Drone-based Salvin's albatross population assessment: feasibility at the Bounty Islands

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Department of Conservation project: Assessment of drone aerial imaging for monitoring Salvin's albatross at the Bounty Islands

PARKER CONSERVATION

Drone-based Salvin's albatross population assessment: feasibility at the Bounty Islands

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Introduction

Salvin's albatross *Thalassarche salvini* are a Nationally Critical seabird endemic to New Zealand. They breed at two sites, predominantly at the Bounty Islands (Sagar et al. 2015) and are one of the New Zealand seabird species most at risk from fisheries bycatch (Abraham and Thompson 2015; Richard and Abraham 2015). The population status at the Bounty Islands is poorly known due to logistical difficulties in conducting research at this remote location, and differences and inherent uncertainties in methods previously used to assess population status (Taylor 2000; Baker et al. 2014; Sagar et al. 2015). By extrapolating densities from one island, population sizes of 76,000 and 31,000 pairs across the group were estimated in 1978 and 1997, respectively (Robertson and van Tets 1982; Taylor 2000). Method differences, including in how densities and areas were estimated, led to targeted repeat censuses of marked areas (Clark et al. 1998; Amey and Sagar 2013) that over time gave worrying data on trends (30% decline in breeding pairs between 1997 and 2011) (Sagar et al. 2015). Repeat counts for trend assessment, however, need to be complemented by whole-population size estimates because a small count site may or may not remain representative of changes in the whole population over time.

Because many of the islands are inaccessible to boat-based landings, aerial photographs appear to be the best way to estimate population numbers across the whole Bounty Island group and assess trends over time. Aerial photographs taken from fixed-wing aircraft have been used to count Salvin's albatross (Baker et al. 2012, 2014; Baker and Jensz 2019). Estimates ranged between 42,800 and 60,400 birds, although not all birds counted in photographs will have been breeding (Baker et al. 2014; Baker and Jensz 2019). However, surveys involving aeroplane charter or helicopters are logistically demanding and expensive, so other methods for aerial surveys are being explored.

Population monitoring by drones hold promise as an alternative way to obtain aerial photographs suitable for estimating albatross numbers at reduced effort and cost. Also known as unmanned aerial vehicles (UAV), drones are increasingly used for seabird population assessment and monitoring worldwide (McClelland et al. 2016; Borrelle and Fletcher 2017; Brisson-Curadeau et al. 2017; Korczak-Abshire et al. 2019). In the New Zealand subantarctic drones have been used successfully for a range of wildlife monitoring at the Antipodes and Auckland Islands (Dawson et al. 2017; Cox 2018; Cox et al. 2019; Muller et al. 2019; G. Elliott pers. comm.). Relative to piloted aerial surveys, drone surveys have low operational costs, simple logistical requirements, and are relatively low risk for operators, while providing data that are systematic, repeatable, and accurate (Adame et al. 2017; McIntosh et al. 2018; Hodgson et al. 2018). Some constraints are similar, particularly the impact of wind, rain, and haze on image acquisition. As with any survey method drones also have limitations, notably in battery life and potential for wildlife disturbance.

Effects on animals are becoming better documented as drone use for wildlife surveys becomes more common (Sardà-Palomera et al. 2012; Borrelle and Fletcher 2017; Brisson-Curadeau et al. 2017; Hughes et al. 2018; Weimerskirch et al. 2018; Mustafa et al. 2018). To date, drones have been used at the Bounty Islands primarily to assess the potential for wildlife disturbance. The islands are densely populated with fur seals *Arctocephalus forsteri*, erect-crested penguins *Eudyptes sclateri* and smaller seabirds as well as the Salvin's albatrosses, so the potential for disturbance by drones was assessed carefully (Rexer-Huber and Parker 2020). Disturbance of animals on the ground or in the air was minimal provided the drone was flown with due caution (avoiding seal clusters near launch site, flight height assessed relative to flying bird density but not below 20m flight height) (Rexer-Huber and Parker 2020).

