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Bounty Islands drone trials: feasibility for population assessment of NZ fur seal

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Introduction

New Zealand fur seals *Arctocephalus forsteri* are captured in the trawl fishery for southern blue whiting around the Bounty Islands at one of the highest rates of any New Zealand trawl fishery (Abraham and Thompson 2015). In this fishery, there were on average 30 observed fur seal mortalities each year (range 8–96 annual observed mortalities) between 2002 and 2018 (Abraham and Thompson 2015). There is little information on the population size and trend of NZ fur seals at the Bounty Islands.

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 aeroplane or boat-based helicopter have been used to count fur seals (Taylor 1982, 1996) and, more recently, Salvin's albatross *Thalassarche salvini* (e.g. Baker et al. 2012, 2014; Baker and Jensz 2019). Since fur seals are also visible in albatross-focused photographs, these more recent photographic data may be useful for assessing fur seal population size and trends. However, surveys involving aeroplane charter or helicopters are logistically demanding and expensive, so other methods for aerial surveys are being explored.

Drones hold promise as an alternative way to obtain aerial photographs suitable for estimating fur seal numbers at reduced effort and cost. Also known as unmanned aerial vehicles or remotely piloted aircraft (UAV, RPA), drones are increasingly used for seal population assessment and monitoring worldwide (Adame et al. 2017; McIntosh et al. 2018; Arona et al. 2018; Gooday et al. 2018; Sorrell et al. 2019). In the NZ subantarctic islands 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 and repeatable (Adame et al. 2017; McIntosh et al. 2018). As with any survey method drones also have limitations, notably in battery life and potential for wildlife disturbance.

Drones have not previously been used at the Bounty Islands. The islands are densely populated with fur seals, erect-crested penguins *Eudyptes sclateri*, Salvin's albatrosses, and smaller seabirds. These busy colonies may be quite steadfast: even when a helicopter flew as low as 80m asl "..there was no problem with birds in the air and no evidence that seals, nesting penguins, or mollymawks were disturbed by the helicopter" (Taylor 1982). However, the potential for disturbance by drones must be assessed carefully. Effects on animals are becoming better documented as drone use for wildlife surveys becomes more common (Adame et al. 2017; Hughes et al. 2018; McIntosh et al. 2018). NZ fur seals have shown awareness and nervous responses to drone activity on the Chatham Islands and elsewhere in the subantarctic (DOC unpubl. data). Careful trials with the closely related Australian fur seals *Arctocephalus pusillus* revealed reactions to a large drone (1.4m diagonal size) but no observable disturbance from a small drone (0.35m diagonal, like that used in this work) (McIntosh et al. 2018).

We aimed to assess whether a drone can be used for aerial surveys to quantify NZ fur seal population size at the Bounty Islands without impacting on seals, penguins and albatrosses there. The trial had three parts:

- Disturbance trials: Flight characteristics (flight speed, height, time of day) trials to find the combination that causes least disturbance.
- Image capture trials: Using the flight characteristics that cause least disturbance, programmed grids flown.
- Image processing: Images of suitable quality for fur seal detection were stitched and counted.

To develop useful recommendations on future data collection suitable for estimating fur seal population size and trend in the Bounty Islands, we compare information from drone trials (new data) with information from piloted aerial photography (existing data). Photographs taken from fixed-wing aircraft are examined to determine their suitability for fur seal population trend estimation. Advantages and limitations of each method are evaluated with respect to data quality and its usefulness for estimating fur seal population size.

Methods

UAV trials

Logistics

This project involved a single trip to the Bounty Islands in October–November 2019, combined with Salvin's albatross work for the Department of Conservation's Conservation Services Programme.

Work was supported by the SV *Evohe*, with the team based on the boat throughout the trip and landing each day for work on the islands. Flights were land-based for these trials at the Bounty Islands, instead of flown from the boat, to ensure the pilot and spotters had the best possible field of view to monitor animal responses.

Since landings at these islands are ocean swell-dependent, and drone flight is weather-dependent, three days of weather contingency were added to the five days expected for all work at the islands.

