, demographic equilibrium, given environmental variability and likely associated fluctuations in fecundity and survival. With these constraints, there seems no alternative at present but to continue building and supporting a long-term monitoring programme aimed at tracking the number of pairs breeding annually, their reproductive success, and the survival of even the small sample of marked birds involved, while continuing to expand this number by additional banding of fledglings (Taylor 2000).

Northern giant petrel

The total of 1,889 northern giant petrels recorded in July 2017 can be compared with the 414 petrel chicks counted on aerial photographs taken in November 2016 (Baker *et al*. 2017). The number of giant petrels overall was not reported because of difficulties in detecting the birds, a similar problem to that met in this study. The discrepancy between the numbers seen on aerial photographs and the numbers on the ground is well illustrated by data from Motuhara, where 370 were counted from aerial photographs and 1,235 were recorded during a ground count there two weeks later (Baker *et al*. 2017; Bell *et al*. 2017).

The proportions of the total number of giant petrels recorded on the two island groups in July 2017 (0.92 on Motuhara; 0.08 on The Sisters) is broadly in line with those reported for their chicks seven months earlier (0.89 on Motuhara; 0.11 on the Sisters: Baker *et al*. 2017). Nevertheless, there may be considerable undercounting, given that 1,235 giant petrel chicks were counted on Motuhara in December 2016 (Bell *et al*. 2017)—implying a minimum of 2,470 adults—whereas only 1,738 birds of all ages were counted in July 2017, immediately prior to the start of the next breeding season. Fraser *et al*. (2010) recorded 270–430 nests in two sample areas (A and B) on Motuhara during four breeding-season surveys conducted between 1993 and 2009. These sample areas are broadly coincident with areas C1 and C2 (Sample A) and E2 and E4 (Sample B) in this survey, which together held 854 birds, albeit in the pre-breeding period. This could indicate a small expansion in the population.

Conclusions

Monitoring long-lived, slow-reproducing species is fraught with difficulties. Detecting population declines from annual counts of nests could take decades (Bakker *et al*. 2018). In any one year, such counts encompass only part of the population, those birds that did not breed the previous year because they had either bred successfully two years before or had bred the year before but failed early in that nesting cycle (but then again, not all pairs that fail then will necessarily try again the following year). What proportion of the breeding population is present in these counts is not known without marking and sampling many breeding individuals across years. The rate at which new birds enter the breeding population also varies, depending presumably on environmental conditions, the age structure of the immature and sub-adult segments of the population, and opportunities (or the lack of them) at a breeding colony.

This and earlier studies have shown that it is feasible, and probably cost-effective, to monitor the number of pairs that breed annually and get comparable measures of reproductive success through twice-yearly aerial photography. Together with data on the survival of even the small sample of currently marked birds, which could be increased in time by further banding, supplemented with data on fishing-related mortality, this should lay a platform for developing a fully integrated population model for toroa. Such models incorporate both population counts and increasingly refined demographic data (Schaub & Abadi 2011) and have been developed using various methods to model joint likelihoods among different data sets. They have been applied in conservation contexts by, among others, Véran & Lebreton (2008) to the black-footed albatross (*Phoebastria nigripes*) and Reid *et al*. (2013) to the flesh-footed shearwater (*Puffinus carneipes*).

Updating and refining the population model developed by Richard *et al*. (2013) for the small Taiaroa Head colony, so that it becomes a regular part of population monitoring and assessment of the wider northern royal albatross population, should be considered.

Acknowledgements

Sarah Matthew and Sara Forder (Department of Conservation, Chatham Islands) took the photographs on behalf of the Department and supplied a copy of the GPS track log. They also kindly answered my queries. Graeme Taylor showed much patience while I slowly worked my way through nearly 1,180 photographs of places that I had not previously seen and provided useful comments on the draft manuscript. Barry Baker (Latitude 42 Environmental Consultants Pty Ltd) and Igor Debski (Department of Conservation) generously provided high resolution images of the islands for mapping purposes. Junichi Sugishita kindly estimated the difference in developmental age between the older chicks illustrated in Figure 6. Dr James Russell gave permission to cite the unpublished MSc thesis of his student, Jemma Welch. Andrew Gray (NERC Open Research Archive) provided a hard-to-get reprint. Thanks to them all.

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Appendices

Table A1. Area-based counts of northern royal albatross and northern giant petrels on Big Sister Island. For the locations of the areas see Figure 4.

	Royal albatross					Giant Petrel		
Area	Chick	Adult	Carcasse	Possible	Detection error (%)	Individuals	Possible	Detection error (%)
A	10	0	0	0	0	4	0	0
B	5	2	0	0	0	1	0	0
C	69	2	0	0	1.4	12	0	0
D	4	1	0	0	0	2	0	0
E	3	0	0	0	0	0	1	0
F	36	4	1	0	2.7	10	4	10.0
G	66	3	0	0	1.5	6	2	0
H	7	1	0	0	0	2	0	0
I	85	3	0	1	1.2	4	1	0
J	8	0	0	0	0	6	0	16.7
K	152	5	0	0	1.3	11	0	9.1
L	19	2	0	0	0	1	0	0
M	24	6	1	0	0	0	0	0
N	73	4	0	0	1.4	0	0	0
O	13	2	0	0	0	0	0	0
Total	**574**	**35**	**2**	**1**	**1.2**	**59**	**8**	**5.1**

Table A2. Area-based counts of northern royal albatross and northern giant petrels on Middle Sister Island. For the locations of the areas see Figure 2.

	Royal albatross					Giant Petrel		
Area	Chick	Adult	Carcasse	Possible	Detection error (%)	Individuals	Possible	Detection error (%)
A	12	0	1	0	0	1	0	0
B	22	0	0	0	0	46	0	4.3
C	33	1	0	0	0	0	0	0
D	176	4	0	0	0.6	19	0	5.3
E	141	1	0	0	0.7	18	0	11.1
F	86	4	0	0	1.2	4	0	25.0
G	26	2	0	0	0	1	0	0
H	43	2	0	1	2.3	3	0	0
Total	**539**	**14**	**1**	**1**	**0.7**	**92**	**0**	**6.5**

Table A3. Area-based counts of northern royal albatross and northern giant petrels on Motuhara. For the locations of the areas see Figure 5.

	Royal albatross				Giant Petrel		
Area	Chick	Adult	Carcasse	Detection error (%)	Individuals	Possible	Detection error (%)
A.1	45	1	1	2.2	58	0	3.4
A.1	0	0	0	0	0	0	0
A.2	9	0	1	0	2	0	0
A.3	2	0	1	0	12	2	8.3
B.1	0	1	0	0	2	0	0
B.2	0	0	0	0	0	0	0
C.1	47	0	1	2.1	49	2	4.1
C.2	117	5	0	1.7	467	4	3.2
C.3	79	2	1	0	140	2	2.9
D.1	63	1	0	0	37	2	2.7
D.2	8	0	0	0	23	0	4.3
D.3	350	9	6	0.3	161	0	4.3
D.4	91	6	1	0	66	2	6.1
E.1	101	3	1	2.0	243	1	4.1
E.2	32	0	1	3.0	220	1	2.7
E.3	30	0	0	0	140	1	2.1
E.4	29	1	0	0	118	0	3.4
S.1-4	0	0	0	0	0	0	0
Totals	**1003**	**29**	**14**	**0.7**	**1738**	**17**	**3.5**