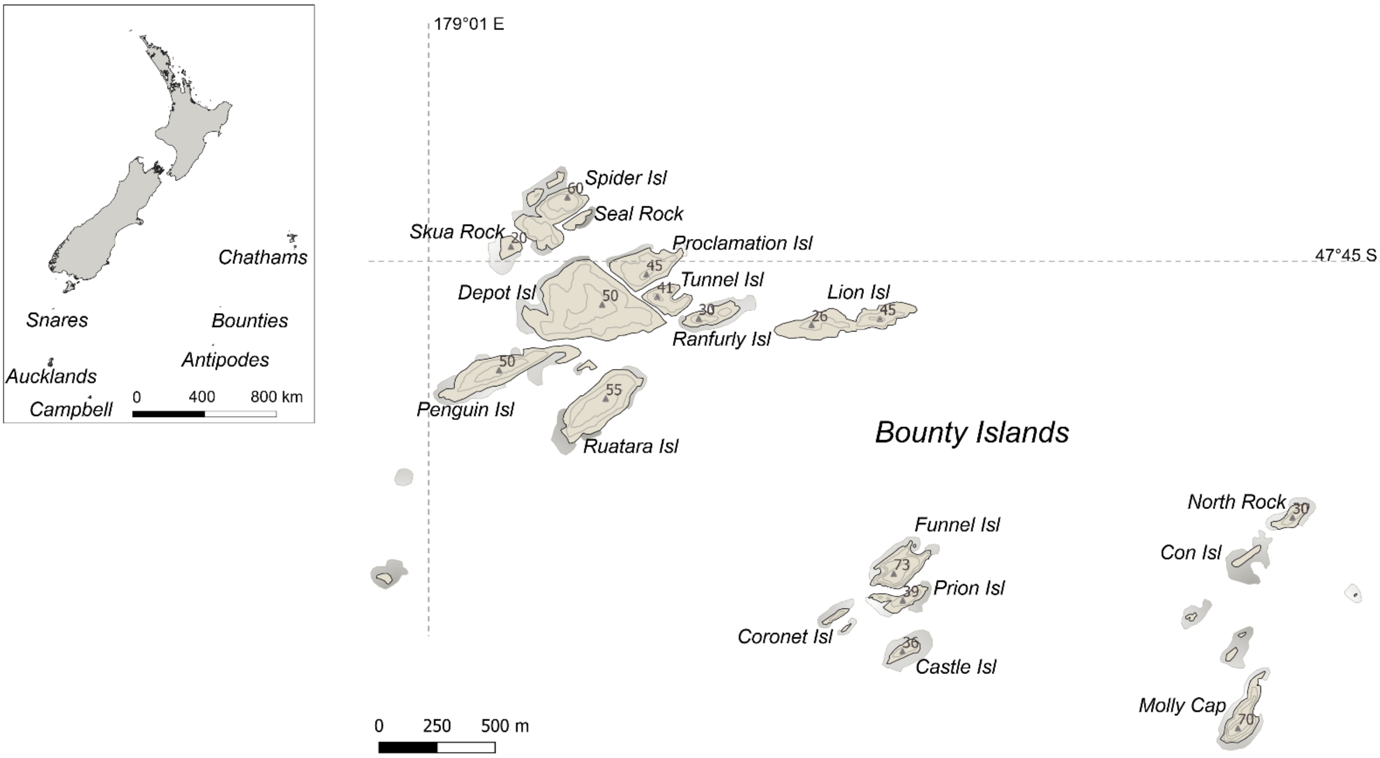

Figure 1. Bounty Island archipelago. Rock barriers and shelves are grey-shaded, and island point heights are in meters. Layers sourced from the LINZ Data Service

Images covering Proclamation, Spider, Tunnel and Ranfurly Islands taken October 2019 are used toward the following objectives:

1. To determine the suitability of drone-based images for counts of Salvin's albatross in light of the potential for future use of drones to obtain a population size estimate of Salvin's albatross at the Bounty Islands;
2. Compare drone-based counts with those from previous work (aircraft photo counts, ground counts) via whole-island counts of Salvin's albatross at Proclamation, Spider, Tunnel and Ranfurly Islands.

First we consider existing drone-based images to gauge their suitability for Salvin's albatross counts. To test how drone flight parameters affect image quality and thus data/count quality, we count albatrosses in the same sub-area in photographs at 40m, 60m and 80m flight height. On the steep sides of the islands, animals are at greater distance to the camera, so data quality is assessed in terms of identification (how reliably Salvin's albatrosses can be identified and distinguished from other animals at each flight height) and status uncertainty (how reliably can loafing and apparently nesting birds be assigned). We discuss the implications of these data quality metrics on the potential for future drone-based estimates of the population size of Salvin's albatross at the Bounty Islands, and provide recommendations for how best to deal with some of the uncertainties inherent in aerial count data.

To assess if drone-image counts are comparable with existing data (photo counts from aircraft, ground counts), we then do whole-island counts of Salvin's albatross on all islands that have had drone overflight (Proclamation, Spider, Tunnel and Ranfurly Islands). We document baseline drone counts, compare results to those from other methods, and discuss the relative utility of survey methods.

Methods

Bounty Islands

The Bounty Islands (47° 44'S, 179° 02'E) are a group of bare rocky islands ~660km south-east of New Zealand's South Island (Fig. 1). Comprising 22 rocky islands and islets with just 135 ha in total area, the islands are steep-sided and difficult to access. The rock is a coarse granite with a blocky, broken surface structure covered in dense mixed-species seabird and seal colonies. Salvin's albatross breed on eight islands in the archipelago: Proclamation, Tunnel, Depot, Ruatara, Penguin, Spider, and Funnel Islands, and Molly Cap (Fig. 1). Although Ranfurly and Lion Islands have been included in this list in the past, birds have not been found there in the last decade (Baker et al. 2012).

Image capture: drone trials

Images were acquired during a single trip to the Bounty Islands in October–November 2019 as part of other work for the Department of Conservation's Conservation Services Programme. Work was supported by the expedition yacht *Evohe*, with the team based on the boat throughout the trip and landing each day for work on the islands. Since the major focus of the drone work was assessing animal responses (Rexer-Huber and Parker 2020), flights took off from/returned to land instead of the boat to ensure the pilot and spotters had the best possible field of view to monitor animal responses.

Images were taken with a high-quality Hasselblad camera (20MP 1" CMOS sensor) on the DJI Mavic 2 Pro drone, using five flight batteries. For manual flight we used the DJI Go4 drone interface software, but grid flights for image capture were programmed and run via Pix4D Capture software.

Image acquisition involved two steps: animal response trials followed by grid flights (Rexer-Huber and Parker 2020). Animal response trials first tested whether drone operations had adverse impacts on fur seals, penguins, or seabirds. Grid flights to capture images over whole islands were initiated after satisfactory animal response trials, but careful monitoring of animal responses continued throughout to enable swift mitigation action if needed (Rexer-Huber and Parker 2020). Programmed grid flights were set to take nadir images, directly overhead, with generous 80% front and 72% side overlap to ensure good coverage of the whole island, including the steep sides of the islands where animals are at greater distance to the camera. Flights longer than 25 min, the average life of a single flight battery, were programmed to ensure photography resumed with suitable overlap after a battery change. Proclamation Island was overflown three times, at 40m, 60m and 80m above launch height (launch platform ~40m asl). Tunnel and Ranfurly Islands are a similar height to Proclamation (high point 40m) so were overflown at 60m. The Spider Island cluster is 60m high, so the drone flew at 80m for these islands.

Photographs were taken on the 28 and 29 October 2019, which is late incubation for Salvin's albatross (two weeks before mean hatching on 14 November; Amey and Sagar 2013).

Image processing and counting

Drone photographs were adjusted for shadows, highlights, and mid-tone contrast, then stitched into composites using the program ICE (Image Composite Editor, Microsoft). The projection used Transverse Mercator; other parameters were left as defaults. Composite images were loaded into the wildlife counting application dotdotgoose (Ersts 2019). All images were counted by the same person for consistency.

Flight height effects

To assess flight height effects on image quality and data quality, a sub-area of Proclamation Island was identified to count at 40m, 60m and 80m flight heights. The subarea comprises about 20% of the island area and included representative areas (broken ground, smoother platforms and sloping downhill) (Fig. 2). Landmarks along the boundary were first marked in images from all three heights. Count categories were chosen to compare identification (how reliably Salvin's albatrosses can be identified and distinguished from other animals at this flight height) and status uncertainty (how reliably can loafing and apparently nesting birds be assigned). Status categories were apparently on nest (AON, where bird sitting on clear nest), loaf (bird not on nest, standing or sitting in colony) and uncertain (albatross status unclear). Where identification was not certain (looks to be an albatross but too fuzzy to be certain) we marked these putative birds as likely-albatross.

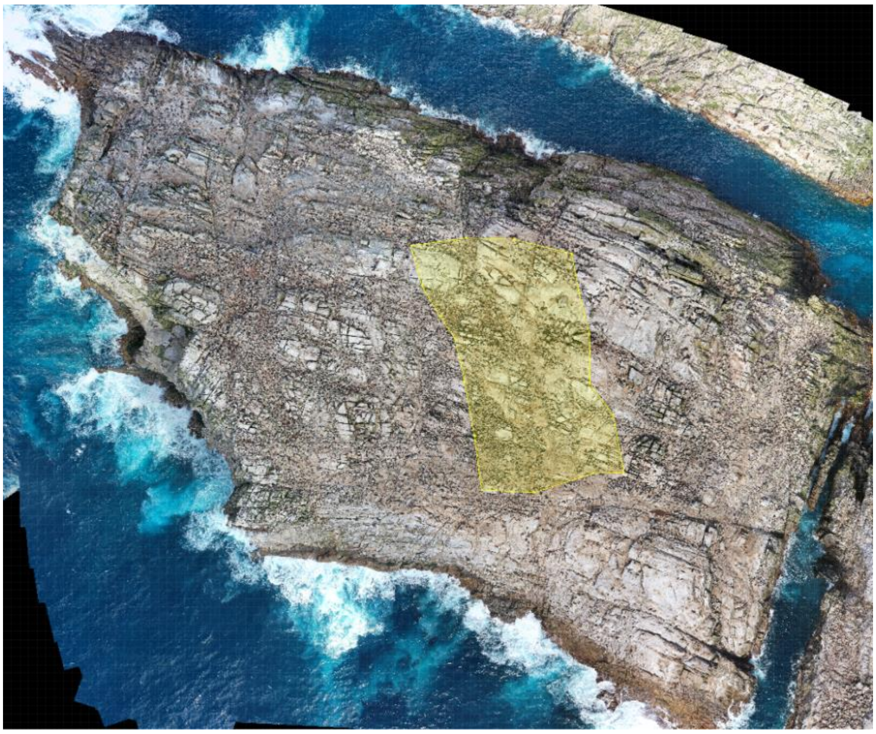

Figure 2. Proclamation Island showing the count sub-area covered at 40m, 60m and 80m flight heights

Whole-island counts

For whole-island counts we counted every bird following Baker et al. (2014). We did not attempt to determine the status of albatrosses in these whole-island counts, based on the preliminary work on flight height effects (very few birds can have status confidently assigned at 60–80m flight height; see below), and the high proportion of birds with unclear status in close-up sections of previous aerial photographic counts (Baker and Jensz 2019). Therefore, count categories were simply albatross and likely-albatross (allowing for cases where identification was uncertain). We also recorded 'ghost-doubles', or double-ups that can occasionally occur if stitching of image composites is imperfect. Image seams were checked carefully for ghost-doubles and one of each duplicate animal masked (marked for exclusion). All Salvin's albatross counts and ghosting records were saved for archiving.

Calculations

Data quality metrics (status uncertainty, identification ability and stitching error) were calculated as follows. For all counts, ghost-doubles were used to quantify stitching error (ghost-doubles/all definite albatross), and likely-albatross used to assess identification ability (definite albatrosses minus likely-albatross/all albatrosses). In assessment of flight height effects, status uncertainty was calculated as albatross status unclear/all definite albatross.

Estimates of whole-island breeding pair numbers were calculated from raw counts of Salvin's albatrosses, multiplied by a ground-truthing correction obtained via ground counts (all definite albatrosses x ground truthing correction). This is crucial because apparently nesting birds cannot be reliably distinguished from loafing birds in aerial images (given the sometimes very minimal nest made by many nesting Salvin's albatrosses) (Amey and Sagar 2013), and it is not possible to tell if a nest actually contains an egg. Ground counts define the proportion of nests that contain eggs out of all birds present in the colony (including loafing birds and apparently incubating birds that do not have an egg). The most recent ground-truthing showed that 0.47 (range 0.41–0.52) of all Salvin's albatrosses in the Proclamation colonies were actively incubating an egg (Sagar et al. 2018).

Results

Height effects

Images from grid flight at 40m, 60m and 80m over the same sub-area of Proclamation are used here to assess the relationship between image quality (ground sample distance, GSD) and count quality (ID confidence and status uncertainty) (Table 1).

Photographs from the drone at 40m were of excellent quality (0.94 cm/pixel GSD) and images from 60m seemed of adequate image quality (1.4 cm/px GSD; Table 1). The greater processing load to stitch image composites at lower flight heights (more images) proved not to be an issue (Rexer-Huber and Parker 2020).

Albatross identification (the proportion of albatrosses identified with certainty out of all albatrosses, considering likely-but-not-certain albatross identifications) decreased from 99% ID confidence to 95% ID confidence as flight heights increased (Table 1). ID confidence remained about the same at 60m and 80m flight heights, with fewer likely-albatross identified at 80m (Table 1). Counting time was not notably affected by increasing flight height.

Table 1. Increasing flight height affects albatross counts

	40m	60m	80m
Quality: GSD (cm/pixel)	0.94 cm/px	1.4 cm/px	1.87 cm/px
Count time (min)	64	66	64
Albatross status unclear	370	579	617
Apparently on nest AON	223	87	35
Loaf	30	7	3
Likely-albatross: probable albatross but not certain	7	42	38
All definite albatrosses	623	673	655
Quality: ID confidence (definite albatrosses/all albatrosses)	0.989	0.941	0.945
Quality: status uncertainty (status unclear/all definite albatrosses)	0.594	0.860	0.942

The ability to determine albatross status with confidence decreases with increasing flight height (Table 1; Fig. 3). Status uncertainty (the proportion with uncertain status out of all definite albatrosses, considering birds clearly loafing or on nest) increases from 59% to 94% as flight height increases (Table 1). A bird clearly sitting on a nest in the 40m image can be of uncertain status in the 80m image (orange circles, Fig. 3). Figure 4 illustrates assignment of uncertain status in the 40m image, showing a clear example of a loafer compared to another likely loafer that is classed as uncertain because it is not possible to see whether the bird has a nest underneath.

Considering the high proportion of uncertain status even at the lowest flight height (59% uncertain at 40m) and under ideal lighting/image capture conditions at 80m (94% uncertain), we suggest that whole-island counts from photographs are best to count all birds, rather than trying to separate by status. Using all-birds raw counts, a correction can then be applied to separate actively breeding from apparently breeding and loafing birds. This approach is more repeatable and consistent, and has the added benefit of removing the element of subjectivity inherent to status assignment in an albatross with such minimal nest structures.

