PARKER CONSERVATION

Foveaux and Otago shag population census methods: drone and camera trials

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Executive summary

Endemic to Southern New Zealand, Foveaux shag *Leucocarbo stewartia* and Otago shag *Leucocarbo chalconotus* are classified as threatened, but little is known of their populations' status and trends to inform conservation management. The aim of this project was to identify current breeding sites and develop a suitable methodology for use in future breeding population census of Foveaux and Otago shag colonies, using two sites for each species. To identify whether suitable aerial population census data for Foveaux and Otago shags can be obtained using a drone, we conducted animal disturbance trials and assessed the quality of imagery for counts. We also determined temporal colony attendance by installing trail cameras. Records of historic and contemporary breeding sites included ten Otago shag breeding sites and 15 Foveaux shag breeding sites. Future comprehensive surveys should include all 25 breeding sites in targeted visits to determine the population size of Otago and Foveaux shags. Animal response trials showed that drones can be flown slowly over Otago and Foveaux shags as low as 20 m without causing notable disturbance. Since this study only covered non-breeding and pre-breeding stages, overflights during the breeding season should first determine the drone flight height that causes minimal disturbance at that stage. Drone footage from 20 m flight height is of excellent quality for counting shag numbers in colonies. To get the best estimate of numbers of breeding pairs, ground-truthing data that assesses nest contents must be collected to correct counts of apparently nesting shags from photographs. Camera monitoring during the non-breeding season showed clear diurnal patterns of colony attendance. Information from cameras deployed into the breeding season should provide nest survival rates, enabling correction of Foveaux and Otago shag population size estimates.

Introduction

Endemic to Southern New Zealand coastal waters and harbours, Foveaux shag *Leucocarbo stewartia* and Otago shag *Leucocarbo chalconotus* are classified as 'Nationally Vulnerable' and 'At Risk - recovering' (Robertson *et al.* 2017). Previously grouped under the single species Stewart Island shag *Leucocarbo chalconotus,* breeding and roost sites have been described for the species since the early 1900s (Guthrie-Smith 1914). Since the 1970s there have been more in-depth studies of breeding sites, populations, and behaviours. However, the last comprehensive assessment of breeding sites for Otago shags took place in 2009 and for Foveaux shags in 1983 (Lalas 1983; Lalas & Perriman 2009).

Both species are susceptible to set-net captures and breeding colony disturbance (Watt 1975; Abraham & Thompson 2015; McKinlay 2017). Emerging threats to population stability arise from indirect fisheries pressures from the expansion of aquaculture in the Foveaux Strait region, and from plans to have more open seas aquaculture on the East and South coasts, in areas these species are known to utilise (DOC CSP annual plan 2021).

There is no up-to-date published literature detailing the location and size of breeding colonies, so changes to distribution patterns of colonies may go undetected. Breeding population trends remain unknown making it difficult to assess the risk of potential impacts. It is therefore important to improve our knowledge in this area to better inform conservation management.

Because most shag colonies are in terrain difficult to access on foot and shags can be sensitive to investigator disturbance, aerial photographs appear to be the best way to estimate population numbers (e.g., Schuckard *et al*. 2018). Boat-based counts and counts on foot tend to underestimate shag numbers compared to aerial photographic counts, with topography, vegetation and even conspecifics obstructing the field of view to an unknown degree (Chilvers *et al.* 2015; Schuckard *et al.* 2015). Aerial census can use platforms from fixed-wing planes to helicopters and drones. Also known as unmanned aerial vehicles (UAV), drones are increasingly used for shag population assessment and monitoring worldwide (Korczak-Abshire *et al.* 2019; Oosthuizen *et al.* 2020; Dunn *et al.* 2021; Pfeifer *et al.* 2021). In NZ aerial census of shags has largely used fixed-wing aircraft (e.g. Schuckard *et al.* 2015; 2018), but drones hold promise as another way to obtain aerial photographs suitable for estimating shag numbers. Drones have recently been explored for survey of Chatham, Pitt Island, and king shags (*Leucocarbo onslowi*, *Stictocarbo featherstoni* and *L. carunculatus*) (M. Bell pers. comm. 2021). Drones have also been used successfully in areas including subantarctic Auckland and Bounty Islands for a range of wildlife monitoring (Cox *et al.* 2019; Muller *et al.* 2019; Parker & Rexer-Huber 2020; Mattern *et al.* 2021), illustrating the flexibility and robustness of the platform. Crucially, drones provide data that are systematic, repeatable and accurate (Adame *et al.* 2017; Hodgson *et al.* 2018). As with any survey method drones also have limitations, notably in battery life and potential for wildlife disturbance.

Disturbance effects on animals are becoming better documented as drone use for wildlife surveys becomes more common (Borrelle & Fletcher 2017; Hughes *et al.* 2018; Mustafa *et al.* 2018; Weimerskirch *et al.* 2018). Before assuming drones are a suitable tool, we must first assess the potential for wildlife disturbance by the drone, particularly in dense multi-species colonies (Irigoin-Lovera *et al.* 2019; Rexer-Huber & Parker 2020).

The aim of this project was to identify current breeding sites and develop a suitable methodology for use in future breeding population census of Foveaux and Otago shag colonies. The project scope was limited to the non-breeding period (shags roosting at colonies) since DOC access approvals were not available until after the breeding season.

Objectives

1. Identify Foveaux and Otago shag breeding colony locations
2. Identify suitability of drone use for Foveaux and Otago shag aerial population census data: animal disturbance trial
3. Determine temporal colony attendance, intermixing of Otago and Foveaux shags, and nest survival rates by installing trail cameras at four sites, two for each Otago and Foveaux shags

Methods

Breeding site locations

To identify all known and potentially new Foveaux and Otago shag breeding colony locations we used currently available information. Resources included published and grey literature, eBird, iNaturalist, and consultation with knowledgeable experts. Satellite imagery (e.g., Google Earth) was considered but not pursued as resolution does not allow shag roosts/colonies to be identified.

Study sites and access

Drone and camera work was carried out at four sites, two for each species: Sumpter Wharf in Oamaru Harbour and Pukekura / Taiaroa Head (Otago shags); and Whero Rock and Kanetetoe Island, both off Rakiura / Stewart Island (Foveaux shags).

Access to Pukekura / Taiaroa Head was granted by Te Poari a Pukekura / the Pukekura Co-Management Trust (permit no 0000082TPP), facilitated by Jim Watts and team from DOC Dunedin.

Permission to fly a drone above Sumpter Wharf and to attach cameras to the wharf piles was provided by the Waitaki District Council (permit no 2021/PR1). The local aerodrome (Helicopters Otago, services Oamaru Hospital) was notified, and the flight plans deposited with AirShare. The Otago Regional Council harbourmaster Steve Rushbrook was also consulted and notified. Access to the Sumpter Wharf piles to install trail cameras was via sea kayak. We did not land on the wharf.

Whero and Kanetetoe access was supported by local DOC offices (Rakiura and Murihiku). Boat support from Oban by Phred Dobbins via stabicraft, with support from a local water-taxi operator taking a tour on the same route. At Kanetetoe, calm seas but a surging swell at the steep landing site options resulted in aborting our landing attempt on the island. The decision not to attempt a landing was based on safety, and the probability of being able to service and retrieve any cameras installed (given the sea state was relatively calm). Drone flights here were also notified on AirShare. Data from cameras at Whero were recovered by Phred Dobbins and Alasdair Burns, DOC Rakiura.

Trail cameras

To understand breeding colony and roost attendance at each colony we planned to deploy two cameras (Bushnell Enduro or Reconyx Hyperfire 2) at each of four sites: Sumpter Wharf and Pukekura / Taiaroa Head (Otago shags), and Whero Rock and Kanetetoe Island (Foveaux shags) (Table 1). Colony sizes ranged between ~40 birds at Pukekura to almost 800 at Sumpter Wharf.

Each camera was set to time-lapse one photo per hour during daylight hours from a half hour before dawn to half an hour after dusk. For Reconyx cameras it is possible to set latitude and longitude so the unit takes images from half hour before dawn and at dusk, with the time changing with the seasonal change. Fixed times for Bushnell cameras were set using a 24-hr clock as follows: 06.30–21.30 for the Otago shag deployments, and 06:30–20:30 for the Foveaux shag cameras.

Table 1. Trail camera deployments at Otago and Foveaux shag roosts

Site	N birds at deploy	Model	Deploy date	Aspect	Recovery date	Days recorded
Taiaroa Head	40–50	Bushnell	18 Feb 21	NW	4 May 21	75
Taiaroa Head		Reconyx		S		
Sumpter Wharf	~150–200	Bushnell	13 Mar 21	~SW	6 May 21	55
Sumpter Wharf		Bushnell		~NE		
Whero Rock	~90–100	Bushnell	19 Mar 21	~W	12 May 21	54
Whero Rock		Bushnell (old)		NE		

Images were set at 12 MP for best image quality, recorded onto 32 gb SD cards, and cameras each used 12 AA batteries. We tested the settings of each camera before first deployment to ensure the cameras were functioning correctly. A DSLR camera was used to take colony photos of camera perspective at each deployment, except Sumpter Wharf where a bird's eye view of the wharf was taken with the drone instead.

Cameras were mounted on 40–90 cm waratahs (Taiaroa, Whero), or on 3 m right-angle steel poles (Sumpter Wharf) (Fig. 1). At Sumpter Wharf cameras were attached to wharf piles from the water level (via sea kayaks) at high tide, attaching poles to piles with ratchet strops and thick cable ties (Fig. 1 right). In all cases, the top of poles or waratahs were padded with a closed-cell foam cap or shielded by the camera itself (camera mounted proud of the top of each waratah) (Fig. 1 top left). At Taiaroa we added flax heads over the top to make the camera more visible to flying birds, and to provide padding if a bird were to collide with the waratah (Fig. 1 bottom left).

Figure 1. Trail cameras mounted at Whero Rock (top left), Pukekura (bottom left) and Sumpter Wharf (right).

Trial of shag response to drone

We cautiously conducted a trial to quantify the sensitivity of both Foveaux and Otago shag species to drones, at at least one site for each species. Ideally, we aimed to select stable 'wild' colonies, not impacted by humans, but DOC access approvals limited available trial sites. The shag response trial overflew the Sumpter Wharf colony of Otago shags, and the Whero Rock and Kanetetoe Island colonies of Foveaux shags.

To assess shag responses before, during and after drone flight, a dedicated observer with binoculars supported the drone pilot. The drone was a DJI Mavic 2 Pro carrying a high-quality Hasselblad camera (20MP 1" CMOS sensor). For the manual flight needed for these animal response trials we used the DJI Go4 drone interface software.

Flights were conducted prior to installing roost cameras, to avoid priming birds with disturbance. All animal response trials were conducted in two stages; launch and ascent (a careful and slow launch and hover then slow ascent to 50 m flight height), then overflight (initial hover at target flight height then if no reaction, progress to a slow flight in a steady and straight transect). Overflight altitude decreasing in 10 m steps from the initial 50 m flight height, until change in animal behaviour noted. Filming with an DSLR camera was used for a full record of responses through all stages, and drone video of key sections / changes was recorded also (see screen-grabs from video, Fig. 2).

At Sumpter Wharf it was possible to conduct a second flight over shags two months after the first to get another time of day replicate. Although it was not possible to conduct response trials during the breeding season, the later flight at Sumpter allowed us to gauge whether there might be a changing seasonal effect to shag responses.

Figure 2. Shag roosts at Whero Rock, Rakiura. Example screen grab from drone video at 20 m flight height.

Results

Breeding site locations

Breeding site records were drawn from peer reviewed published literature, unpublished reports, eBird and expert knowledge. All breeding sites were listed in a PhD thesis (Lalas 1983), although the two species were grouped together as Stewart Island shags at that time. The breeding range of Otago shags is from the Catlins to near Moeraki in North Otago, although a few have started breeding in Timaru (Table 2). Foveaux shags breed around Foveaux Strait and Rakiura (Table 3).

The current breeding sites for Otago and Foveaux shags are poorly described. Recent work has been focused on records of Otago birds (Lalas 1993; Lalas & Perriman 2009) (Table 2). Heather and Robertson (2015) state there are 'about 15 colonies of 10–500 pairs each'. Rawlence *et al.* (2014) state that Otago shags breed between Maukiekie Island and Kinakina Island (Table 2), although breeding and roost sites are not separated in that paper or the later paper splitting Stewart Island shags into Otago and Foveaux shags (Rawlence *et al.* 2016). Crossland (2012) reviewed the current range of the then Stewart Island shag, but only identified a single breeding site in the short-note review (Table 2). More recent reports have small numbers of Otago shags now breeding at Timaru (A. Crossland in Stuff 2021). The Otago breeding locations were provided by Lalas and Perriman (2009), with five breeding sites recorded (Table 2). Four Otago breeding sites were identified in Lalas (1993). In a comprehensive review of historic breeding sites for the then Stewart Island shags, eleven sites were recorded, four for Otago and seven for Foveaux (Marchant & Higgins 1990) (Tables 2, 3). Eleven breeding and roosting sites for Stewart Island shags were described by Watt (1975) (Table 3). The DOC database to 2005 specifies breeding sites, with 11 Foveaux shag sites identified (Table 3).

Table 2. Breeding sites of Otago shags

	eBird (n = 4995) 2021	Crossland 2021	Crossland (1996-07) 2012	Lalas & Perriman 2005	Lalas 1993	Marchant & Higgins 1990	Lalas 1983	Watt 1975
Maukiekie Island (Moeraki Point)	breeding	-	breeding	breeding	breeding	-	breeding	-
Pukekura / Taiaroa Head	breeding	-	-	breeding	breeding	breeding	breeding	breeding
Wharekakahu (Allans Beach, Otago Peninsula)	-	-	-	breeding	breeding	-	breeding	-
Okaihe / Green Island	breeding	-	-	breeding	breeding	breeding	breeding	breeding
Kinakina Island (Chaslands, Catlins)	-	-	-	breeding		-	-	-
Gull Rocks (Sandfly Bay, Otago Peninsula)	-	-	-	former	-	breeding	-	breeding
Otago Harbour	-	-	-	transient	-	-	breeding	-
Sumpter Wharf (Oamaru)	breeding	-	-	NA *	-	-	-	-
Goat Island (Moeraki)	-	-	-	-	-	breeding	-	breeding
Timaru Harbour	-	breeding *	-	-	-	-	-	-

- : no information provided in reference; NA: not applicable; * : Not reported breeding at Sumpter Wharf before 2014 (Lalas and Perriman unpubl. data 2020) or at Timaru harbour before 2019 (A. Crossland in Stuff 2021)

Important roost site: Shag Point, Oamaru, The Sisters (west of Chaslands Point). Transient: Okahau Point (between Moeraki and Katiki Points) (Lalas & Perriman 2009)

Other roosting sites: Wainono Lagoon, