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Digital imaging tools for remote sites: Bounty Islands Salvin's albatrosses

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SUMMARY

This paper summarises novel methods increasingly being used for monitoring at remote sites, via the case study of Salvin's albatrosses *Thalassarche salvini* at the Bounty Islands. Salvin's albatross are a Vulnerable (Nationally Critical) endemic to New Zealand. They are one of the seabirds most at risk from fisheries bycatch in New Zealand, and breed mainly at the remote, hard to access Bounty Islands. Population research at this site was recognised as a regional priority programme at PaCSWG5. Projects summarised here assessed the effectiveness of drones for aerial imaging to estimate population size, and of automated cameras for recording the little-known breeding cycle. We showed that drones are suitable for estimating the Salvin's albatross population size at the Bounty Islands, and time-lapse cameras deployed for a year provided new information about colony occupancy, the timing of key events during breeding, and productivity. Next steps are exploring what appears to be surprisingly low nest success, and planning a full population size estimate for Salvin's albatrosses at the Bounty Islands. A population size estimate will require drone overflight of the eight albatross islands in the group, and ground-truthing to estimate detectability and nest contents.

1. BACKGROUND

Seabird populations breeding in remote locations and challenging environments can be difficult to access. When only intermittent, infrequent visits are possible, effective monitoring is challenging and key information often remains little-known.

Digital imaging tools have become more useful for remote sites as the technology has evolved (Edney and Wood, 2021). With these developments comes the need to keep considering whether new tools might be useful for a given species, site and question. For example, a seabird population that is hard to access might benefit from time-lapse cameras, satellites, manned aircraft, or unmanned aerial vehicles / drones (Edney and Wood, 2021). The question will guide which tool is most appropriate. Time-lapse cameras, for example, are cost-effective and can provide continuing information at remote sites to inform productivity and phenology, but can typically only view a sample of the colony or population (e.g. Otovic et al., 2018). Aerial photography can provide high-quality imagery at the scale needed for population size estimates, but usually cannot view nest contents (Mischler, 2018; Oosthuizen et al., 2020).

Here we summarise tests of new digital tools for Salvin's albatross *Thalassarche salvini* at the Bounty Islands: drone imagery (population size estimate) and time-lapse cameras (timing of breeding events). Salvin's albatross breed predominantly at the Bounty Islands and are one of the seabird species most at risk from fisheries bycatch in New Zealand (Richard et al., 2017; Sagar et al., 2015). The population status at the Bounty Islands, breeding timings and productivity are poorly known due to the challenging logistics of research at this remote location (Baker et al., 2014; Sagar et al., 2015; Taylor, 2000), and population research at this site was recognised a regional priority programme at PaCSWG5. The Bounty Islands are a group of bare rocky islands ~ 660 km 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 (Fig. 2). 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).

The Salvin's albatross population at the Bounty Islands has been visited intermittently since the late 1970s, but information about the timing of breeding remains sparse (two visits 1978 and 1997; Robertson and van Tets, 1982; Sagar et al., 2015). Population census efforts at this group have been similarly limited by topography. Because many of the islands are inaccessible to boat-based landings, densities were initially extrapolated to population size (Robertson and van Tets, 1982; Taylor, 2000), or trends were monitored in marked areas (Amey and Sagar, 2013; Clark et al., 1998). To estimate population numbers across the whole Bounty Island group, aerial photographs appear the best tool. Aerial photographs taken from fixed-wing aircraft have been used to count Salvin's albatross (Baker and Jensz, 2019; Baker et al., 2012, 2014). Now drones are being tested as an alternative platform for aerial photography to deal with some of the challenges faced by manned aircraft (Rexer-Huber and Parker, 2020).