Image quality is not just affected by image resolution but also by light and shading, which we expect will also influence count data quality. Animals in highly shaded areas were difficult to detect. For example, the 40m overflight of Proclamation had flat light conditions throughout, with little to no shadows thrown, while bright sunlight the next day produced deep shadows and contrast in some of the images (60m overflight; Fig. 3). Similarly, Tunnel Island overflight occurred under bright sunlight, with both rocks and animals casting long shadows. This slowed counting as well as probably affecting count accuracy. Flight should occur on an overcast day, or at least around noon if a bright and sunny day cannot be avoided.

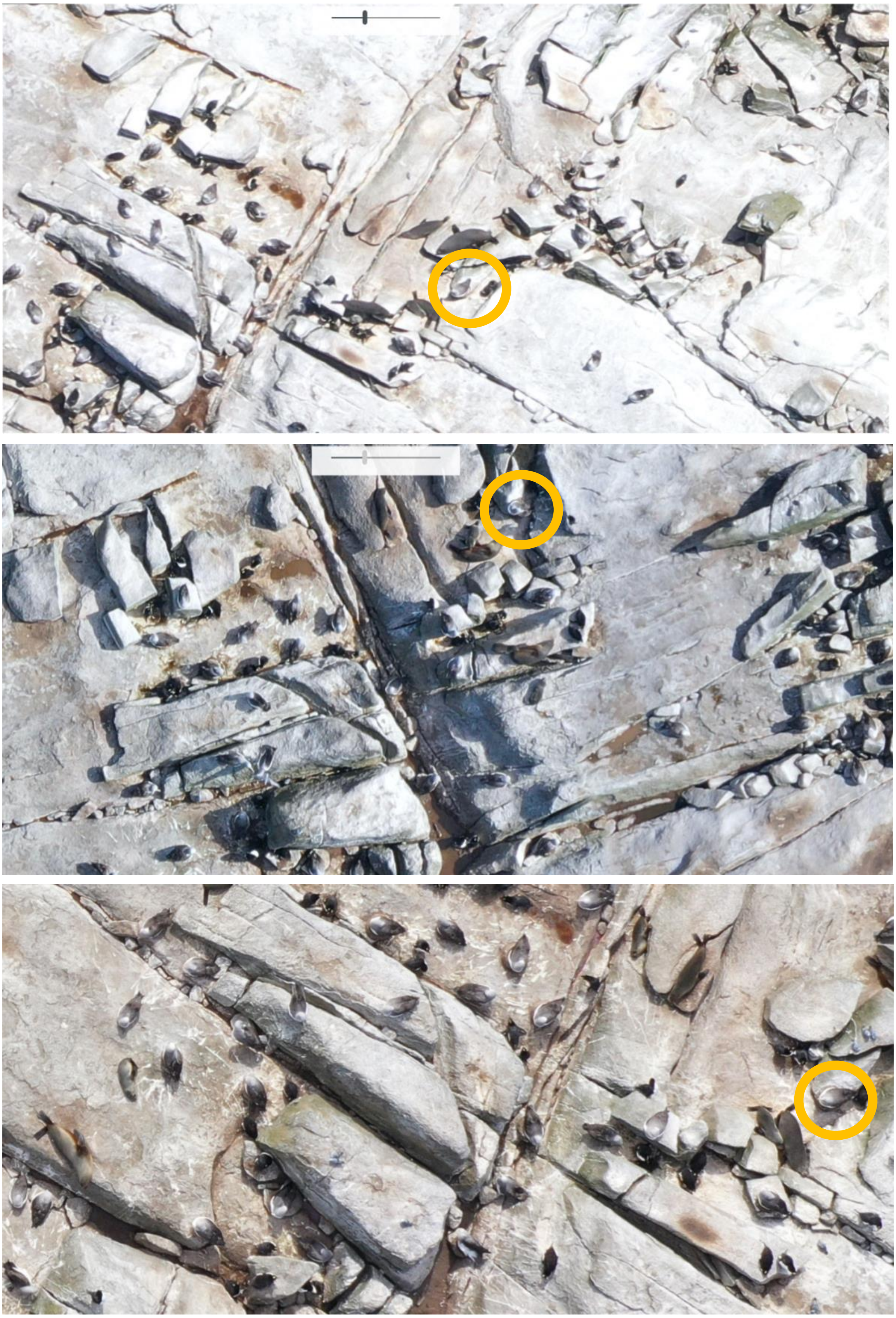

Figure 3. A site at Proclamation Island photographed at 80m, 60m and 40m flight heights (top, middle and bottom images, respectively). All to 30% magnification. Circles identify the same albatross in each image.

