RAPID POPULATION ESTIMATE OF A SURFACE-NESTING SEABIRD ON A REMOTE ISLAND USING A LOW-COST UNMANNED AERIAL VEHICLE

GREGORY T.W. McCLELLAND[1,2], ALEXANDER L. BOND[2], ANIKET SARDANA[3] & TREVOR GLASS[1]

[1]*Conservation Department, Government of Tristan da Cunha, Edinburgh of the Seven Seas, Tristan da Cunha, TDCU 1ZZ, South Atlantic Ocean (mcclellandgreg@gmail.com)*
[2]*RSPB Centre for Conservation Science, Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire, SG19 2DL, United Kingdom*
[3]*26 Arlington, Woodside Park, London, N12 7JR, United Kingdom*

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SUMMARY

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Unmanned aerial vehicles (UAVs) offer a number of potential applications in wildlife monitoring, including the aerial surveying of seabird populations on remote islands. While UAVs may represent considerable improvements and/or cost savings over other survey techniques, such as ground searches or surveys via fixed-wing aircraft or helicopter, their use to date has been rare. The few studies that have used UAVs have employed systems that are either custom-made or beyond the budget of many small conservation programs. In this study we tested a low-budget (US$2 600), off-the-shelf UAV (DJI Phantom 2) equipped with an on-board camera (GoPro Hero4) as a tool for rapidly assessing the population status of the endangered Tristan Albatross *Diomedea dabbenena* on Inaccessible Island, South Atlantic Ocean. The Tristan Albatross population on Inaccessible Island was estimated as one breeding pair and four additional non-breeding birds in February 2015. The UAV successfully surveyed 3.28 km^2 of the island in 32.1 min flight time. While the survey was successful, future surveys would be greatly improved by some form of pre-programmed navigation capability.

Key words: Inaccessible Island, Tristan Albatross, Tristan da Cunha, unmanned aerial vehicle

INTRODUCTION

Accurate and consistent monitoring of populations is vital to successful wildlife conservation. Seabirds often nest on remote islands, where monitoring is impeded by difficult access and lack of infrastructure, and obstacles to successful monitoring may include difficult access to the island in general, or to breeding sites in particular. Even on relatively accessible islands, frequent unfavourable weather or sea conditions may prevent access in all but ideal conditions. Researchers must therefore complete their work while conditions remain favourable. In addition, many seabird islands are large and remote, and lack a constant human presence or research station. Monitoring on these islands must be carried out during often-infrequent visits that are limited in duration because of ship costs or the island's management strategy (e.g. Heard Island; Commonwealth of Australia 2014), yet monitoring may have significant land area to cover.

For surface-nesting seabirds, ground counts on foot of breeding adults are the predominant monitoring method (e.g. Cuthbert *et al*. 2014). However, this can be time-consuming and requires covering a considerable area if birds are sparsely distributed. Furthermore, birds nesting in sheltered hollows or dense vegetation can be easily overlooked. Aerial photographic surveys via fixed-wing aircraft or helicopter can also be used and have the benefit of covering large areas and recording birds that may go unobserved on foot, while lessening the need to land researchers on islands (e.g. Robertson *et al.* 2008, Sagar *et al.* 1999, Pitma *et al.* 1995). However, such surveys are costly, and beyond the budget or logistical capabilities of many monitoring programs. Clearly, additional methods that can lessen the time constraints on researchers during visits to islands while remaining cost-effective would be of significant benefit.

A potential alternative method of counting surface-nesting birds on islands is the use of unmanned aerial vehicles (UAVs). As the affordability and capability of UAVs and their on-board cameras continue to increase, so too do their potential applications in wildlife management and monitoring. Commercial UAVs, either fixed-wing or multi-rotored "copters," have been used in a variety of conservation tasks, including aerial surveys of seabird and marine mammal populations on remote islands (Goebel *et al.* 2015, Ratcliffe *et al.* 2015, Sweeney *et al.* 2016). However, while UAV-based surveying represents a cost savings over fixed-wing aircraft or helicopter surveys, the cost of the vehicle (*ca*. US$25,000; Sweeney *et al.* 2016) may still be beyond the budgets of many research programs. Low-budget (<US$3,000), off-the-shelf UAVs are commonly available but lack many of the features of more costly models, such as autonomous flight capability, real-time transmission of telemetry and more than four rotors (and therefore greater payloads and, potentially, platform stability). To our knowledge, no study has yet examined the feasibility of using these more basic but less expensive UAVs for rapid assessment of ground-nesting bird populations during brief visits to seabird islands.