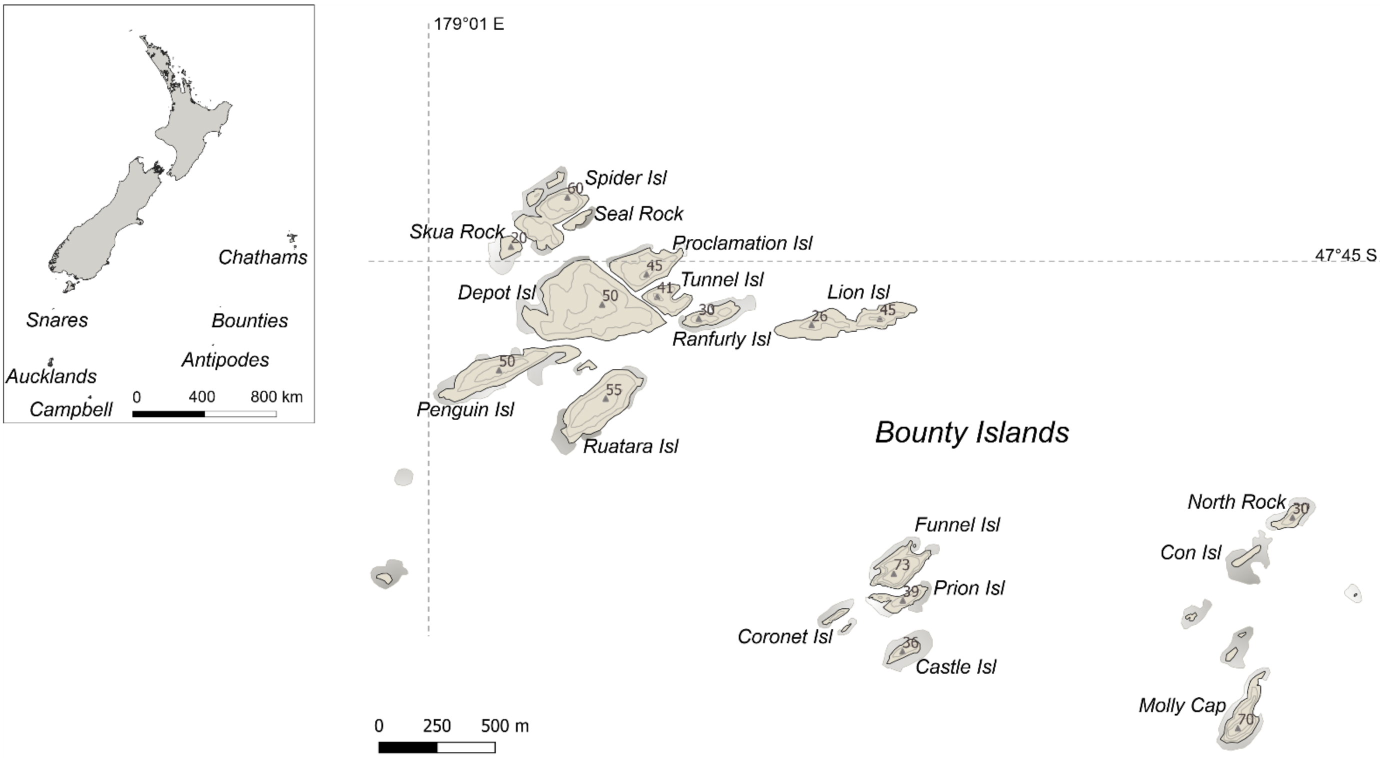

Figure 1. Bounty Island archipelago, New Zealand. Rock barriers and shelves are grey-shaded, and island point heights are in meters.

Figure 2. Part of the Bounty Island archipelago viewed from sea. Accessing the islands poses obvious logistical constraints. Photo: Igor Debski

Salvin's albatross phenology has largely been inferred because only hatching dates have been recorded directly (i.e., observers present). Lay date estimates were all back-calculated from hatching dates using incubation periods from other species (Clark et al., 1998; Robertson and van Tets, 1982; Sagar et al., 2015). Nest cameras can provide direct data on breeding timings and productivity (Edney and Wood, 2021; Hinke et al., 2018; Otovic et al., 2018), and camera waterproofing, robustness and longevity has advanced such that year-long deployments are feasible.

