A Census of Northern Royal Albatross Nesting on the Chatham Islands, February 2022

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Cover image

Eastern end of Motuhara with Northern Royal Albatross nesting on the plateau and Northern Buller's Mollymawks nesting on cliff edges and recesses. For a sense of scale note the person standing near the centre of the image. February 2022 (Canon EOS 77D, FL 103 mm, f/13, 1/1300s)
(photograph taken by Gemma Greene)

Summary

1. An aerial photographic survey of Northern Royal Albatross | Toroa *Diomedea sanfordi* nesting on two groups of privately-owned islands, Rangitautahi and Te Awanui (both islands in the Rangitatahi/Sisters group) and Motuhara, was carried out on 1 February 2022. Together, these colonies hold >99 % of the global populations of this species.

2. The survey was carried out at the end of incubation–start of the chick brooding and guarding phase because poor weather prevented a survey being carried out at the start of incubation.

3. During the flight, 1295 photographs were taken from which 71, together covering all of each island, were selected for broad analysis. For each island, the selected images were partitioned into contiguous sections with no overlaps or gaps. In each section, all Northern Royal Albatrosses present on the ground were classified by their apparent behavioural state and tallied. A total of 3546 individuals (95% CL: 3272–3848) were counted across all three islands, of which 3257 were judged initially to be either still incubating eggs, brooding recently hatched chicks or guarding chicks more than a few days old. No lone chicks were seen.

4. A further 22 non-overlapping close-up images from all three islands were then selected and the birds clearly visible in them classified by behavioural state. Omitting those birds whose status was uncertain, the proportions of individuals clearly occupying a nest, standing or sitting around as a partner, or loafing, were then calculated for each island. These proportions were then used to adjust the initial numbers categorised and counted.

5. When these proportions were used to correct the initial counts, 3269 birds (95% CL: 3018–3547) were judged to be incubating eggs or brooding/guarding chicks, distributed as follows: Motuhara 1601; Rangitautahi 993; Te Awanui 675. This total is less than the average number of birds apparently occupying nests (AON) in 2016–2021 (4229 nests), but higher than the average number of chicks counted between 2016 and 2019 as being close to fledging (2103 chicks).

6. In addition to the images of Motuhara taken from the survey aircraft, a further 221 images, taken on 31 January 2022 from a DJI Mavic Air 2 drone, were received. Ten of these were wide-angle views of the western half of the island, whereas the rest were taken on 10 more-or-less parallel transects aligned approximately along the long axis of the island. Among this set, those images containing five recently established 20 x 20 m Northern Royal Albatross study plots and five of ten 10 x 10 m Northern Buller's Mollymawk monitoring plots (some of which dated back to 2007/2008), were selected for detailed analysis. The number of active nests in these quadrats, which had been surveyed on the ground a couple of days earlier, were then identified and counted. Images taken of these quadrats from the aircraft were also assessed and the number of apparently nesting birds compared with the drone and ground counts.

7. In general, the average of these image counts for both species compared favourably with those made on the ground. Some differences stood out, however, with both over-counting and under-counting evident (range +7% to -8%), especially among the drone images. Apparent problems were in accurately deciding which birds were sitting on nests as opposed to standing or sitting around when viewed directly overhead in the drone images, and in determining if a bird sitting on a nest close to the superimposed boundary line was inside or outside a quadrat when viewed obliquely on the aircraft-derived images.
8. Despite the various uncertainties involved in surveying seabird populations from aerial photographs or drone-based imagery, there is little alternative at this stage for monitoring species such as Northern Royal Albatross and Northern Buller's Mollymawk nesting on remote, difficult-to-access offshore islands. Continued monitoring of the survey quadrats set out on Motuhara for these species, both on the ground and from the air, can complement the wider coverage achieved through aerial survey, but further development of this approach is needed, particularly in ensuring that these quadrats are representative of these larger populations.
9. To ensure comparability of ground counts and those obtained from aerial images, taken either from an aircraft or a drone, a protocol is needed as to which individuals nesting on the quadrat boundaries should be included in the count.
10. While recognising the difficulties involved in doing this, conducting regular, twice-yearly, coordinated aerial and ground surveys of breeding Northern Royal Albatross—ideally in December, soon after egg laying has been completed, and in August, just before the chicks fledge—would enable more robust assessment of this species' population dynamics.

Introduction

Around 99% of the global population of Northern Royal Albatross | Toroa *Diomedea sanfordi* breeds on three outlying privately-owned islands in the Chatham Islands: Rangitautahi (Big Sister) and Te Awanui (Middle Sister) in the Rangitatahi group (The Sisters), and Motuhara/Motchuhar (The Forty-Fours). The only other colony is a tiny one, around 40–60 pairs, at Taiaroa Head, Otago Peninsula. The species breeds biennially. With a 10.5-month breeding cycle, from incubation to fledging, birds that successfully rear a chick in one year have no time to recover physiologically to breed again the next.

The breeding population of Toroa on Motuhara and Rangitatahi has been assessed sporadically since the 1970s through a mix of ground counts of nesting birds, usually made during the early incubation period (November–December), and counts of birds from aerial photographs, also taken early in the breeding season (Robertson 1998; Baker *et al*. 2017). Assessments of breeding success have been equally sporadic, typically involving aerial surveys carried out in July–August, before the chicks start fledging in early September (Robertson 1998; Frost 2017, 2019, 2021a).

This report details the counts of Northern Royal Albatross adults visible on aerial photographs of Rangitautahi, Te Awanui and Motuhara taken on 1 February 2022, when eggs were hatching. It also includes an assessment of drone images taken on Motuhara on 31 January, the day before the aerial survey. These were focused largely on quadrats around nesting albatrosses but also included some views of five smaller 100 m^2 quadrats encompassing nesting Northern Buller's Mollymawk *Thalassarche bulleri.* The mollymawks nesting in these smaller quadrats were also counted, both on the aircraft-based and drone photographs, and compared with ground counts made on 29 January 2022 (Bell 2022).

Study area

Rangitatahi (The Sisters), centred at 43.5642°S, 176.8075°W, lie 20 km due north of Rēkohu (Chatham Main I.). They comprise three islands: Rangitautahi (Big Sister, 7.3 ha), Te Awanui (Middle Sister, 4.8 ha) and Little Sister, a low-lying c. 5-ha reef. The islands are volcanic in origin, comprising massive limburgitic basalt with associated deposits of breccia, scoria and tuff (Campbell *et al*. 1988). The soils on the two higher-lying islands are generally thin and support only sparse vegetation other than in basins on the plateaus, where the Chatham Island button daisy *Leptinella featherstonii*, and a groundsel, *Senecio radiolatus*, are well established. The button daisy apparently thrives on nutrient inputs from nesting seabirds.

Motuhara (called Motchuhar by Moriori, and previously known as The Forty-Fours), centred at 43.9622°S, 175.8347°W, is an 11.5-ha, 60-m high island lying 42 km east of Rēkohu. In contrast to the volcanic origin of Rangitatahi, Motuhara consists predominantly of hard, fine- to medium-grained, partly recrystallised quartzofeldspathic sandstones or feldsarenites (Andrews *et al*. 1978). It is the most easterly outcrop of Mesozoic basement rocks in New Zealand. The soils are patchy and generally thin, supporting a mixture of open herb-fields and low-growing semi-shrubland dominated by the Chatham Island button daisy, mostly concentrated in the middle and eastern sections of the central plateau.

Methods

Aerial survey

The survey was carried out from an Air Chathams Cessna 206 on 1 February 2022 between 09:35 and 11:00. Conditions at the time were clear and sunny. The 9 a.m. weather data for 1 February 2022 from the Chatham Island Aero automatic weather station (https://cliflo.niwa.co.nz/pls/niwp/wstn.stn_details?cAgent=39523) showed NNW wind of 3.3 m/s (6.4 knots) with gusts up to 9.3 m/s (18 knots), which accords with the sea state seen in some of the images taken during the survey.

The flight path was recorded by GPS (Garmin 64s), with position and altitude logged at 1-sec intervals, allowing airspeed and direction to be calculated with minimal distortion. Although the camera times were not synchronised at the start of the flight with GPS time, a photograph was taken of the GPS at the start, showing the satellite time. From the camera's Exif data for that image, the offset between it and the GPS was determined (+53.23 min). The time difference between the two cameras (+0.33 min) was established later by comparison. Once these offsets were applied to the times recorded on the images, Garmin BaseCamp (v.4.7.4) was used to geo-tag the images against the recorded location of the aircraft at the corrected time for each image. The approximate positions from which the images were taken were then estimated. Several images were then checked visually to ensure that their views broadly fitted those expected from these locations.

Time spent circling and photographing Rangitatahi and Motuhara was short, 13.4 min and 12.5 min, respectively. Nine circuits were flown around Rangitatahi: three each around Rangitautahi and Te Awanui separately; and three around both islands together (Figure 1). Five full circuits were flown around Motuhara, plus two narrower circuits around the eastern and western halves, respectively (Figure 1). Other details of the flight around the islands are given in Table 1.

Table 1. Times, average airspeeds and altitudes flown during the 1 February 2022 aerial survey of Northern Royal Albatross colonies. 'Start' and 'End' refer respectively to the time when the first and last aerial images were taken during the surveys.

Island group	Start	End	Survey time (mins)	Mean airspeed (±1 SD), kph	Mean altitude (±1 SD), m a.s.l.
Rangitatahi	9:50:08	10:03:30	13.4	159 (13.6)	273 (22.4)
Motuhara	10:26:48	10:39:17	12.5	161 (11.3)	243 (22.9)

Airspeed, altitude and distance from the islands all influence the level of detail seen in the resulting images. The QGIS (v.3.22.5) plugin, NNJoin, was used to measure the approximate distance from where individual photographs were estimated to have been taken to the nearest point on a vector tracing the edge of an island's plateau. Assessed this way, the average image distances (± 1 SD; range) were: Rangitautahi, 363 (83, 241–641) m; Te Awanui, 239 (66; 207–479) m; Motuhara, 361 (139; 32–678) m, excluding those photographs taken when the aircraft flew directly above the island.

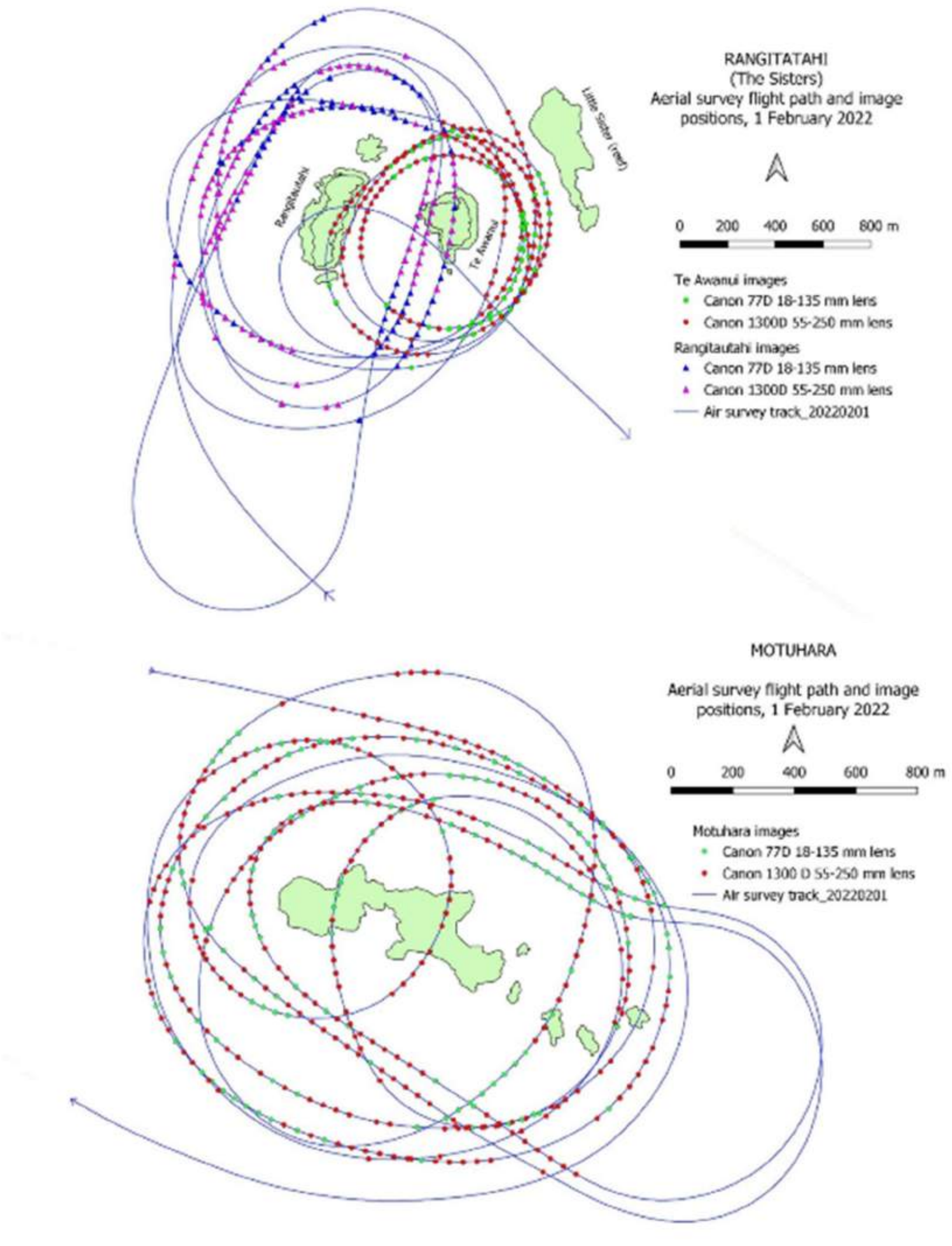

Figure 1. Flight paths flown during the 1 February 2022 aerial survey of Northern Royal Albatross colonies as established by GPS. The points along the flight path show the approximate positions from which the Northern Royal Albatross and several Northern Buller's Mollymawk colonies were photographed.