Equipment

We used a DJI Mavic 2 Pro drone with three flight batteries, supplemented with another two flight batteries from the back-up drone (five batteries in total). The Mavic 2 Pro carries a high-quality Hasselblad camera (20MP 1" CMOS sensor) used here with aperture priority to minimise overexposure. Low-noise rotors were taken in case of disturbance to wildlife from standard rotors but were not used. For manual flight (animal response trials) we used the DJI Go4 drone interface software. Grid flights were programmed and run via Pix4D Capture software. UgCS software was back-up for offline programmed grid flights but was not required.

Animal response trials

To assess whether drone operations had adverse impacts on fur seals, penguins or seabirds, we ran careful tests of animal responses while flying the drone manually. Two spotters assisted the pilot during test flights: one focusing on the reactions of animals on the ground (fur seals, nesting and loafing albatrosses, penguins and prions), and the other monitoring seabird interactions in the air (flying albatrosses, prions *Pachyptila crassirostris* and gulls *Larus dominicanus*). Spotters were Paul Sagar and Kalinka Rexer-Huber, aided by Bill Morris.

We assessed animal responses to drone operations during two flight phases: vertical launch/landing, and horizontal overflight. Animal responses to a given set of flight parameters were recorded (speed, height). For example, launch/landing was either slow or fast, rising vertically to 5m, 10m, 15m, 20m, 40m, 60m, or 80m (above launch point at ~40m asl) before hovering in place. Horizontal flight was tested at 40m, 60m and 80m. Time of day can influence the density of birds in flight around the islands, so this was also recorded. Careful notes were taken of animal responses, and video recorded wherever possible.

Grid flights were initiated after satisfactory animal response trials, but we continued careful monitoring of all launch/landing phases for animal responses to detect any changes. Spotters continued with the pilot during all grid flights to ensure no new animal interactions occurred during operations.

Aerial photography trials

Once the extent of animal interactions had been assessed, we moved to testing the flight parameters required for the drone to produce images suitable for estimating fur seal numbers.

Programmed grid flights were set to take nadir images, directly overhead, with 80% front and 72% side overlap. The generous overlap was chosen because the steep-sided islands mean greater distance to ground at the island sides. Flights longer than 25 min (average life of 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 (or ~80m, 100m and 120m asl, since the launch platform was ~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.

Flights were tested in winds up to approximately 15 knots at the launch height. Weather conditions were recorded throughout to gauge how much time would have been suitable for flying.

Animal response mitigation

During any part of this work (or during any stage of all flights), the following animal-response mitigation actions were planned:

- If an animal exhibits a negative reaction to the presence of the drone (restless movements, fleeing etc by fur seals or seabirds on the ground) flight heights will be adjusted, flight path will be altered, or the drone will be removed from the vicinity of the animal.
- Mass movement of seals could damage themselves and breeding seabirds and would limit the accuracy of data collected from the images. If there is any indication of mass movement of seals, the flight will be aborted, and no further drone flights will occur that day.
- If there is an interaction of a bird with the drone (close miss with flying bird, collision), the current flight plan will be abandoned, and a new flight altitude tested.

Existing data

Existing aerial photographs from the Bounty Islands were taken between 1974 and 1994 by Rowley Taylor and the NZ Airforce to count fur seals (Taylor 1982, 1996) and in 2010, 2013 and 2018 by Barry Baker of Latitude 42 Environmental Consultants to count Salvin's albatross (Baker et al. 2012, 2014; Baker and Jensz 2019). Here we used the most recent set of images from Latitude 42 as these were most comparable with drone photographs, both being taken at nadir, while 2010 and 2013 photographs were taken at ~65–70°.

In 2018 photographs were taken on 25 October from a fixed-wing aircraft at 400m asl moving at ground speed 120kn. Photographs were taken by Baker on a Nikon D800 full-frame DSLR with a 70–200 mm f2.8 lens at 70mm photo extension. The window for photography was limited to 75 mins. Photographs were taken mid-afternoon on an overcast day with winds ~30kn at flight height (Baker and Jensz 2019).

Existing aircraft-derived photographs were provided already processed (adjusted for shadows, highlights and midtone contrast, then stitched into image composites in Photoshop). For direct comparison with drone imagery we used only images from Proclamation Island. Two composites were required to cover Proclamation at the highest resolution for counting; files 'Main 4c (5802–5805)_2018' and 'Main 5a (5809–5812)_2018' (Fig. 1). These images were representative of the whole dataset, in terms of image quality and resolution (88–99mb, overall dataset image range 17–113mb).