We first look at the suitability of drones for estimating the population size of Salvin's albatrosses, using imagery of four of the islands in the Bounty Island group. Secondly, we evaluate the effectiveness of an automated camera system for long-term monitoring in a challenging environment, and document the little-known breeding cycle of Salvin's albatrosses on the Bounty Islands. These projects have been reported separately and in more depth elsewhere (Parker and Rexer-Huber, 2020; Rexer-Huber et al., 2021), but summarising them together here provides useful insight.

2. DRONES FOR POPULATION SIZE

Drones are increasingly used for seabird population assessment and monitoring worldwide (Dunn et al., 2021; Hayes et al., 2021; Korczak-Abshire et al., 2019). The first step is to consider their potential to disturb wildlife (Borrelle and Fletcher, 2017; Brisson-Curadeau et al., 2017; Mustafa et al., 2018; Weimerskirch et al., 2018). Drone work at the Bounty Islands first carefully assessed the potential for wildlife disturbance, since 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 (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).

Images of Proclamation, Spider, Tunnel and Ranfurly Islands taken October 2019 were used to determine the suitability of drone-based images for Salvin's albatross counts, and assess potential for future use of drones to obtain a population size estimate of Salvin's albatross across the Bounty Islands.

2.1. Methods

Image capture

Images were taken on the 28 and 29 October 2019 (late incubation for Salvin's albatross) after satisfactory animal response trials (Rexer-Huber and Parker, 2020). Images were taken with a high-quality Hasselblad camera (20MP 1" CMOS sensor) on a DJI Mavic 2 Pro drone, using five flight batteries. Grid flights for image capture were programmed in Pix4D Capture to take nadir images, directly overhead, with generous 80% front and 72% side overlap to ensure good coverage of the whole island. Flights longer than 25 min (average life of a flight battery) were programmed to resume with suitable overlap after a battery change. Proclamation Island was overflown three times, at 40 m, 60 m and 80 m above launch height (launch platform ~40 m asl). Tunnel and Ranfurly Islands are a similar height to Proclamation (high point 40 m) so were overflown at 60 m. The Spider Island cluster reaches 60 m asl, so the drone flew at 80 m for these islands. Animal responses were monitored throughout to enable swift mitigation action if needed, with two spotters aiding the pilot (Rexer-Huber and Parker, 2020).

Image processing and counting

Drone photographs were stitched into composites, projection transverse Mercator, using ICE (Image Composite Editor, Microsoft). Composite images were counted by the same person for consistency in the wildlife counting application dotdotgoose (Ersts, 2019).

To assess flight height effects on image quality and data quality, a sub-area of Proclamation Island was counted at 40 m, 60 m and 80 m flight heights. The subarea comprises about 20% of the island area and included representative areas (broken ground, smoother platforms and sloping downhill) (Fig. 3). 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).

Figure 3. Proclamation Island drone image composite showing the count sub-area (yellow) that was covered at 40 m, 60 m and 80 m flight heights

For whole-island counts we counted every Salvin's albatross following Baker et al. (2014). 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. Ground-truthing is crucial because apparently nesting birds cannot reliably be distinguished from loafing birds in aerial images (particularly given the sometimes very minimal nest made by many nesting Salvin's albatrosses) (Amey and Sagar, 2013; Baker and Jensz, 2019), and it is not possible to tell in photos 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).

2.2. Results and discussion

Height effects

Drone overflight at 40 m provided excellent imagery suitable for albatross counts. Resolution was such that at the top of the island, animal behaviours could be observed including pairs allopreening. As flight height increased over the same sub-area of Proclamation Island (and resolution decreased), it became progressively harder to assign a bird's status to loafing or apparently nesting with any confidence (Fig. 4). At 40 m flight height, 46% of birds had clear status, compared to 6% at 80 m flight height (status uncertainty, Table 1). A bird clearly sitting on a nest in the 40 m image can be of uncertain status in the 80 m image (orange circles, Fig. 4). Albatross identification decreased from 99% ID confidence to 95% ID confidence as flight heights increased (Table 1). ID confidence remained about the same at 60 m and 80 m flight heights (Table 1). Counting time was not notably affected by increasing flight height.