Our goal was to test a low-budget, off-the-shelf UAV as a tool for rapidly assessing the population status of the Tristan Albatross *Diomedea dabbenena* on Inaccessible Island, Tristan da Cunha, South Atlantic Ocean. This species is listed as "Critically

Endangered" by Birdlife International (2016), and the small satellite population on Inaccessible Island represents the only members of the species breeding elsewhere than Gough Island, where the population is declining by 3.0% per year owing to a combination of chick predation by invasive house mice *Mus musculus* and adult mortality from longline fishing (Cuthbert *et al.* 2014, Wanless *et al.* 2009, Davies *et al.* 2015). However, despite the species' conservation status and Inaccessible Island's proximity (40 km) to the settlement of Edinburgh of the Seven Seas on Tristan da Cunha, attempts to count the number of incubating pairs on the island are rare, with few published surveys (Table 1). The paucity of counts is especially problematic for Tristan Albatross because accurate population estimates require several consecutive years of surveys owing to the biennial breeding cycle of successful breeders (Cuthbert *et al.* 2004). This dearth of monitoring is predominantly because favourable landing conditions at Inaccessible Island are often too brief to allow meaningful surveys. Therefore, using a UAV could make it feasible to survey the island in a brief timeframe and allow regular and accurate monitoring for the first time.

TABLE 1
A summary of Tristan Albatross surveys on Inaccessible Island, adapted from Ryan (2005)[a]

Year	Incubating pairs	Fledglings	Source
1870s	~200		Stoltenhoff (1952)
1937	2		Hagen (1952)
1950	2–3		Elliott *et al.* (1957)
1982		1	Fraser *et al.* (1988)
1983	1		Fraser *et al.* (1988)
1987		0	Fraser *et al.* (1988)
1988		2	Ryan *et al.* (1990)
1989		0	Ryan *et al.* (1990)
1990	1		Ryan *et al.* (1990)
1999		1	Ryan *et al.* (2001)
2000	1		Ryan *et al.* (2001)
2004		0	Ryan (2005)
2009		0[b]	P.G. Ryan unpubl. data
2011	1[c]	1	RSPB, P.G. Ryan unpubl. data
2012	1[d]		RSPB unpubl. data
2014		1	B. Dyer, pers. comm.
2015	2-3[e]		This study

[a] Non-breeders and immature birds were not regularly recorded. All surveys were ground counts with the exception of 2015.
[b] Plus one loafing adult in November.
[c] Plus three additional adults observed in February.
[d] Plus one additional adult in March. Different nest site than in 2011.
[e] One breeding pair, two non-breeders and two pre-breeders (see Methods).

METHODS

Study area

Inaccessible Island (37°18′S, 12°41′W), 14.4 km^2 in area, forms part of the Tristan da Cunha archipelago (Fig. 1). It is characterized by sheer cliffs that rise from the sea around the entire coastline, with a 9.7 km^2 plateau that ranges in elevation from 150 m at the eastern end to over 500 m at the western end. Narrow boulder beaches are found along much of the shoreline; however, the only landing site with access to the island's interior is at Blenden Hall, near the western end of the island. This beach is relatively unprotected and requires calm sea conditions for landing, which often limits possible landing days to less than six per year (TG, pers. obs.). For this reason, visits are rare and either for a single day or multi-week expeditions with uncertain and unpredictable end dates. Single-day visits can provide insufficient time for a proper survey, and the multi-week expeditions are logistically complex, difficult to plan and present a considerable safety risk.