Aircraft-based images

A total of 1295 photographs were taken using two cameras: 299 of Rangitautahi; 319 of Te Awanui; and 677 of Motuhara. The main camera (Canon EOS 77D, EF-S18-135mm f/3.5-5.6 IS USM lens) was used to take wide-angle views of the colonies.

Close-up photographs of sections of the colonies were taken with the second camera (Canon EOS 1300D, EF-S55-250mm f/4-5.6 IS STM lens). The Exif data for each image—date and time when it was taken; camera make and model; shutter speed, aperture setting, ISO number and lens focal length—were extracted using Picture Information Extractor (v.6.99.10.61; Picmeta Systems, http://www.picmeta.com). Particulars of the cameras and settings used are summarised in Table 2. Both cameras were set on automatic focusing with shutter priority, pre-selected shutter speed and a reasonably high ISO number, to counter the aircraft's airspeed. The aperture settings were adjusted automatically to accommodate changes in lighting.

Drone images

In addition to the aircraft-based images of Motuhara, a further 221 images, taken on 31 January 2022 from a DJI Mavic Air 2 drone, were examined (Table 2). These were taken with a specific focus on nesting Northern Royal Albatross. Ten of these were wide-angle views of the western half of the island taken from an average altitude above launch point of 72 m, which gave an image footprint on the ground of around 103 x 60 m. The remaining images were taken from c.50 m altitude above launch point, giving an image footprint of c.72 x 40 m. These were taken at more-or-less set intervals along 10 near-parallel transects aligned on an average bearing of 97° E (±0.6 SD) over the centre and eastern parts of the island. Adjacent images in this set overlapped by c.56% and 75% on their long and short axes, respectively.

Table 2. Cameras, lenses and settings used during the January 2022 drone (Hasselblad) and February 2022 aerial (Canon) surveys of Northern Royal Albatross colonies. See text for details.

Camera	Lens	Shutter speed	ISO	Aperture	Focal length
Hasselblad FC3170	24 mm f/2.8	variable (1/160-1/640 s)	100	F4.5	4.5 mm
Canon EOS 77D	EF-S18-135 mm f/3.5-5.6 IS USM	1/1328 s	1600	F7-F20	35–135 mm
Canon EOS 1300D	EF-S55-250 mm f/4–5.6 IS STM	1/1328 s	1600	F5–F20	55–250 mm

Image analysis

Images received in Canon RAW format were converted to JPEG format using Digital Photo Professional 4 (v.4.12.60). Selected images were then processed further using Adobe Photoshop Elements 2020 (v.18.0 x64) and, where necessary, Topaz Sharpen AI (v.4.1.0, 2022) and Topaz DeNoise (v3.7.0, 2022), to bring out as much detail as possible without introducing confusing artefacts.

The aircraft-derived images from each island (hereafter aerial images) were collated and subsets chosen that, together, covered all of each island. Within these, discrete, contiguous (non-overlapping) areas were identified and outlined on adjacent images, using prominent common features visible in both as boundary markers: *e.g.*, rocks; fissures; distinctly shaped bare areas; or conspicuous clumps of vegetation.

Where a dividing line passed close to a bird, care was taken to ensure that it was consistently included or excluded in the defined zone on the relevant images, to avoid it being double-counted or left out. The main delineated zones used in this survey are shown in Figure 2.

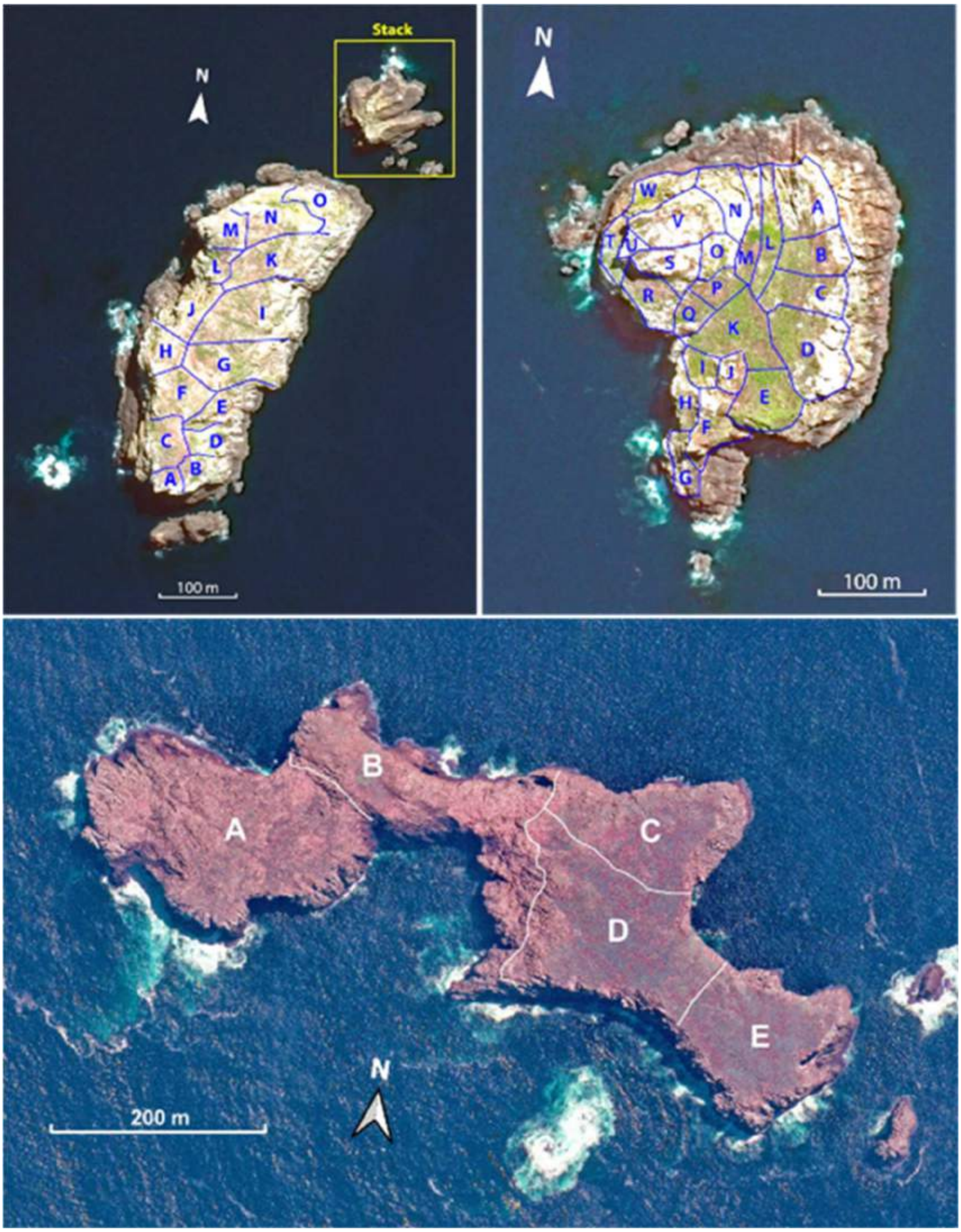

Figure 2. Locations of the main survey areas on the three islands on which Northern Royal Albatross | Toroa nest. For the sake of clarity, the subdivisions of these areas, used when analysing the aerial photographs, are omitted. The islands are not shown to the same scale.

All Toroa seen in each zone were counted and catalogued using DotDotGoose (v.1.5.3, Ersts 2022). Individuals were classed as follows: adult on a nest, either incubating an egg or brooding or guarding a newly hatched chick; adult adjacent to one on a nest (partner); adult standing or sitting in the colony separate from a nest or nesting individual; adult uncertain; adult flying; or carcass (Figure 3).

Figure 3. Main behavioural classes used in categorizing individual Northern Royal Albatross | Toroa nesting on Rangitatahi and Motuhara in early February 2022: A. Incubating or brooding bird; B. Bird guarding a newly hatched chick; C. A partner of a bird on a nest; D. A loafing or loitering bird away from any occupied nest (either birds in transit to or from an occupied nest, or loafing birds, including several apparently incipient pairs). Categories A and B together constituted birds apparently occupying a site.

Whereas the analysis of these landscape-level images provided as accurate a total count of individuals present on the islands as possible, not all birds were equally clearly visible and personal judgement was exercised when allocating them initially to the various behavioural classes. To estimate more accurately the proportions of birds in each class, a series of close-up photographs (235–250 mm focal length) of separate areas of these islands were selected, to avoid double-counting, and the birds clearly visible in these samples classified in the same way as above. Because these close-up images did not cover all of each island, they could not be used for the overall assessment. Instead, they are treated as quasi-independent samples.

For Motuhara, six non-overlapping close-up images were analysed. Of the 1331 individuals assessed, 208 were classed as indeterminate, and so were excluded when calculating the proportions of birds in the various behavioural classes. For Rangitautahi and Te Awanui, six and ten non-overlapping close-up images were analysed, respectively covering 744 and 654 individuals. Of these, 73 and 52 birds were judged to be indeterminate and excluded from further consideration. The proportions of birds on nests (either still incubating an egg or brooding/guarding a chick), or associating with bird on a nest (presumed to be its partner), or loitering (either loafing or transiting to or from a nest elsewhere) were then calculated from the balance of the birds on the ground (*i.e.,* those that could be clearly classified). These proportions were then used to correct the initial total counts.

For the images derived from the drone camera (hereafter drone images) the two sets (wide-angle and lower-altitude vertical) were processed differently. Brightness, contrast and colour-balance were adjusted in the wide-angle images to bring out as much detail as possible. In these images, the corner markers of several 10 x 10 m permanent plots for monitoring nesting Northern Buller's Mollymawk were visible (NBM 1–2, 8–9). These quadrats were then marked up on the images (Figure 4).

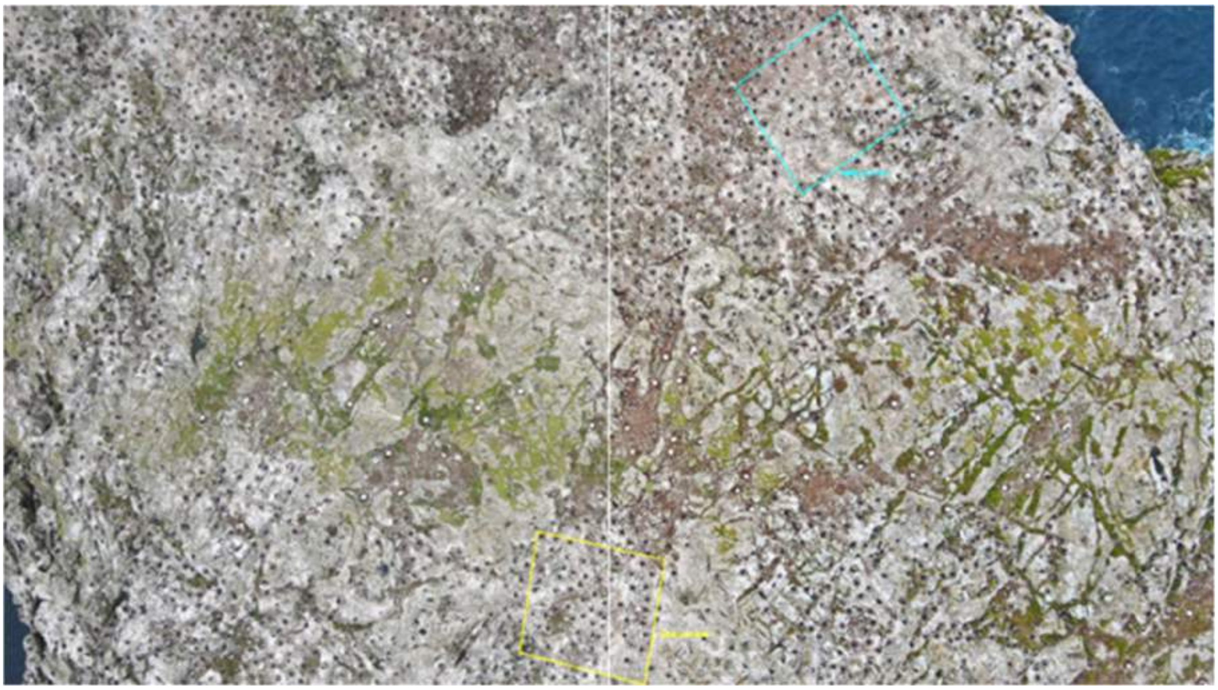

Figure 4. High-altitude drone image showing two 10 x 10 m Northern Buller's Mollymawk monitoring quadrats (NBM 1 [blue] and 8 [yellow]). The area to the right of the central white line has been processed, as an example, to show improved colour balance and clarity. The white dots are nesting Northern Royal Albatross.

The remaining extensively overlapping images, taken at a lower altitude, were stitched together in various combinations using Microsoft's Image Composite Editor (v2.0.3.0, 2015). The initial composites were aligned separately along the axes of the 10 transects, but larger ones, covering the centre and the eastern end of Motuhara, were then created by stitching together the relevant images across the transects (including an overlap between the two composites). These produced two large images: central region, 12914 x 12375 pixels (105 MB); and eastern end, 9577 x 12467 pixels (81.6 MB). These were searched for the corner markers of a recently established 10 x 10 m Northern Buller's Mollymawk monitoring quadrat (NBM 6) and five 20 x 20 m Northern Royal Albatross (NRA 1–5) monitoring quadrats. Their exact locations were not known at the time, although some marked rocks had been seen when analysing the aerial images. Once the corner markers had been located, the quadrats were marked up, first on the composites then on individual drone images once these had been identified. Because the axes of the drone transects (97 ± 0.6 °E) were not aligned along the axis of the NRA quadrats (131.6 °E), the quadrats were only fully visible each in one drone image.

Once the locations of these quadrats had been established, they were then found and marked on several aerial images covering these sites. The numbers of apparently nesting birds counted in both the drone and aerial images were then compared. The contrast between the two views is shown in Figure 5. The same procedure was followed when counting the number of apparently nesting Northern Buller's Mollymawks in the smaller 10 x 10 m quadrats.

Figure 5. Comparison of the views of Northern Royal Albatross monitoring grid NRA2 as seen in aerial (A) and drone (B) images. The blue arrow in B shows the direction of the view of the aerial image (A). Note the person on the lower left of image A for a guide to size. The NRA monitoring grids measure 20 x 20 m, extending from painted rocks at each corner.

To express the uncertainty in the counts of Northern Royal Albatross for each island, 95% confidence limits (CL) were calculated using the *poisson.exact* function in the R package *exactci* (Fay 2017). This corresponds to the exact central confidence interval of Garwood (1936), a widely used method for calculating this parameter in a one-sample case, assuming that the counts follow a Poisson distribution, in which the mean and variance of a sample are the same (Baker et al. 2013). The confidence limits of summed counts were estimated as the sum of the respective lower and upper 95% CL of those counts. The confidence intervals for the adjusted counts were calculated in the same way as for the counts themselves, by allocating the summed lower and upper 95% CL values proportionately among the behavioural states.

Results

Northern Royal Albatross

Across all three islands, an adjusted total of 3269 (95% CL: 3018–3547) Northern Royal Albatross | Toroa were judged to be either incubating eggs or brooding/ guarding young chicks (Table 3). No chick was more than a few days old. In addition, 77 birds were seen sitting alongside occupied nests, presumably as partners of the occupants. A further 200 were present on the ground away from any occupied nest and were either transients, moving to or from an occupied nest elsewhere, or were loafing in the colonies. At least eight of these loafing birds were in pairs and could have been pre-breeders or pairs that had recently lost their egg/chick. Only five relatively recent carcasses were seen in the initial count (Table 3).

The number of nesting birds counted in five 20 x 20 m quadrats established in January 2021 are given in Table 4, including those from single drone images taken from above each quadrat, and various oblique views of these quadrats present in the aircraft-derived (aerial) images. They are compared with ground counts of active nests—egg or chick present—made 2–3 days earlier (Bell 2022) and serve as a partial test of the accuracy of these counts.

For plots NRA1 & 2 the three sets of counts produced the same number of apparently occupied nests. For plot NRA3, the ground and drone counts were the same, but those from the aerial images were one apparently nesting bird higher. For the last two plots, NRA4 & 5, the drone and aerial-image counts were 1–4 apparently nesting birds higher.

The largest disparity was between counts from the various aerial images of plot NRA4. This quadrat is situated towards the middle of central plateau, an average of 615 m (range: 526–737 m) from the circling aircraft, so judgements as to which birds were inside the quadrat boundary and which were outside were difficult to make. Different views produced different counts. To a lesser extent, the same problem of deciding whether a bird nesting on or close to the boundary line should be counted or not also affected the assessment of plot NRA5. In this case, it is possible that a couple of birds nesting on the boundary line, as drawn between the corner markers, were not included in the ground count, but were counted in the photographic analysis.

Table 3. Numbers of Northern Royal Albatross | Toroa adults present on Motuhara, Rangitautahi and Te Awanui on 1 February 2022, as initially classified from an analysis of wide-view aerial photographs, and as adjusted following closer examination of a selection of close-up images (235–250 mm focal length). 95% confidence limits are given in parentheses below the actual and adjusted counts (see text for details of their calculation).

	Motuhara			Rangitautahi			Te Awanui		
Behaviour class	Actual count	*Proportion estimated from close-up photos*	Adjusted number	Actual count	*Proportion estimated from close-up photos*	Adjusted number	Actual count	*Proportion estimated from close-up photos*	Adjusted number
On nest (AOS)	1594 (1517-1674)	*0.939*	1601 (1501-1704)	998 (937-1062)	*0.899*	993 (911-1087)	665 (615-718)	*0.917*	675 (606-756)
Partner bird	32 (22-45)	*0.018*	31 (29-33)	35 (24-49)	*0.025*	28 (25-30)	14 (8-24)	*0.025*	18 (17-21)
Loitering	72 (56-91)	*0.043*	73 (69-78)	59 (45-76)	*0.076*	84 (77-92)	41 (29-56)	*0.058*	43 (38-48)
Uncertain	7 (3-14)			13 (7-22)			16 (9-26)		
Total on ground	1705 (1598-1815)		1705 (1599-1815)	1105 (1013-1209)		1105 (1013-1209)	736 (661-824)		736 (661-824)
Flying	1			4			3		
Carcass	1			4			0		

Table 4. Counts of apparently nesting Northern Royal Albatross in five 20 x 20 m quadrats established on Motuhara in 2022, as determined by direct ground counts on 29 January 2022 (Bell 2022), and through counts made from near-vertical drone images (DJI) and oblique aerial images (IMG) taken on 31 January and 1 February 2022, respectively. Birds judged to be sitting on an egg or brooding/guarding a chick are reported as apparently occupying a nest (AON). Others, either partnering a sitting bird or loafing, are listed as additional (ADD). Where several aerial images have been analysed, the range of counts are given in parentheses.

Plot	Source	Direct	AON	ADD
NRA1	Ground count	23		
	DJI-0377		23	1
	IMG_8133/316/422		23 (23-23)	3 (2-4)
NRA2	Ground count	29		
	DJI-0321		29	2
	IMG_8256/273/674		29 (29-29)	1 (0-2)
NRA3	Ground count	38		
	DJI-0288		38	3
	IMG_8142/214/276		39 (39-39)	11 (10-11)
NRA4	Ground count	30		
	DJI-0266		31	6
	IMG_8143/184/278/331		34 (32-36)	13 (12-15)
NRA5	Ground count	28		
	DJI-0238		30	6
	IMG_8250/307/332/397		30 (29-30)	3 (2-4)

Northern Buller's Mollymawk

General counts of Northern Buller's Mollymawk nesting on all three islands were unsuccessful because of the difficulty of deciding reasonably confidently whether a bird was sitting on a nest or not. There are several reasons, principally low resolution and lack of definition in many images. Moreover, some chicks were seen alone but their small size and grey nestling down made them difficult to see consistently. Consequently, attention focused on counting the number of apparently active nests within five 10 x 10 m quadrats established in 2007 and 2008 on Motuhara (Fraser *et al*. 2010), and a further five set up in 2022 (Bell 2022), only four of which were found in the aerial and drone images. An active nest was one with an adult present and either incubating an egg or brooding/guarding a small chick, or a small chick alone in a nest. Table 5 gives the counts made from several aerial and drone images, together with the ground counts made a couple of days earlier. The results are variable.