Table 1. Increasing flight height affects Salvin's albatross counts

	40 m	60 m	80 m
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	7	42	38
Definite albatrosses	623	673	655
Quality: ID confidence	0.989	0.941	0.945
Quality: status uncertainty	0.594	0.860	0.942

Likely-albatross: probable albatross but not certain; ID confidence = definite albatrosses / all albatrosses; status uncertainty = status unclear / definite albatrosses

Considering the high proportion of uncertain status even at the lowest flight height (59% uncertain at 40 m), similar to that from photos from fixed-wing aircraft (49% status uncertain in a small set of close-up shots) (Baker and Jensz, 2019), whole-island counts from photographs are best to count all albatrosses instead of trying to separate by status. Using raw counts of all albatrosses, a correction can then be applied to separate actively breeding from apparently breeding and loafing birds. This approach is more repeatable and consistent, removing the element of subjectivity inherent to status assignment in an albatross with such minimal nest structures.

Figure 4. Proclamation Island from at 80 m, 60 m and 40 m flight heights (top, middle and bottom images, respectively). All to 30% magnification. Circles identify the same albatross in each image.

Overflights at 60 m and 80 m took less flight time than at 40 m but resolution was lower, with reduced ability to determine status and likely reduced accuracy. The time / battery savings of higher overflight were outweighed by the loss of image quality. Image quality was also affected by light and shading, which should influence count data quality because animals in highly shaded areas were difficult to detect. For example, the 40 m overflight of Proclamationhad 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 (60 m overflight; Fig. 4). 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.

Whole-island albatross counts

Counts of Salvin's albatrosses on Proclamation Island in 2019 (5,227 individuals representing an estimated 2,457 breeding pairs, Table 2) 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 and Jensz, 2019; Baker et al., 2012, 2014). Spider Island had a count of 3,862 individuals giving an estimated 1,815 (1,583–2,008) breeding pairs (Table 2). Albatrosses were absent from the other islands and islets in the Spider Island group (Skua Rock, Seal Rock and unnamed islets). Similarly, Ranfurly Island did not have any albatrosses. Tunnel Island had a raw count of 3,595, giving an estimated 1,690 (1,474–1,869) breeding pairs of Salvin's albatrosses. However, the image quality for Tunnel was poorer than some of the other whole-island photographs (deep shading), 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.

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	238	0	511	57
Quality: ID confidence	0.926	na	0.873	0.986
Breeding pairs estimate	1815	0	1690	2457

Likely-albatross: probable albatross but not certain; ID confidence = definite albatrosses / all albatrosses; Breeding pairs = 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).

2.3. Summary

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. Hayes et al., 2021; McClelland et al., 2016; Weimerskirch et al., 2018). Drones have several advantages compared to fixed-wing aircraft. These are mostly operational (flexibility of use around brief weather windows, cost sharing with other work), with the resulting images from the Bounty Islands largely comparable to images from fixed-wing aircraft for counting purposes (Rexer-Huber and Parker, 2020). Another advantage is that programmed flight paths can be saved and re-used over time, a repeatability that is particularly useful for estimating trends.

A population size estimate of Salvin's albatrosses at the Bounty Islands requires (a) drone overflight be expanded to include the other albatross islands in the group (Depot, Ruatara, Penguin, Funnel and Molly Cap) with continued monitoring of animal disturbance risk (Rexer-Huber and Parker, 2020), and (b) ground-truthing to estimate detectability and status / nest contents. Ideally photos should be taken over two successive years, to allow for the possibility that Salvin's albatross are more semi-biennial than truly annual breeders (Rexer-Huber et al., 2021; Sagar et al., 2011). Images taken at 40 m flight height during overcast conditions provided best data quality. 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).

Figure 5. Ground-truthing of aerial photographic counts of Salvin's albatross checks for nest contents, status and detectability

3. PHENOLOGY CAMERAS

From time-lapse images taken over a year, we determined when chicks fledge, when adults departed the colony at the end of the breeding season, and when adults returned to the colony. We also estimated nest success during the relevant periods (distinguishing nest success from overall breeding success).