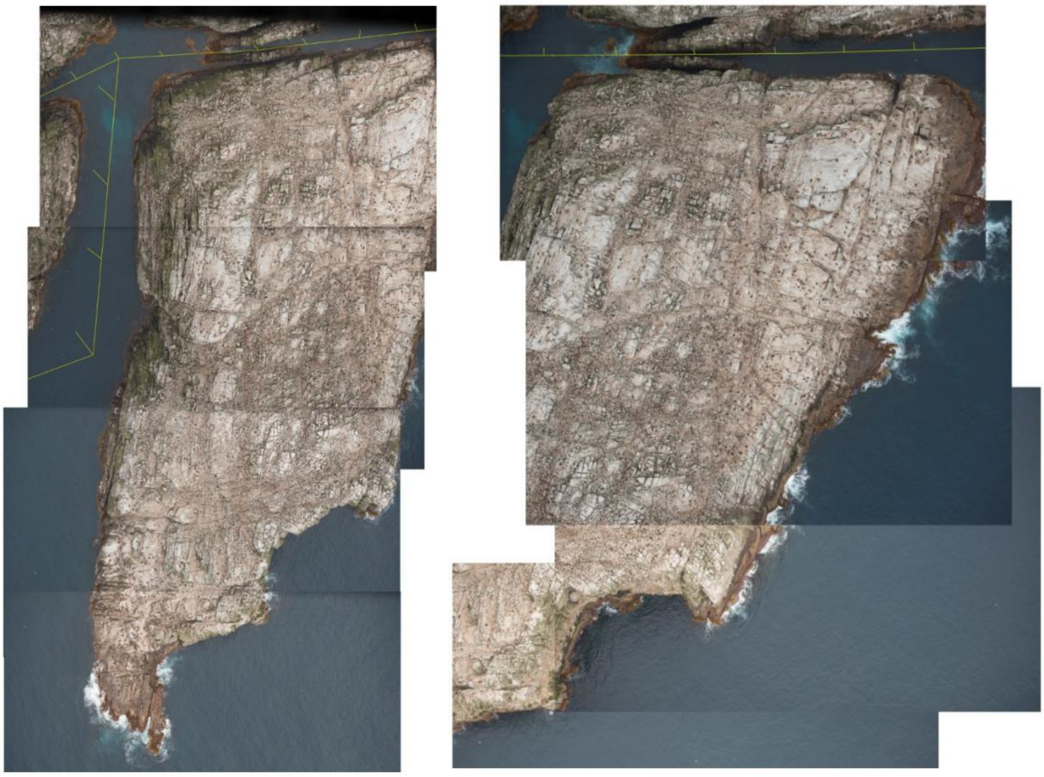

Figure 1. Existing plane-based photographic data for Proclamation Island, showing best-resolution imagery for counting. Photographs by Barry Baker.

Image processing

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 of Proclamation Island from fixed-wing and drone were loaded into the wildlife counting application dotdotgoose (Ersts 2019). All images were counted by the same person for consistency. One of the drone composites was also counted by a second person (Thomas Mattern, using Proclamation 40m composite), allowing us to assess observer effects.

Imperfect stitching sometimes produced double-ups or 'ghosting' near image seams in composites from both ICE and Photoshop. Seams were checked carefully for ghosting and one of each duplicate animal masked (marked for exclusion). For existing data (aircraft-derived imagery), the two composites required for the best resolution of Proclamation required lines be drawn between landmarks that were clear in both images to avoid double-counting across images. All animal counts and ghosting records were saved for archiving.

Results

UAV trials: animal responses

Manual flight during animal response trials showed that with due caution, drone operations appeared to have few adverse effects on animals.

Animals on the ground. Animal responses were most marked during launch and landing, with fur seals in the immediate vicinity of launch (<20m) sitting up and watching the drone (larger animals) or moving into rock crevices (smaller animals). We saw no fleeing or mass movements/stampede. Restless movements by seals eased as the drone gained height. Once the drone was above ~8–10m, animals lay back down; hover at 10m caused continued watching, but no further movement; and hover at 20m or above was largely ignored.