Table 5. Counts of apparently nesting Northern Buller's Mollymawk in ten 10 x 10 m quadrats established on Motuhara in 2007 (NBM1-3), 2008 (NBM4-5) and 2022 (NBM6-10) (Fraser *et al*. 2010; Bell 2022), as determined by direct ground counts made on 29 January 2022 (Bell 2022), and through counts made from near-vertical drone images (DJI) and oblique aerial images (IMG) taken on 31 January and 1 February 2022, respectively. Only birds judged to be sitting on an egg, brooding or guarding a chick, or a chick on a nest by itself are included.

Plot	Source	Direct	Average	Min	Max	*CV%*
NBM1	Ground count	34				
	DJI-0188/214/215/216/217		36	35	37	*2.5*
	IMG_8224/237/466/514		35	29	37	*11.1*
NBM2	Ground count	56				
	DJI-0214/215/216/217		55	47	61	*10.5*
	IMG_8464/503/570/572/617/618 /685		55	47	60	*8.9*
NBM3	Ground count	46				
	IMG_8293/461/513/621/622/650		46	43	49	*4.3*
NBM4	Ground count	57				
	IMG_8247/303/465/527		58	57	59	*1.4*
NBM5	Ground count	58				
	IMG_8247/303/465		58	57	59	*1.7*
NBM6	Ground count	64				
	DJI-0241		59	-	-	-
	IMG_8247/357/397		61	59	64	*4.1*
NBM7	Ground count	47				
	IMG_8256/300/301/608		47	46	47	*1.1*
NBM8	Ground count	61				
	DJI-0188/189/214/215/216/217		65	62	70	*4.5*
	IMG_8286/287		62	61	62	*1.1*
NBM9	Ground count	47				
	DJI-0214/216		47	46	47	*1.5*
	IMG_8231/234/381		48	47	49	*2.5*
NBM10	Ground count	40				
	Not seen on drone images		-	-	-	-
	Not seen on aerial images		-	-	-	-

Whereas the average counts are broadly comparable with those made on the ground a few days earlier, being only 1-2 nesting birds different (plots NBM 6 and 8 are exceptions), the same does not apply when the range of values are considered. The counts from some plots were as much as nine nesting birds different on either side (±15–16%). Most of the uncertainty stems from decisions about whether a nesting bird was inside or outside a quadrat, particularly when the quadrats were viewed obliquely, as in the aerial images. These images were also taken from a considerable distance away (Table 6). In contrast, the drone images were taken closer to the quadrats and from almost vertically above (Table 6).

Oblique views of these quadrats sometimes makes it difficult to judge accurately the position of objects in relation to others apparently in the same plane. This is especially problematic when the quadrat boundaries are overlain on an image to demarcate it. (The only physical presence of these quadrats on the ground are painted corner-marker rocks.) Birds crossed by the line or appearing beneath it could be tallied inside or outside depending on the angle at which the quadrat is viewed, which in turn depends on the image.

Table 6. Attributes of the images taken of the marked Northern Royal Albatross (NRA) and Northern Buller's Mollymawk (NBM) quadrats during the aircraft-based survey (aerial images) and drone survey (drone images). The angles should be considered as approximations only because of high uncertainty in the accuracy of GPS-measured altitudes, even though these measurements showed considerable internal consistency.

	NRA quadrats *(± 1SD, N)*	NBM quadrats *(± 1SD, N)*
Mean distance from quadrats (m)		
Aerial images	551 *(116.3, 17)*	434 *(120.7, 35)*
Drone images	52 *(0.9, 5)*	73 *(6.1, 18)*
Approximate angle below horizontal (°)		
Aerial images	20 *(4.7, 17)*	26 *(7.7, 35)*
Drone images	81 *(7.5, 5)*	88 *(0.5, 18)*

Discussion

Northern Royal Albatross

The number of active Northern Royal Albatross|Toroa nests recorded in February 2022 cannot be compared directly with any previous year's counts, which were made either c.2 months earlier, at the start of incubation, or 6 months later, around the time chicks were fledging. The overall number of birds still incubating eggs or brooding/guarding young chicks, 3269, is c.77% of the average number of nests at the start of incubation noted in three aerial surveys undertaken between 2016/17 and 2020/21 (Table 7). Conversely, the average number of chicks estimated to have fledged annually over this period is 36% lower than the February count (Table 7).

Table 7. Average counts (± 1 SD) from aerial photographs of the number of apparently occupied nests (AON) of Northern Royal Albatross at the start of incubation in 2016, 2017 and 2020 (Baker *et al*. 2017; Frost 2019, 2021b) and the average number (± 1 SD) of chicks estimated to have fledged in 2017, 2018 and 2020 (Frost 2017, 2019, 2021a), contrasted with the number of apparently active nests at the time of hatching in February 2022 (this study).

	Motuhara	Rangitautahi	Te Awanui	Total
Average AON (start of incubation 2016–2021; N = 3)	1737 (± 47)	1480 (±239)	1011 (±249)	4228 (±473)
Apparently active nests Feb 2022	1601	993	675	3269
Average chicks fledged (2017–2020; N = 3)	1133 (± 113)	536 (± 47)	434 (± 54)	2103 (± 54)

There are large variations around these average values, however. Not knowing just how many nests were present at the start of the nesting season is one complication. Although royal albatrosses are biennial breeders, birds that fail during incubation or the early chick-guard stage in one nesting season can breed again the following year (Robertson 1998). Consequently, the average number of birds nesting at the start of incubation, as shown in Table 7, can only serve as a rough guide to the actual number present in any given year, as that depends on the level of failures the previous year and what proportion of failed breeders returned to try again the next. It is unlikely to be all.

Determining when during the nesting cycle, and to what extent, nests fail is also problematic. Among the birds nesting in the five 20 x 20 m quadrats on Motuhara during the 2021/22 nesting season, 6.0 ± 5.4% (mean ± 1 SD) of nests had failed by the time of the 29 January 2022 survey, when eggs were hatching (Bell 2022). Of the surviving nests, however, around one-third involved birds apparently still incubating. Some of these birds could have been sitting on eggs that were infertile or contained dead embryos, for whatever reason (G.A. Taylor pers. comm.). Such birds may continue sitting on their eggs for some time beyond the normal incubation period before giving up and their failure becoming apparent. As such, therefore, the full scale of possible nest failures during incubation cannot be known until well after hatching has ended, by which time some mortality of newly hatched chicks will likely also have occurred.

Nevertheless, these complications aside, the number of active nests counted in this survey, situated more-or-less midway between the average number of nests recorded near the start of incubation during 2016–2021 and the average number of chicks fledging over much the same period, does not suggest any recent major changes in the Northern Royal Albatross population.

Northern Buller's Mollymawk

Long-term monitoring of the Northern Buller's Mollymawk population on these islands is problematic, given the numbers and dispersion of the birds involved and the kinds of environments in which they nest (largely on cliff ledges and recesses, and on Motuhara, fissured ground at either end of the island). Whole-island ground counts, as done on Motuhara, 2007–2009, by Fraser *et al*. (2010), and in 2016 by Bell *et al*. (2017), and in 2017 on Rangitatahi (Rangitautahi and Te Awanui) by Bell *et al*. (2018), certainly produce the most accurate counts but are time-consuming. Furthermore, access to and departure from the islands is weather- and transport-dependent, which partly explains the intermittency of the few ground surveys to date.

Estimating the mollymawk population by aerial photography has been used apparently successfully once (Baker *et al*. 2017). Subsequent attempts to replicate this have been thwarted by difficulties in clearly distinguishing nesting birds, not only from their often dark backgrounds but also among themselves. Additionally, complete coverage of the species' nesting areas requires taking photographs down most of the vertical profile of the cliffs around each island, especially Rangitautahi, where some birds seem to nest low down, as well as of the stacks offshore from Rangitautahi and Motuhara. Although a particular effort was made in the present survey to cover these areas, the resulting images still proved difficult to analyse consistently, primarily because of motion blur and low resolution. Moreover, some birds nesting in fissures and recesses may just not be visible from the air (M. Bell pers. comm.). Resolving these problems is still a work in progress. It may require new or additional approaches, such as the use of thermal imaging (G.A. Taylor pers. comm.), although this presents its own unique challenges.

Recognising the difficulties in monitoring Northern Buller's Mollymawk regularly and consistently, five 10 x 10 m quadrats were laid out on Motuhara in 2007 and 2008, with painted rocks marking the corners (Fraser *et al*. 2010). A further five quadrats were added in 2021 (Bell 2022). Figure 6 shows the counts of nesting birds both from ground counts made in January 2022 and from those apparent in aerial images taken a few days after, on 1 February 2022, compared with counts from earlier years made near the start of the nesting cycle.

The difference in timing between the present counts, which took place at the end of incubation/start of chick-rearing (by which time some occupied nests at the start of incubation are likely to have failed), and those made in earlier years soon after incubation started, undoubtedly explains the generally lower numbers recorded in later January and early February 2022. Bell (2022) reported a nest-failure rate of 30 ± 8.5% in these quadrats up to just before the aerial survey. Taking this into account, shown as the vertical black line in Figure 6, suggests that numbers have remained relatively stable, perhaps even having increased slightly in recent years. As Bell (2022) has suggested, a new island-wide census may be warranted, to determine what overall changes, if any, have occurred since 2016, when the last complete survey was done (Bell *et al*. 2017). This would show if the slight upward trend suggested by the quadrat data holds more widely, and therefore whether monitoring these quadrats adequately tracks the broader trend.

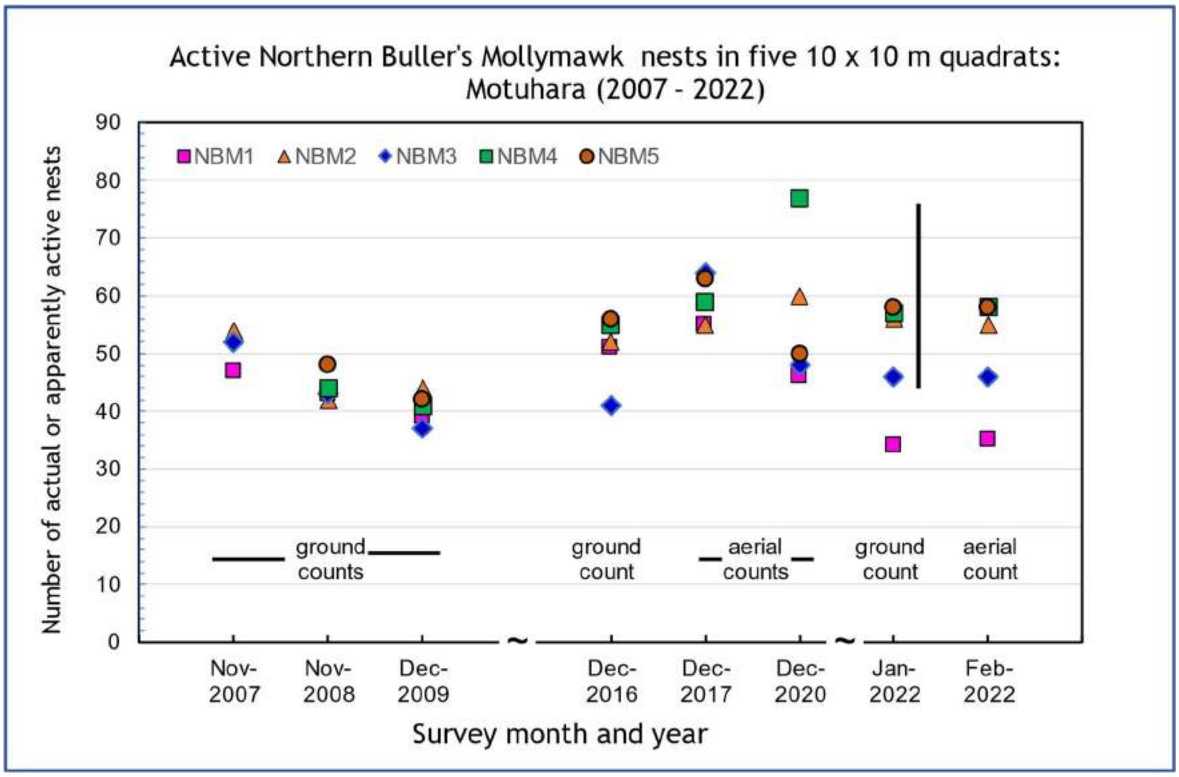

Figure 6. Time-series of counts of nesting Northern Buller's Mollymawk in a set of five 10 x 10 m quadrats laid out on Motuhara in 2007 and 2008. Data for 2007–2009 from Fraser *et al*. (2010); 2016 (Bell *et al*. 2017); 2017 (Frost 2019); 2020 (Frost unpublished); and 2022 (this study, using data from aerial images only, to be consistent with earlier aerial counts [Table 5]). The solid black line shows the likely range in the number of mollymawks incubating eggs at the start of the nesting season, considering the known failure rate of nests in these quadrats to just before the aerial survey (see text for more details).

Conclusion

The usefulness of periodic surveys of permanent quadrats for tracking broader population trends depends not only on how representative these quadrats are of the larger population but also on the accuracy of different kinds of counts. Comparing the counts of apparently occupied nests visible in the near-vertical drone and obliquely angled aerial images of these quadrats with the number of active nests in them counted on the ground (Bell 2022) shows that each approach has advantages and disadvantages.

Direct counts on the ground are obviously the most accurate, but even here some degree of observer choice can influence the results. For example, the quadrats are defined in the field by the position of painted rocks at the corners. Which birds to include during these ground surveys was decided visually by one observer positioned at a corner marker looking down the line to the next corner marker, while the second observer tallied the nests agreed as being inside that boundary (M. Bell pers. comm.). The problem is greater for the smaller 10 x 10m mollymawk quadrats, not only because of the 4x larger edge-to-area ratio, but also because the density of nesting mollymawks is over 6x higher (2 m^2 per bird) than of toroa (~12.5 m^2 per bird). Many more nesting mollymawks than albatrosses are likely to be on the boundaries of these quadrats, increasing the number of subjective decisions required.