Figure 4. Salvin's albatross status, where yellow: albatross status uncertain, purple: apparently nesting, pink: loafing. a) Loafing bird with no trace of nest, shadow showing it is standing, status: loaf. Compare with b) where uncertain if there is a nest under the bird (status: uncertain). c) Probably nesting but not sure, see what might be a tiny crescent of nest; status: uncertain. d) The smudge of earth above the bird may be nest-related, but not sure so status: uncertain.

Whole-island albatross counts

The Spider Island group had a count of 3,862 albatrosses giving an estimated 1,815 (1,583–2,008) breeding pairs (Table 2). All albatrosses were found on the main Spider Island, with albatrosses absent from the other islands and islets in the group (Skua Rock, Seal Rock and unnamed islets). Similarly, Ranfurly Island did not have any albatrosses present on land.

Tunnel Island had a raw count of 3,595, giving an estimated breeding number of 1,690 (1,474–1,869). However, the image quality was poorer than some of the other whole-island photographs, giving lower identification confidence (0.87 instead of 0.93–0.99 elsewhere; Table 2). We expect Tunnel Island counts will be underestimated to a greater (but unknown) extent than at other islands. Quality issues were partly due to poorer resolution (file size smaller than other composites) but also poorer light conditions (more deep shading than in other images).

Proclamation Island had a raw count of 5,227 birds, comprising an estimated 2,457 breeding pairs (range 2,143–2,718 pairs; Table 2). High image quality gave high identification confidence (99% ID confidence). Albatross numbers on Proclamation, separated according to the count blocks established in 1997 (Clark et al. 1998; de Roy and Amey 2004), are provided for reference in Appendix A.

Table 2. Salvin's albatross counts for several islands in the Bounty Islands

	Spider group	Ranfurly	Tunnel	Proclamation
Flight altitude (m)	80	60	60	40
Total flight time (mins)	30	10	12	35
Albatrosses (raw count)	3862	0	3595	5227
Likely-albatross: probable albatross but not certain	238	0	511	57
Ghost doubles	69	na	12	8
quality_ID (definite/all albatrosses	0.926	na	0.873	0.986
stitching error (ghosts/birds)	0.018	na	0.003	0.002
Breeding pairs estimate (range)	1815 (1583–2008)	0	1690 (1474–1869)	2457 (2143–2718)

Breeding pairs is raw counts multiplied by status correction (proportion of breeding birds out of all birds present). Status correction used (mean 0.47, range 0.41–0.52) is from Sagar et al. (2018)

Stitching error was quantified for each image as the number of ghost-doubles as a percentage of all albatrosses, giving an average 0.8% stitching error in this set of drone-derived imagery. The smallness of this error is reassuring but may change if raw images are stitched again since stitching quality can differ between processing attempts. For example, the 60m overflight was stitched poorly in ICE on first attempt, with some areas excluded entirely. If a poorly stitched image like that one was to be counted, stitching errors would certainly affect accuracy. However, in images counted for this work, stitching error mostly just resulted in more counting time to carefully check and mask duplicated areas for animals' ghost-doubles.

Discussion

Height effects

Drone overflight at 40m provides excellent imagery suitable for albatross counts. Resolution is such that at the top of the island, animal behaviours can be observed including pairs allopreening. As flight height increases and resolution decreases, it becomes progressively harder to assign a bird's status to loafing or apparently nesting with any confidence. At 40m flight height, 46% of birds had clear status, compared to 6% at 80m flight height. Status uncertainty was similarly high in counts of photos from fixed-wing aircraft, with the status clear for around 51% of Salvin's albatross visible in a small set of close-up shots (Baker and Jensz 2019). While a correction for nest contents is still needed even when status is clear (73% of apparent nesters in 2018 had an egg, range 62–86%) (Sagar et al. 2018), a count corrected only for nest contents remains a more refined estimate than one where all birds of any status are lumped together and corrected for the breeding proportion (47% of all birds in 2018 had an egg, range 41–52%) (Sagar et al. 2018).

Flying lower to improve image resolution further is unlikely to fix the issue of uncertain status since at 40m, birds are clear and distinct, and the issue is more one of nest detection. At the Bounty Islands, some nesting birds have minimal nests (as little as a short retaining wall/lip to stop the egg from rolling away) which is aerially indistinguishable from a loafing bird resting on the ground. Distinguishing loafers from nesting birds is a substantial part of the status uncertainty in Bounty Isl aerial photographic counts.

We cannot test whether accuracy of counts decreases with increasing flight heights, but a proxy for accuracy is identification confidence. Most albatrosses are easily identifiable as such, but the proportion of uncertain identifications (likely-albatross) increased from 1% to 6% as the image gets fuzzier from 40m to 60m. However, at 80m there were fewer uncertain identifications. This is likely because at 80m flight height, the most distant and/or poorly photographed birds (that would otherwise have been marked as likely-albatross) become lost in general image fuzziness. The islands are steep-sided, so even at 40m flight height images are lower resolution near sea level where animals are ~80m below the camera. This could be addressed by first flying the drone to obtain a digital elevation model, then programming drone flight to maintain a given altitude to land, therefore maintaining a consistent distance between camera and focal animals

Overflights at 60m and 80m took less flight time than at 40m but resolution was lower, with reduced ability to determine status and likely reduced accuracy. The time/battery savings of higher overflight are outweighed by the loss of image quality.