Seabirds on the ground near launch/landing showed less response than seals. Albatrosses and penguins within ~5m cocked heads to watch the drone but with little shift in body position, and once above ~5m the drone was largely ignored.

Air traffic. Seabirds in flight were clearly able to detect and avoid the drone during standard launch (head movements seen, no near misses) (Fig. 2). Slower and faster ascent speeds made little apparent difference to drone detectability, but we took care to avoid erratic movements and fast acceleration or deceleration to help flying seabirds adjust their flightpath if need be. Air traffic appeared greatest around the perimeter of the islands and thinnest over the tops of the islands, forming a bird halo.

Animal response trials were conducted on two separate occasions, from mid- to late afternoon and from early- to mid-afternoon. Further monitoring also covered flights over the middle of the day. There was no indication that time of day influenced how animals reacted to drone operations. Flight activity was expected to be lower during the middle of the day, but on this visit flight activity seemed more linked to passing frontal systems. Air traffic was minimal on response trial days and increased notably following a north-westerly front (e.g. Fig. 2). However, even when the skies were busier, continued monitoring of launches/landings showed no problems for seabirds detecting the drone in the 10–15m of busy airspace capping the islands.

Horizontal flight at 40m, 60m and 80m above launch point got reactions only from gulls. Black-backed gulls occasionally approached the drone, flying in loose circles below and calling but not approaching closely. This occurred at all flight heights, speeds and times of day. If the drone continued horizontal flight (i.e. away from the site where gulls had first approached), gulls followed briefly then appeared to lose interest. Stationary hovering and vertical ascent/descent also eventually caused gulls to lose interest, but this seemed to take longer (5–10mins instead of 1–2mins).

Suggestions. Choose launch/landing site as far from seal clusters as possible; assess height of busy airspace above the island (may differ at other times of year or after weather fronts) cf. planned flight elevation; mitigate restless movements by fur seals by ascending promptly to flight elevation; avoid overflight below 20m.

Figure 2. Drone launch (top) and landing (bottom) through busy airspace after a north-westerly front. Screen grabs from monitoring footage.

UAV trials: image capture

Grid flights were conducted without complications. Flights were fit in around other work and as weather opportunities allowed. For example, the 40m and 60m flights at Proclamation took place on the first flight day (sixth island day), followed by 80m flight on the next day.

The drone behaved normally in winds up to about 15kn (at launch height), without adverse effects on avoidance by flying birds. Greater wind speeds are workable with our drone but were not tested at the Bounties. We note that other types of drone can handle substantially more wind. Weather conditions suitable for flying occurred during about 50% of our time at the islands. Flyable conditions occurred in short windows (e.g. afternoon of first island day, three hours on the evening of the second day) and over whole days.

A single flight battery covered 20–25min flight time, excluding a generous buffer of power for return to home. Two batteries were needed to cover Proclamation at 40m flight height (~340 x 200m took 35min), or to cover the Spider Island group at 80m (630 x 400m grid, 30min). Larger islands like Depot would require 2–3 batteries, depending on flight height.

Ground counts to assess the accuracy of counts from photographs were not conducted, given the limited time available for fur seal work. For this trial, it seemed more important to test the drone's ability to fly islands further away than to show that ground counts can be done. Ground-truthing transects can be conducted without major disturbance, as can exhaustive ground counts in defined blocks (e.g. Amey and Sagar 2013; Sagar et al. 2018).

The drone successfully overflew islands 400–500m away from launch at Proclamation. Around this distance it became difficult to maintain line of sight with the drone. Higher-spec binoculars than the 10x42 used here could help keep the drone in view. Another option is to approach islands further from Proclamation by boat and launch the drone from deck, given suitable sea conditions.

Pre-programmed saved flight grids for the islands were particularly helpful. Despite testing various methods to make background maps available offline for flight planning once at the islands, maps were not available. Without background maps, flight planning for new areas involved trial and error, and more battery use.

Figure 3. Composite image of Proclamation Island from 40m drone overflight.

Image capture: pros and cons

Flight time. Fixed wing aircraft flight over the islands in 2018 was limited to 75mins by fuel capacity. Despite flight speed of 120kn and considerable effort by pilot and photographer for maximum coverage, this was not long enough to photograph all islands (Baker and Jensz 2019). In contrast, a team present at the islands can fly a drone over much longer periods, reacting to even small weather window opportunities. Drone battery limitations mean that charging was needed after 120mins flight with five batteries. Coverage of the whole island group would require more batteries, or capacity for recharging (periodic return to boat, or battery bank or small generator ashore).

Flight speed. Fixed-wing aircraft cannot easily fly at speeds below 120kn and are not particularly manoeuvrable, putting pressure on pilot and photographer and potentially affecting image clarity (Baker et al. 2015). The drone is programmed to move at airspeed optimal for image clarity (here average flight speed was 13kn). Much slower flight speed from drone cf. aircraft means more flight time required to cover whole island group.

Reactivity. It can be difficult to assess if weather conditions at the Bounties are suitable for flight (Baker et al. 2015), sometimes resulting in long stand-by delays as in 2018. For drone flight people are necessarily present so weather is gauged on the ground, and survey can be started or continued whenever conditions improve (e.g. conditions on second island day poor until late afternoon, when conditions suitable for flying for ~3hrs).

Camera specs and flight height. Fixed wing flight at 400m is well above altitude where disturbance would be expected, and high-quality large lenses can be used for adequate resolution. In contrast, the specs of camera for this drone limit altitude to max. 100m to get adequate resolution of fur seals. In practise, seals near island edges are difficult to detect when overflight at 80m (120m asl). Either plan flight height to 40–60m or consider drones that can carry higher-quality cameras. We note that camera load capabilities and drone performance are advancing rapidly.

Image processing

Photographs from the drone at 40m were of excellent quality (0.94 cm/pixel GSD or ground sample distance), but with almost 800 images processing was expected to be computationally intensive. More images could also result in more stitching errors.

Grid flight at 60m and 80m over the same site (Proclamation) allowed us to check the trade-off between image quality and image number/processing load. For example, images from 60m of 1.4 cm/px GSD also seemed of adequate image quality but involved 604 files and a final .jpg composite of 80mb (cf. final 40m jpg of 187mb). However, processing time to stitch image composites proved not to be prohibitive, even at 40m flight height. Fixed-wing flight at 400m required stitching of much fewer image files. For example, just four photographs were required for each of Baker's two composites covering Proclamation (Fig. 1).

At 40m flight height, fur seals including small pups are easily detected for most of the island (Fig. 4 bottom). Smaller animals are grainy and slightly harder to detect at the island edges (70–80m from drone), but adults remain easy to identify. Fur seal detection was slightly but not markedly harder in images produced at 60m (Proclamation, Tunnel, Ranfurly Islands), but at 80m fur seals at the islands' edges are grainy and smaller animals may be overlooked (Proclamation, Spider Island cluster) (Fig. 4 top). In contrast, the change from 40m to 60m overflight made penguin counts substantially more difficult (T. Mattern pers. comm.). Albatrosses were similarly easy to detect at 40m and 60m.