The climate on Inaccessible Island is cool-temperate, with orographic clouds covering the plateau on roughly half the days in summer (Ryan 2005). The predominant vegetation on the western plateau is the bog fern *Blechnum palmiforme* with interspersed stunted thickets of island tree *Phylica arborea*. Near the western summit of the island, the bog fern is stunted, with grasses such as *Calamagrostis deschampsiiformis* and *Agrostis holdgateana*. Dense stands of taller (≥3 m) island tree cover the lower, eastern portion of the plateau.

Tristan Albatross

The number of Tristan Albatross pairs on Inaccessible Island has numbered less than five for the past 80 years. However, they once numbered "not more than 200 pairs" in the 1870s (Stoltenhoff 1952) before the population collapsed to current levels, probably as a result of predation from feral pigs *Sus scrofa* (extinct since the 1930s) and human exploitation (Fraser *et al.* 1988). While the albatross' size (*ca.* 10 kg) and white plumage make both adults

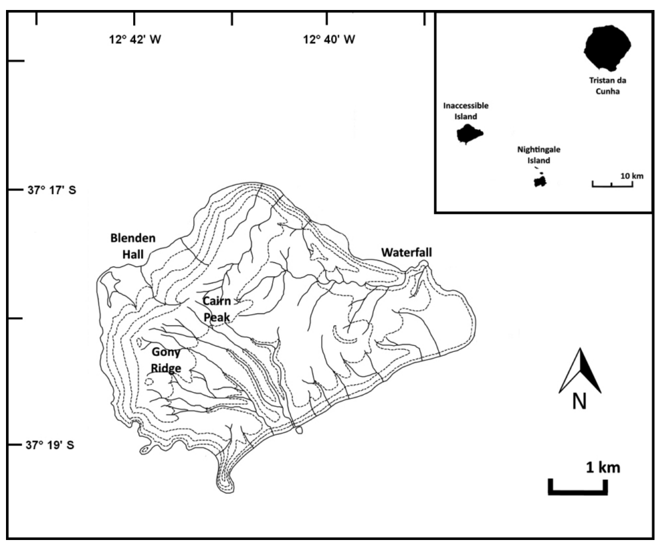

Fig. 1. Map of Inaccessible Island and the Tristan da Cunha archipelago (inset). Modified from Ryan & Glass (2001). Dashed lines are ~100 m contours.

and chicks observable with binoculars from several hundred metres away, their tendency to nest in sheltered hollows make thorough ground counts essential for population estimates (Ryan 2005).

Unmanned aerial vehicle

We used a white DJI Phantom 2 quadcopter (DJI, Shenzhen, China). The unit has a diagonal length of 350 mm, a noise level of 60 dB at 2 m, a maximum speed of 15 m s^{-1}, and a vertical and horizontal positioning accuracy of 0.8 m and 2.5 m, respectively. We equipped the UAV with a GoPro Hero4 camera (GoPro, San Mateo, CA) with the factory-issued *f*2.8 wide-angle lens and a 32 GB microSD card. The camera was mounted on a Zenmuse H3-3D gimbal (DJI, Shenzhen, China), which allowed the UAV pilot to control the tilt of the camera. The total mass of the UAV with camera and gimbal was 1 400 g. The camera relayed images in real time onto a Boscam Galaxy FPV ground station (800 × 480 pixel resolution; Shenzhen ChuangXinKe Electronic Technology Co., Shenzhen, China) mounted on the UAV's controller. We had three UAV batteries with *ca.*18 min available flight time per battery. Battery life (and therefore available flight time) was monitored via LED indicators on the front panel of the remote control. The cost of the complete unit was *ca.* US$2,600. Under the current configuration, the UAV could not record its location using global positioning system (GPS) coordinates.

The camera was set to record 4 000 × 3 000 pixel still images (each *ca.* 12 MB) with the shutter set to release every 2 s. The UAV was flown at a relatively constant altitude, but sloping terrain meant that photos were taken at elevations from 20 m to 150 m over the study area. All photos used in the analysis had resolutions of at least 0.2 m GRD (NIIRS 8, Irvine 1997). At the flight heights used, the field of view (width × height) ranged from 42 m × 53 m to 316 m × 400 m, as calculated by equation 1 (e.g. http://photo.stackexchange.com/questions/56596/how-do-i-calculate-the-ground-footprint-of-an-aerial-camera):

$$\text{field of view} = a \times tan\left(x + \frac{1}{2}\left(2tan^{-1}\left(\frac{d}{2f}\right)\right)\right) - a \times tan\left(x - \frac{1}{2}\left(2tan^{-1}\left(\frac{d}{2f}\right)\right)\right) \quad (1)$$

where a is the elevation of the drone (m), d is the dimension of the camera sensor (width or height; mm), f is focal length of the camera lens (mm), and x is the angle of the camera (horizontal or vertical axis).

We landed on Inaccessible Island on 25 February 2015 and flew a total of three survey flights. The survey area was located on the island's plateau, between its western edge and Cairn Peak. We chose these boundaries because Tristan Albatross nests have been observed here previously (Fraser *et al.* 1988, Ryan *et al.* 1990, Ryan *et al.* 2001, RSPB unpubl. data). Accessing the plateau from the landing site required a difficult hike of several hours, and time constraints did not allow us to survey other areas.

Two people undertook the survey. The pilot (AS) steered the UAV remotely by monitoring the live image on the control-mounted screen and had approximately 25 h experience piloting the UAV at the time of the survey. The second person (GM) acted as "spotter" and monitored the UAV through 10 × 42 binoculars, noting its location and any interactions with seabirds. The camera was angled at 30° on the vertical axis for an overhead view of the ground below, but occasionally had to be angled to 0° to see the horizon and confirm the UAV's orientation. Launches were from elevated locations that maximized the observer's line of sight with the UAV while in flight, its location being recorded by a hand-held GPS. For each flight, the UAV first flew to a height of 20 m above the study area, then flew 850–1300 m southeast before rotating left 90°, flew until only the edge of the area recorded in the first portion of the transect remained in the screen, rotated left another 90°, then followed the bearing needed to return to the launch site, forming a teardrop-shaped transect. The average speed of the UAV was approximately 5 m s^{-1}.

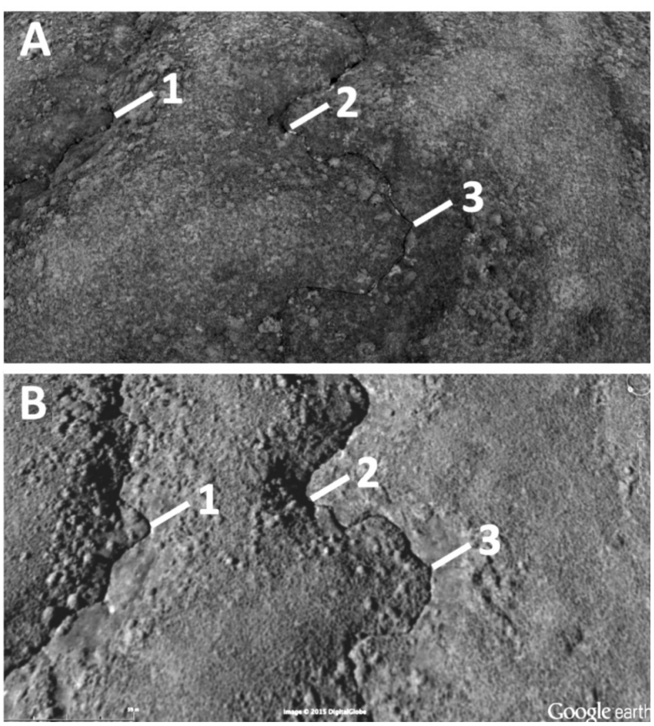

Fig. 2. Sample aerial imagery of Inaccessible Island captured by the UAV (A) and corresponding locations in Google Earth (B). Matching numbers highlight corresponding geographic features.