3.1. Methods

Six automated cameras (Bushnell Enduro) were deployed at Proclamation Island 21 October 2018–24 October 2019, taking images hourly during daylight. Cameras were mounted on customised aluminium brackets bolted to small vertical sections of rock, high enough to be out of the way of wildlife traffic (Fig. 6).

Images were reviewed systematically to mark every nest visible (Fig. 7) and identify for each nest the end of brood-guard (date chick first left unattended), fledging (date chick departed nest), or failure. Nests from before the wintering period (mid-incubation to fledge) were separated from post-winter new nests (lay to mid-incubation). We also identified the last colony departure (date last adult and/or fledgling visible at the end of the season), the first colony return (date first bird seen back in colony), and colony reoccupied (date adults staying in colony).

Brood-end date can be detected with confidence, unlike hatching or laying, so hatching and laying dates were estimated using brood-end dates. Since incubation and brood-guard duration are not available for Salvin's albatross, we used shy albatross *T. cauta* durations: mean 73 days incubation and mean 27 d brood-guard (Hedd and Gales, 2005). That is, Salvin's albatross hatching dates were estimated by subtracting 27 d from brood-end dates, and laying dates estimated by subtracting a further 73 d from estimated hatch dates.

Figure 6. A camera mounted to view Salvin's albatross nesting at Proclamation Island; inset: the camera after a year in situ.

Figure 7. Example of Salvin's nests marked to follow over time to identify key dates and outcomes.

Breeding success cannot be determined when nest cameras follow only part of the breeding season. Cameras were deployed two-thirds of the way into incubation in the 2018/19 breeding season, then followed the first two-thirds of the 2019/20 incubation (Fig. 8). From this we calculate apparent chick success (from last third of incubation to fledging) and apparent incubation success (from lay for the first two-thirds of incubation).

3.2. Results and discussion

Cameras recorded up to 368 days or 12.3 months of images (Fig. 8). Camera performance was excellent, with all but one recording for the full year. Three cameras continued recording even after having been knocked into a mud slurry, recording for up to 10 months longer (grey bars, Fig. 8). Despite mounting cameras on vertical sections of rock > 1.5 m high, it appears that fur seals do slide down these rock faces.

Cameras recorded 18,291 images useful for review of Salvin's albatross breeding. At camera deployment 74 nests from the 2018/19 breeding season were visible (Table 3). Despite displacement of three cameras, 40 nests from three cameras could be followed through to the end of the breeding season to determine fledging dates (Fig. 8). A further 50 new 2019/20 nests were visible when birds returned after winter (~3 months; Fig. 8).

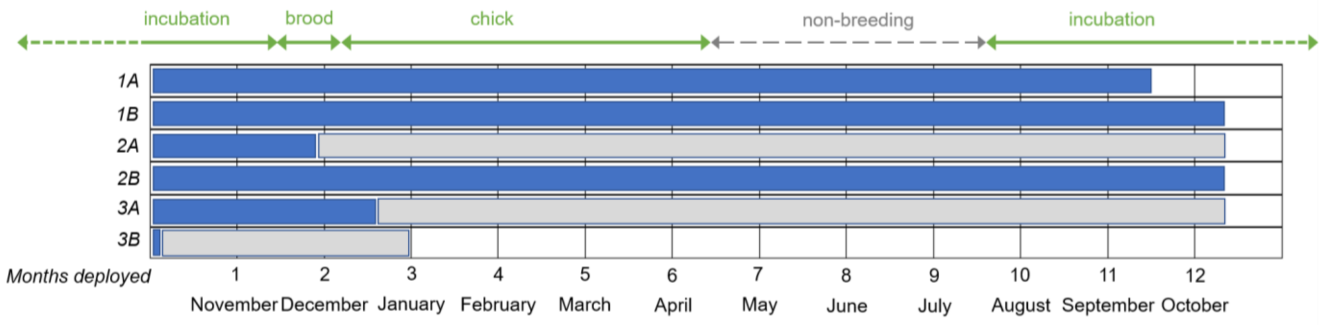

Figure 8. Salvin's albatross nest camera recording duration, Proclamation Island, relative to breeding stages. Blue bars: duration of albatross records; grey bars: camera longevity. Cameras deployed 21 October 2018 to 24 October 2019.