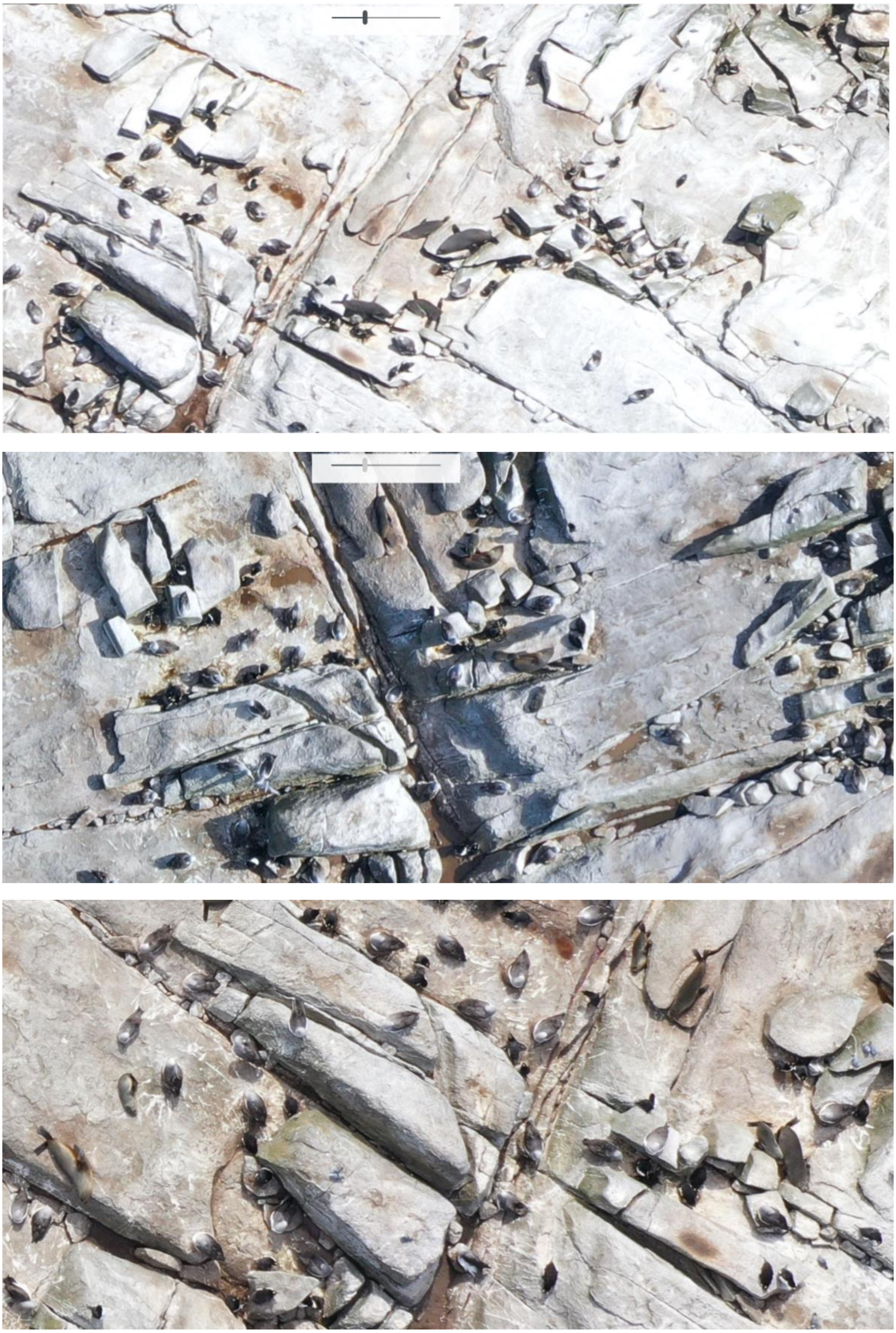

Figure 4. Same location on Proclamation Island photographed at 80m flight height; middle: 60m height; bottom: 40m flight height, all to same magnification (30%).

At Proclamation Island 1,154 fur seals were counted ashore in the 40m composite taken 28 October 2019. This included 341 pups (particularly small animals), although pup numbers are likely greater as any animal too large to be certain it was a pup was classed as fur seal. Likely-but-not-certain fur seals (65) are excluded from this count. This compares to 972 fur seals counted from the fixed-wing composite, taken 25 October 2018, where we excluded 34 likely-but-not-certain seals.

Independent counts for fur seals in the 40m imagery gave 1,102 individuals (T. Mattern pers. comm.), suggesting that counter variability is about 4.5%. Penguin and albatross counts are reported separately in the trip report (Parker et al. 2019), and a paper elaborating on ground and aerial penguin counts is in progress (Mattern et al. in prep).

Processing images from plane vs. drone

Images from drone and plane differed in resolution as follows: At 40m and 60m flight height, the drone used here produced composite images with better resolution than those taken from fixed-wing aircraft (Fig. 5). This was not true for images from 80m flights, where image resolution did not differ markedly from photographs from fixed wing.