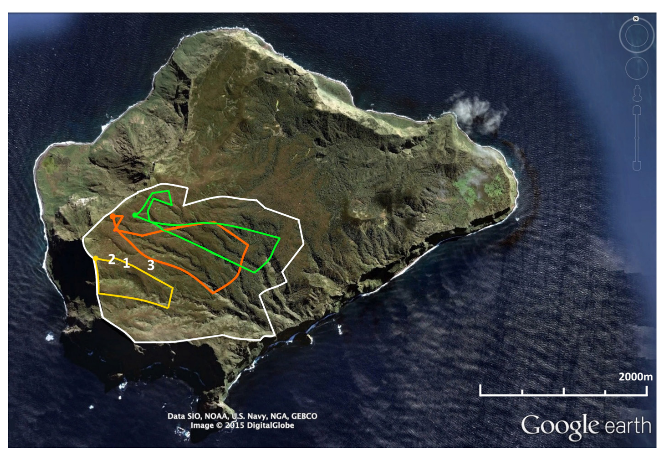

Fig. 3. Google Earth image of Inaccessible Island showing the flight path of each individual drone flight (yellow, orange and green lines with circles showing launch sites), the borders of the survey area (white line), and the locations of the Tristan Albatross nest (1) and loafing non-breeding birds (2 and 3).

We plotted the UAV's flight path and marked out the boundaries of the survey area by georeferencing distinct geographic features in the photographs to their locations in Google Earth Pro (Google Inc., Mountain View, CA; Fig. 2). The "path" and "polygon" tools were used to calculate flight distances and estimate the size of the search area, respectively (Fig. 3). We considered the survey area to be any location captured in photographs where it was reasonable to assume that a Tristan Albatross would be observed if present. Often this was informed by the ability to detect the much more common Atlantic Yellow-nosed Albatross *Thalassarche chlororhynchos*, the only other large seabird nesting on top of the plateau. Digital photographs were examined by GM. Counting consisted of scanning each photograph for possible Tristan Albatrosses and then examining additional photographs of the same area but from differing heights, angles and distances until a bird was identified definitively.

Population estimate

Because Tristan Albatrosses often breed biennially (Cuthbert *et al.* 2004), we estimated the total breeding population by assuming a typical breeding success of 0.7 for *Diomedea* spp. albatrosses (Tickell 2000, Davies *et al.* 2015), the probability of a sabbatical (skipped breeding) of 0.72–0.85 for successful breeders, and 0.22–0.32 for failed breeders (Wanless *et al.* 2009). The total number of breeding pairs can therefore be estimated as the sum of observed pairs, successful breeders on sabbatical and unsuccessful breeders on sabbatical (equation 2). We generated a range of estimates using the minimum and maximum values for each parameter:

$$N = [n \times Fa \times P(\text{skip}|\text{successful})] + [n \times (1\text{-}Fa) \times P(\text{skip}|\text{unsuccessful})] \quad (2)$$

where N is the total number of breeding pairs, n is the annual number of breeding pairs, Fa is the proportion of pairs breeding successfully, and P(skip) is the probability of a sabbatical given successful and unsuccessful breeding.

RESULTS

Our total survey area covered by three flights was 3.28 km^2, with 881 photographs taken during 31.2 min of flight time (Table 2). The total survey time was 133 min, which included hiking to and from the launch locations as well as unpacking and repacking the UAV between flights, but does not include the time required to land on the island or access the plateau.

For all three UAV launches, Brown Skuas *Stercorarius antarcticus* briefly flew within 3 m of the UAV but made no attempts to attack it and did not pursue it once the UAV began travelling horizontally. We also recorded close approaches (≤5 m) by two Atlantic Yellow-nosed Albatrosses and one Sooty Albatross *Phoebetria fusca* during surveys, but these were brief and the UAV was not pursued. No Tristan Albatrosses appeared to take notice of the UAV and these albatrosses remained in the same position during sequential photographs as the UAV passed over.

We recorded 1 nesting Tristan Albatross: an adult in a sleeping position encircled by an unvegetated ring characteristic of Tristan Albatross nests (Fig. 4). We also identified two non-breeding adults and two immature birds that were clearly not on nest bowls (Fig. 5), for a population of at least six birds when the missing member of the breeding pair is considered. Using equation 2, our estimate for the breeding population on Inaccessible Island is two to three pairs, consistent with previous recent estimates (Ryan 2005, RSPB unpubl. data).