The colony was empty of Salvin's albatrosses for less than three months until adults started to return early- to mid-July (Table 3). The short absence could suggest that Salvin's are more semi-biennial than annual breeders as thought (Sagar et al., 2011), since the semi-biennial white-capped albatrosses also leave the colony empty for just under three months (Rexer-Huber et al., 2019). However, shy albatrosses are annual breeders and spend just 1.5 months away from the colony, returning to spend the remainder of non-breeding at the colony (Hedd and Gales, 2005). Adult Salvin's albatrosses attended the colony for 32–40 days at the start of the breeding season before the estimated lay date.

Salvin's albatross laying was estimated as 28 Aug (21 Aug–5 Sep). Estimated mean hatch of 9 Nov (2–17 Nov, Table 3) was earlier but still in line with the 15 Nov recorded during nest monitoring over the pipping-hatching period in 1997 (Sagar et al., 2015). Fledging was around 7 April, but chicks fledged as late as 20 April (Table 3). This suggests a chick-rearing period of 162 days (estimated hatching to fledge), longer than the 125 days for shy albatrosses (Hedd and Gales, 2005).

Breeding success cannot be determined when nest cameras follow only part of the breeding season, but apparent chick success was 0.45 (Oct to Apr, late incubation to fledging; Table 3). For white-capped albatrosses chick success was 0.29 over the same breeding stages (late incubation to fledge) (Rexer-Huber et al., 2019). These estimates for part-season breeding success are very low; we are currently looking into this further via nest survival models, which will appear as an update in Rexer-Huber et al. (2021).

Hatching appears to be the most vulnerable breeding stage for Salvin's albatrosses, with fewer nest failures during incubation (apparent incubation success 0.80 cf. 0.45 chick success, Table 3). Failures mostly occurred when chicks had just hatched, with mean failure 23 d after estimated hatch. Similarly, fieldwork in 1997 showed 34% failure of Salvin's nests checked daily during pipping / hatching (31 Oct–17 Nov) at the Bounties (Sagar et al., 2015), while at the Snares Salvin's albatrosses lost about half of eggs during Oct–Nov (Clark, 1996). In contrast, most shy albatross nest failures occurred late in chick rearing (Hedd and Gales, 2005).

Table 3. Salvin's albatross breeding dates and productivity from time-lapse nest cameras at the Bounty Islands

	all nests	just nests from whole-season cams
unique nests viewed at deploy (18/19 season)	74	40
n fledged/near-fledged	na	18
hatching and chick success	na	0.45
fail dates (average, incub–fledge 18/19)	25 Nov (n=28)	
nests start 19/20 season	50	50
nests with egg at end cam life (19/20)	na	40
incubation success	Na	0.80
fail dates (average, lay–mid incub 19/20)	21 Sep (n=9)	
days wintering, colony empty	86.3	
first ad return (on ground, even if brief)	4 Jul	
colony return dates (>2 full-time)	19 Jul	
estimated lay (mean 73 d incubation)	28 Aug	
estimated hatch (mean 27 d brood)	9 Nov	
brood end date average	6 Dec (n=25)	
fledging dates average	7 Apr (n=16)	
fledging date range	27 Mar–16 Apr	
last date bird present in colony	20 Apr	

3.3. Summary

Automated cameras deployed for a year at Proclamation Island provided new information about when Salvin's albatross occupy the breeding colony and documented the timing of key events during breeding. Productivity appears surprisingly low and it is unclear why. Further analyses are in progress (see for update Rexer-Huber et al., 2021). Camera deployments designed to capture the full breeding season are recommended to obtain direct data on breeding success. Camera performance was excellent, with disturbance by fur seals the main issue limiting recording performance at the Bounty Islands. Ideally cameras should be mounted under overhanging rock, or more cameras deployed to counter expected data loss.

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