Drone-camera technology is advancing rapidly, so resolution could be improved by via drone that can carry other lenses. The drone-camera technology is advancing rapidly. A photographer in a plane can simply switch to a different lens. An example of close-up photos using a 300mm f4 PF telephoto lens is on the cover of Baker and Jensz (2019), showing similar resolution to the 40-m drone overflight below (Fig. 5 right).

Figure 5. Same location on Proclamation. Left: section of image from fixed-wing plane at 400m by Barry Baker (October 2018). Right: section from image by drone at 40m flight height (Oct 2019).

Stitching error was worse in Photoshop than in ICE in the 400m and 40m images, respectively, despite much fewer images in Photoshop processing. Stitching error was quantified for each image as the number of masking dots expressed as a percentage of all fur seal dots, giving 10.5% stitching error or ghosting of fur seals in existing data (existing aircraft-derived imagery) and 0.09% in new data (new drone-derived imagery). This may not be a reliable pattern, since the 60m overflight was stitched poorly in ICE on first attempt. If a poorly stitched image like that one was to be counted, stitching errors would certainly affect accuracy, since some areas were excluded entirely. However, in images counted for this work, stitching error mostly just resulted in more counting time to carefully check and mask duplicated areas for ghost animals.

Shading affected counts from both fixed-wing and drone images similarly. Animals in highly shaded areas were difficult to detect. For example, the 40m overflight had flat light conditions throughout, with little to no shadows thrown, while images the next day (60m and 80m overflight) had bright sunlight producing deep shadows and contrast. This significantly slowed counting as well as probably affecting count accuracy. For both platforms, flight should occur on an overcast day, or at least around noon if a sunny day cannot be avoided.

Discussion

Drone operations had little apparent effect on animals, when operated with due caution, and obtained excellent imagery at 40m for counting fur seals and other animals. By 'due caution' we mean careful choice of launch site, checks of the busy airspace relative to planned flight height; and avoiding flight heights below 20m. Similarly, closely related Australian fur seals showed no observable disturbance to overflight at 40m by a drone (McIntosh et al. 2018), and California sea lions *Zalophus californianus* did not react when the drone was 15m or higher (Adame et al. 2017). Notably, even a low-flying helicopter did not disrupt the Bounty Island colonies (Taylor 1982), with flight heights of 80–115m asl comparable to drone overflight here (ie. overflight at 40–75m above the top of Proclamation Island).

Excellent imagery was obtained by drone overflight at 40m and 60m that is suitable for fur seal counts. Resolution was such that at the top of the island, fur seal pups could be identified, and animal behaviours observed (yearlings playfighting, pups suckling). The islands are steep-sided, so images are lower resolution near sea level where animals are ~80m below the camera. This is also a problem for photographs from fixed-wing aircraft. This could be addressed by flying the drone to obtain a digital elevation model, then programming drone flight to maintain a given distance to land.

Overflights at 60m and 80m were faster than at 40m but resolution was lower, with more time involved in counting and likely reduced accuracy. The time/battery savings of higher overflight are outweighed by the loss of image quality. Since pups (not adults) typically underpin fur seal abundance estimates (e.g. Taylor 1996; McIntosh et al. 2018; Sorrell et al. 2019) and are easiest to identify in higher resolution images, we recommend 40m overflight. These high-resolution images would then also be suitable for penguin and albatross counts (T. Mattern pers. comm.).

Advantages of piloted vs. drone surveys

Fuel. Flight fuel limits photography time for both fixed-wing aircraft and drones. An aircraft can carry significant fuel load but must return to the mainland within hours. Drones are limited by batteries and are slower to cover the same area than aircraft. For a drone to overfly all islands in the group, more batteries could be taken; charging could be ongoing if launching from a boat; a battery bank or small generator could be used if launching on island; or a larger drone that is capable of longer flight time could be considered.

Animal effects. Fixed-wing flies at altitude where no disturbance is likely; drone must fly lower to get good image resolution, so potential for animal disturbance must be monitored closely. No adverse effects from drone flight recorded in this work.

Weather. Both plane and drone are limited by high winds, rain, haze or fog, and bright sun makes images from both platforms harder to count. Fixed-wing aircraft can fly in windier conditions than drone. Drone can be more reactive to even short weather windows as they arise, with team present at the island, while fixed-wing must rely on forecasts. Drones involve less risk to the operator/s.