TABLE 2
Summary of three UAV flights over the western plateau of Inaccessible Island, 25 February 2015

Flight	Duration (min)	Total transect length (km)	Survey area (km^2)	Number of photographs
1	9.2	2.31	1.26	275
2	10.7	3.96	2.01	285
3	11.3	4.54	1.39	321
Total	31.2	10.81	3.28	881

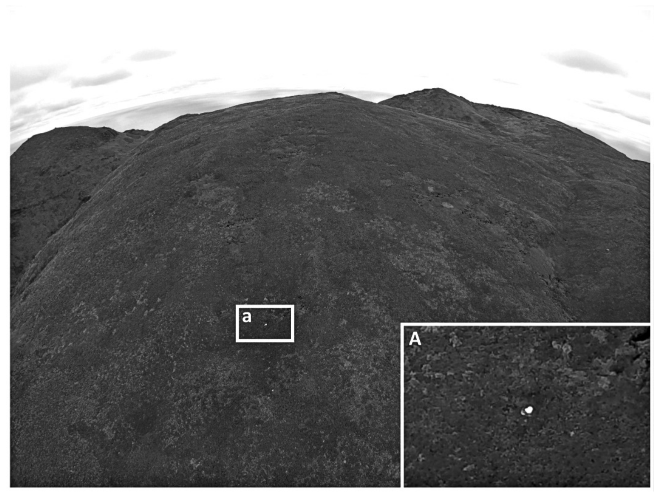

Fig. 4. Tristan Albatross nest captured by the UAV at an approximate height of 100 m. Box (A) is an enlarged photo of the area in Box (a).

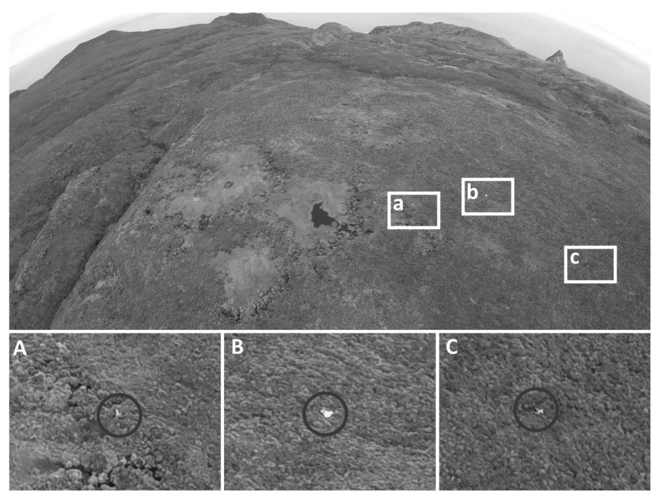

Fig. 5. Non-breeding Tristan Albatrosses captured by the UAV at an approximate height of 90 m. Each box with upper case letters is an enlarged photo of the area in each smaller box with the corresponding letter in lower case. Birds are circled.

DISCUSSION

Using a UAV was a viable survey method to count Tristan Albatrosses on Inaccessible Island. Adult Tristan Albatrosses were highly visible and could be identified confidently, as they are brighter and larger than Atlantic Yellow-nosed Albatross adults and chicks and have a distinct colour pattern. Immature Tristan Albatrosses were more challenging to identify because of their darker plumage but were still discernible. The large number of sequential photographs was of significant benefit, as it ensured that birds appeared in several photographs and increased the probability of a relatively clear and close image of the bird from which it could be identified. Furthermore, photographs were of sufficient resolution (≤0.2 m GRD) to distinguish breeding adults from non-breeders based on the presence or absence of a nest or an encircling ring of removed vegetation.

The use of the UAV allowed 33.8% of the plateau to be surveyed in just over two hours. By contrast, we estimate two people surveying this area on foot would require upwards of eight hours based on previous surveys on Inaccessible Island and on surveys of Atlantic Yellow-nosed Albatross in similar habitat on Tristan. With this study's demonstrated "proof of concept" of the UAV method, future surveys can invest in more flight time (via more UAV batteries) and expand the survey to less frequently visited areas of the island, potentially yielding additional birds.