The same arbitrariness applies when assessing the near-vertical drone images of both sets of quadrats. Although the position of the boundaries of these quadrats can be drawn precisely on the images, there were several occasions where the line fell on or close to a nesting bird. Whether to include or exclude such individuals was a judgement call. The problem was even more acute when assessing the number of nesting birds in these quadrats on obliquely angled aerial images. Some of the differences among the ground counts and the aerial and drone images are almost certainly due to variations in interpreting the positions of birds nesting on or close to the quadrat boundaries. To ensure the comparability of ground counts with those made from aerial images taken either from an aircraft or a drone, a protocol is needed to ensure consistency in the decisions as to which individuals nesting on the quadrat boundaries should be included in the count: for example, only count every second bird judged to be on the boundary line; alternatively, include (or exclude) them all.

For Northern Buller's Mollymawk, there were sometimes substantial differences between the number of apparently active nests counted on the drone images and those counted on the aerial imagery. When viewed from directly above, as in the drone images, it was often difficult to tell if a bird was sitting on an egg (or brooding a chick), as opposed to simply sitting or standing around. This was less of a problem in the aerial images because, with the birds being viewed partly side-on, it was generally easier to interpret what they were doing, unless partly obscured by vegetation, rocks or other birds. The downside of the aerial images, however, was the presence of often indistinct figures of the birds and the problem of deciding which ones close to the boundaries were in or outside a quadrat. With around 40–60 Northern Buller's Mollymawk nests in a quadrat, even a few miscounted birds would mean about a 5–10% error in the counts. A set of criteria for analysing material from different kinds of surveys is needed to ensure consistency of approach and greater comparability in the results of surveys carried out over time.

Analysing aerial and drone imagery is subject to several other sources of uncertainty. Most important are (a) a failure to detect birds present, either missing them outright or because their presence is obscured by vegetation or rocks; (b) misinterpreting an individual's behaviour, leading to it being counted as nesting when it is not, or not being tallied when it is; and (c) being unable to account for nests that may have failed prior to the census, or which were started after it (Wolfaardt & Phillips 2020; Parker & Rexer-Huber 2022). Careful delineation of boundaries used to partition the colonies for counting purposes and having many aerial images covering each island and its subsets from different perspectives, as in this study, can help to reduce some of these uncertainties. But without being able to contrast the counts with whole-island ground counts, the precise levels and nature of these uncertainties are unknown. In an earlier aerial survey of Rangitautahi and Te Awanui, which coincided with a ground survey of the islands (Bell *et al*. 2018), the aerial counts of Northern Royal Albatross were 2.4% and 0.9% higher, respectively, than the corresponding ground counts on these islands. For Northern Buller's Mollymawk, the differences were greater; the aerial survey counts were 4% and 9% less than the ground counts for Rangitautahi and Te Awanui, respectively (Frost 2019). The reasons for the differences are not known but observer error is likely.

Beyond the technical issues of achieving reasonably accurate and consistent counts of these species at the relevant stages of their breeding cycles, the biggest problem is that in any year the counts are usually constrained, for practical and financial reasons, to being ad hoc events. As such, they are only providing snapshots at a colony or population level of the ongoing underlying processes: *i.e.,* pair formation, egg laying, incubation, brood-guarding, fledging. These events are not precisely synchronous among individuals. Whereas in planning such surveys the aim is to time them as close as possible to the relevant key event in the nesting cycle, the picture that emerges always has some inherent uncertainty attached because of this individual variation in phenology. This limits the scope for interpretation.

Despite these and other uncertainties, aerial survey is still the most practical means of tracking populations of surface-nesting seabirds on remote, difficult-to-access islands. At least on Motuhara, setting up several study quadrats for both Northern Royal Albatross and Northern Buller's Mollymawk provides a specific focus for aircraft- and drone-based aerial surveys, and helps to complement periodic ground counts in instances where whole-island counts cannot be carried out. Although there are additional uncertainties, not only in surveying these quadrats but also in how representative these samples are of the larger population, this mix of methods remains the most viable approach to monitoring these populations at this stage.

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Appendix

Raw counts of Northern Royal Albatross | Toroa by survey area on each island (see Figure 2 for the locations of these areas) and by initial assessment of behavioural state. For the purpose of counting, these areas usually comprised several contiguous subdivisions, as shown by the varying number of images analysed for each area.

1. Motuhara

Area	Image(s)	AOS	Partner	Loafing	Carcass	Unknown
A	IMG_8163/237/243/275	70	0	4	0	1
B	IMG_8170/176/178/182	33	1	0	0	0
C	IMG_8182/188/355	312	6	21	0	6
D	IMG_8142/182/274	895	19	32	1	0
E	IMG_8132/137/272	284	6	15	0	0
Total		**1594**	**32**	**72**	**1**	**7**

2. Rangitautahi

Area	Image(s)	AOS	Partner	Loafing	Carcass	Unknown
A	IMG_7809/954	21	0	0	2	0
B	IMG_7809	8	1	0	0	2
C	IMG_7868	101	3	10	1	0
D	IMG_7864	8	0	0	0	2
E	IMG_7860/895	0	0	0	0	4
F	IMG_7802/870/895	76	2	4	0	0
G	IMG_7860	90	3	2	0	0
H	IMG_7872	7	2	0	0	0
I	IMG_7827/858	204	9	9	1	1
J	IMG_7872/875	19	3	2	0	0
K	IMG_7852/855	137	6	4	1	1
L	IMG_7875	33	1	2	0	0
M	IMG_7855/877	96	3	13	0	1
N	IMG_7851	198	2	13	0	2
O	IMG_7852/883/8000	0	0	0	0	0
Total		**998**	**35**	**59**	**5**	**13**

3. Te Awanui

Area	Image(s)	AOS	Partner	Loafing	Carcass	Unknown
A	IMG_8032	21	1	1	0	1
B	IMG_7937	59	3	3	0	0
C	IMG_7937	30	1	5	0	0
D	IMG_7938/8079	84	2	6	0	1
E	IMG_8092	97	1	7	0	1
F	IMG_8083/8085	0	0	0	0	3
G	IMG_8085	0	0	1	0	1
H	IMG_8089	14	0	2	0	0
I	IMG_8093/8094	39	0	1	0	1
J	IMG_8082/8083/8121	19	2	0	0	1
K	IMG_8082/8094	124	1	3	0	0
L	IMG_8077	40	1	6	0	0
M	IMG_7934/7976	37	1	0	0	0
N	IMG_7929/8005	2	0	0	0	5
O	IMG_8009	4	0	1	0	0
P	IMG_8009	20	0	1	0	0
Q	IMG_8009/8095	23	0	1	0	0
S	IMG_8421/8023	18	0	1	0	0
RT	IMG_8056	10	0	0	0	2
U	IMG_7931	3	0	0	0	0
V	IMG_7931	21	1	2	0	0
W	IMG_7929	0	0	0	0	0
Total		**665**	**14**	**41**	**0**	**16**