Albatross numbers

Counts of albatrosses on Proclamation Island in 2019 (5,227 individuals representing an estimated 2,457 breeding pairs) are comparable to estimates from fixed-wing aerial photographs, with estimates ranging from 1,762 to 4,880 breeding pairs at a similar time of year 2010–2018 (Baker et al. 2012, 2014; Baker and Jensz 2019) (Table 3). Numbers of breeding Salvin's declined by ~30% at Proclamation between 1997 and 2011, based on repeated ground counts using the same method (Amey and Sagar 2013). Those ground counts at Proclamation took place several weeks later but fall in the range of aerial photographic counts (3,062 and 2,634 in 1997 and 2004 respectively; Table 3) (Clark et al. 1998; Amey and Sagar 2013;

Sagar et al. 2015). Subsequent repeated aerial photo counts for Proclamation suggest a recovery in Salvin's numbers 2010–2013 has been followed again by substantial declines (Table 3).

Crucially, to compare ground counts with counts from aerial photographs, aerial image counts must be corrected for the proportion of birds that are actually breeding. This is especially true at the Bounty Islands, where nesting birds often have minimalist nests that are much harder to see than the large pedestals of other *Thalassarche*, so nesting birds can be difficult to reliably distinguish from loafing birds (e.g. Baker et al. 2012). Thus, breeding pair estimates for aerial image studies are raw counts from the initial study, corrected here in Table 3 using the ground-truthing data closest in time to the photographic data (Amey and Sagar 2013; Baker et al. 2014; Sagar et al. 2018).

Table 3. Summary of whole-island counts of nesting Salvin's albatrosses over time. Ground counts are the number of breeding pairs counted; aerial counts are the raw count from the source corrected using ground-truthing data to give estimated number of breeding pairs. Ground counts from Proclamation in 2011 not included as only a partial count of the island was possible

		Proclamation	Tunnel	Ranfurly	Spider	timing	source
1997	Ground	3062	-	-	-	12–16 Nov	(Clark et al. 1998)
2004	Ground	2634	-	-	-	15–23 Nov	(Amey and Sagar 2013)
2010	Aerial plane	1762 [a]	1442 [a]	0	2318 [a]	12 Oct	(Baker et al. 2012)
2013	Aerial plane	4880 [b]	3435 [b]	0	3446 [b]	23 Oct	(Baker et al. 2014)
2018	Aerial plane	3150 [c]	2394 [c]	0	2499 [c]	25 Oct	(Baker and Jensz 2019)
2019	Aerial drone	2457 [c]	1690 [c]	0	1815 [c]	28–29 Oct	This study

Status correction applied (proportion of breeding birds out of all birds present):
[a] 0.618 in 2011 (Amey and Sagar 2013); [b] 0.74 in 2013 (Baker et al. 2014); [c] 0.47 in 2018 (Sagar et al. 2018)

A decline in breeding numbers in the mid-2000s, followed by apparent recovery in the early 2010s and a decrease in numbers later in the 2010s coincide with the timing of similar trends in both Gibson's and Antipodean albatross (Elliott and Walker 2020; Rexer-Huber et al. 2020). Whether these changes over time at Proclamation are representative of other islands is unknown, but the pattern since 2010 of increasing numbers that have been declining again 2018–19 also is seen on Tunnel and Spider Islands (Table 3).

Suitability for population estimate

Drone pros and cons

Our trials of a drone at the Bounty Islands show that drones are suitable for assessing Salvin's albatross numbers there, in line with work on albatrosses elsewhere (e.g. McClelland et al. 2016; Weimerskirch et al. 2018) and seabirds generally (Borrelle and Fletcher 2017; Brisson-Curadeau et al. 2017; Muller et al. 2019; Korczak-Abshire et al. 2019). Drones have several advantages compared to fixed-wing aircraft. These are mostly operational (flexibility of use cf. weather windows, cost able to be shared with other work), with the resulting images from the Bounty Islands largely comparable for counting purposes (Rexer-Huber and Parker 2020). Programmed flight paths can be re-used over time, providing repeatability that is particularly useful for estimating trends.

Practical scaling up

For a population size estimate of Salvin's albatrosses at the Bounty Islands, overflight at Proclamation, Tunnel, Ranfurly and the Spider Island group would need to be expanded to include all other islands in the group. This is feasible since Depot, Ruatara and Penguin Islands could be flown from Proclamation, and other islands in the group can be approached by boat and the drone flown from the vessel's deck. Boat-based flight is a widely used approach (e.g. Dawson et al. 2017; Steve Bradley, Bill Morris pers. comm.). Planning would need to consider swell along with weather contingency. For data from all islands, battery number and charging options will need to be considered as battery life is the primary factor limiting coverage. Even small weather windows can be utilised, targeting overcast flat light conditions as less shading greatly aids counting.

Precision and accuracy

For population size estimates, associated precision and accuracy estimates are critical. Count precision could be estimated by double-counts in photographs of small areas of each major island. The accuracy of counts in photographs can be assessed from ground-truthing data, with ground truthing at islands that workers can access useful for interpreting images for islands where ground truthing was not possible. Ground-truthing data are needed to assess the accuracy of counts from any aerial photographs, for any albatross species (Baker et al. 2015).

For population size estimates, accuracy has two parts: detectability (what proportion of birds are missed, for example under overhangs or in deep shade?), and status or nest contents (what proportion of apparently nesting birds are actually breeding?) (Parker and Rexer-Huber 2015). Detectability assessment involves ground-counts of a given area to assess what proportion of birds in deep shade and under overhangs are missed in aerial photographs of the same area, ideally concurrent with drone overflight.

Status assessment was conducted in 2013 and 2018, checking the contents of nests along transects and quantifying the proportion of loafing birds (Table 4). Whole-island count data from earlier work can also provide useful correction data for the actual proportion of breeding birds (Table 4). The proportion of actively breeding birds ashore was notably lower in 2018 (47%, compared to 58–74% in four earlier ground-truthing counts; Table 4). As observed by Baker & Jensz (2019), a possible explanation is some shift in oceanic conditions leading to more early nest failures than usual. Given that the proportion of breeding birds present has been relatively stable in the past, this illustrates the importance of continued breeding status checks over time, rather than using existing values from earlier work to correct whole-island counts.

Table 4. Summary of Salvin's albatross ground-truthing over time. Ground counts of actively breeding albatrosses (bird on nest with egg) and loafing (bird not on nest, or on empty nest) on Proclamation Isl. % breeding is proportion breeding of all birds present

	Bird on nest with egg	loafing	% breeding	Method	
1997	3051	1518	0.67	Whole-island counts	Clark et al. 1998
2004	2622	1916	0.58	Whole-island counts	Amey & Sagar 2013
2011	1693	1047	0.62	Whole-island counts	Amey & Sagar 2013
2013	800	278	0.74	Transects	Baker et al. 2014
2018	439	500	0.47	Transects	Sagar et al. 2018

Recommendations

Population size estimates of Salvin's albatrosses at the Bounty Islands from drone imagery would require drone overflight of other islands in the group where Salvin's albatross are present, and ground-truthing to estimate detectability and status/nest contents. Scaling up coverage is entirely feasible, and quality ground-truthing data can be acquired while at the islands.

Drone overflight

The best data quality came from images taken at 40m flight height during overcast conditions. Drone flights must monitor animal disturbance risk (Rexer-Huber and Parker 2020); in brief, fur seal clusters should be avoided at launch and landing, and flight heights should stay above 20m. To scale up photographic coverage in the Bounty group, consider power (plenty of batteries and a good charging method) and plan for boat-based flights for islands distant from landing islands.

Ground-truthing

Ground-truthing data are needed to assess the accuracy of counts from any aerial photographs (concurrent ground counts in a defined area to estimate detectability, and nest contents checks to address status uncertainty). Raw bird counts can then be corrected to estimate the number of actively breeding birds, accounting for detectability (birds not visible from the air).

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Appendix A: Proclamation Island count blocks

Count blocks on Proclamation Island were established in 1997 (Clark et al. 1998) and the GPS positioning refined in 2004 (de Roy and Amey 2004). Count block boundaries are illustrated below, followed by counts of Salvin's albatrosses subdivided by count block.

Figure A1. Proclamation Island count block boundaries

Table A1. Proclamation Island Salvin's albatross by count block, from drone imagery taken October 2019

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	Outside blocks
Albatross, status uncertain	417	152	350	453	286	355	539	609	713
Apparently nesting albatross, AON	122	58	161	233	158	85	199	183	75
Loafing	6	2	8	8	4	15	28	6	2
Likely-albatross:									12
probable albatross but not certain	11	0	7	5	4	2	11	17	
Ghost doubles	0	0	0	0	0	0	0	8	0
All definite albatrosses, raw count	545	212	519	694	448	455	766	798	790
Breeding pairs estimate (range)	256 (223–283)	100 (87–110)	244 (213–270)	326 (285–361)	211 (184–233)	214 (187–237)	360 (314–398)	375 (327–415)	371 (324–411)

Breeding pairs estimate is raw counts multiplied by status correction (proportion of breeding birds out of all birds present). Status correction used is 0.47 (0.41–0.52) is the mean and range from Sagar et al. (2018)