Ground-truthing is a vital component of aerial surveys, and although we report only the results of the UAV flights, this represents a vital first stage that will make improved monitoring of Tristan Albatross on Inaccessible Island possible. With foreknowledge of nest locations, researchers can return to the island, if landing conditions allow, relocate nests, identify individual breeders, ring chicks and estimate breeding success. Tristan Albatross' large size and contrast with background vegetation make it very unlikely that additional birds were missed within the catchment area of the survey.

The UAV unit was not capable of flying autonomously along a predetermined flight path under our setup. Instead, it required a pilot to navigate it using the controller-mounted view screen and a spotter to help guide the vehicle. This system was successful in completing the survey with no omissions within the boundaries of the study area. Furthermore, by being in continuous control of the UAV, we were well positioned to mitigate any disturbance issues if they arose. However, this method also relied on a degree of guesswork, and adequate coverage could only be confirmed after the surveys were completed. Indeed, our third flight had a high amount of overlap with the second to hedge against inadequate coverage after the return path of the second flight was deemed potentially too wide. In total, 43.0% of the survey area was covered twice by UAV flights. While this ensured ample photographic coverage, less overlap could have significantly increased the total survey area without compromising our ability to locate and identify birds. To this end, future surveys should include some form of pre-programmed navigation capability if possible. Doing so will increase the probability of adequate coverage while minimizing overlap and increasing survey area. On other islands where navigating by sight is not possible, either because geographic features are too few or are obscured by vegetation, or observers cannot maintain a line of sight with the UAV, this ability should be considered a basic requirement. We also found that a survey elevation of 30 m above the study area offered the best trade-off between field of view (63 m × 80 m) and the ability to identify birds. However, maintaining this height over sloping terrain was challenging. Gauging the UAV's altitude from the view screen was difficult, as was the spotter's ability as the UAV moved further away. A pre-programmed flight path would ensure that the UAV maintained an ideal height.

The application of UAVs for surveying seabird islands is not without challenges. UAVs should not be flown in wet weather or strong winds (e.g. >9 m s^{-1} for our model), which can push the UAV off course or increase the possibiliity of an accident. This restriction will limit their use on islands that often experience inclement weather, although this is not necessarily a major barrier, considering the high overlap between ideal UAV flight and researcher landing conditions. Thick overhead vegetation may also obscure surface-nesting birds, which may rule out the use of UAVs in heavily forested areas. The impact of colder temperatures on UAV batteries may also reduce flight times significantly. While we found no indication of disturbance to seabirds in this study, and other studies suggest disturbance to birds from UAVs is low compared with researchers on foot (Chabot & Bird 2010, Sarda-Palomera *et al.* 2012, Vas *et al.* 2015), such observations are based on behavioural responses; experiments that include physiological responses to UAV presence are required to better assess their impact (Carey 2009). Finally, the need for government approval before launching any flight may be the most significant barrier in adopting UAVs as a survey method, as even remote islands with minimal human presence and air traffic may require permits from governing agencies. Such approval may be challenging as regulating bodies struggle to accommodate this new technology (Rango & Laliberte 2010, Bicknell *et al*. 2015).

CONCLUSIONS

We demonstrated that surveys of surface-nesting seabirds covering significant area can be achieved in a few hours with the use of low-budget, off-the-shelf UAVs. This capability is likely to improve as advances in autonomous flight capability and the ability to land on water, currently seen in more costly UAV systems (e.g. Parscal *et al.* 2014), become less expensive. These features are especially promising and could conceivably eliminate the need to land researchers on islands, instead launching from nearby research vessels or small watercraft. Such developments could not only greatly increase the frequency of surveys and the areas in which surface-nesting birds are monitored, but eliminate potential hazards of landing on remote islands, such as researcher safety and the introduction of alien species. While the use of low-cost, off-the-shelf UAVs is not without challenges, it represents a promising tool for monitoring on remote islands.

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