Image quality. The resolution of images suitable for counting animals is a factor of flight height, flight speed and lens specifications, for both fixed-wing and drone platforms. Drones like the one used here must fly lower, or a drone that can carry other lenses be considered. A fixed wing can carry multiple large lenses so the photographer can choose a different lens, although the plane cannot then fly slower to improve image quality. Drone manoeuvrability means that they can be flown alongside steep areas to improve image quality.

Repeatability. Programmed grid flights can be saved and re-used for drone overflight on subsequent visits, giving significant control and reproducibility cf. piloted aerial surveys.

Fur seal numbers

Counts of fur seals ashore on Proclamation Island in 2019 (1,154 individuals ashore, including at least 341 pups) compare to 972 fur seals at a similar time in 2018. This probably means little change in numbers on Proclamation, considering the variable proportion of seals at sea at any given time. Seals will also be underestimated in the 2018 image because of more pronounced blur at the island's edges, and greater stitching error. To untangle such counting-related noise from a trend, it would be useful to count fur seals in the 2010 and 2013 aerial photographs of Proclamation (taken for Salvin's albatross counts, Baker et al. 2012, 2014). Fur seals on Proclamation have been counted from photographs in other years 1974–1994, but the only year where the photography timing was similar (7 Nov 1978) gave 590 adult seals ashore, excluding pups (Taylor 1982, 1996). Changes over time on Proclamation may yet prove to be representative of changes in the wider Bounty Island group.

Counts of fur seals ashore are provisional as they have not been adjusted for the detectability of animals in aerial photographs. No recent ground-truthing data are available, but we expect that a small proportion will have been missed in deep shade and under overhangs. In 1985, ground counts estimated that less than 2% of seals would have be hidden from aerial photography by boulders and overhangs (Taylor 1996). Ground-truthing data are needed to assess the accuracy of counts from any aerial photographs, for any species (Baker et al. 2015). Flights by fixed-wing aircraft would need to be coordinated with a shore party to assess the proportion of animals in crevices/under overhangs, while drone flight from boat or from land necessarily has people present who can land for ground-truthing.

Suitability for population estimate

Our trials of a drone at Proclamation Island, and a handful of other islands in the group, show that drones are suitable for assessing NZ fur seal numbers. This is in line with work on fur seals elsewhere (McIntosh et al. 2018; Sorrell et al. 2019). Drones have several advantages and disadvantages compared to a 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 for counting largely comparable. Programmed flight paths can be re-used over time, providing repeatability that is very useful for estimating trends.

For a population size estimate of fur seals 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. Depot Island could be flown from Proclamation, but other islands may best be approached by boat and the drone flown from deck. Boat-based flight poses its own challenges, being limited by swell as well as wind, and rigging and interference from the steel boat can affect ease of launch and landing. For data from all islands, more batteries 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.

For population size estimates, associated accuracy and precision 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.

Counts of fur seals over the whole Bounty Island group would be complemented by counting Baker's 2010 and 2013 photographs for fur seals, as well as islands other than Proclamation in the 2018 photographs. These population estimates may be useful for looking at trends, adding to Taylor's fur seal data from the period 1974–1994.

Recommendations

Drone flight around busy mixed colonies of seals and seabirds should carefully consider animal behaviour. In general, all flights should involve at least one observer to help the pilot monitor animal reactions, especially around launch and landing. For drone flight at the Bounties, we suggest that:

- the density of flying Salvin's albatrosses above the islands be checked relative to planned flight elevation *for every flight* since airspace busyness changes in short timescales and likely at other times of year;
- a launch site away from fur seal clusters be chosen;
- the drone ascend promptly to flight elevation to reduce seal restlessness;
- overflight below 20m be avoided.

High-quality imagery was obtained with overflight at 40m. Overflight should target overcast conditions since there is less dark shading, increasing count accuracy. Ensure plenty of batteries are available, with a good charging method (battery bank, small generator). Boat-based flights may be useful for islands distant from landing islands. Ground-truthing data are needed to assess the accuracy of counts from any aerial photographs. Aerial photographs from 2010 and 2013 should be counted to gauge changes in fur seal numbers over time and viewed together with historical data (Taylor 1982, 1996).

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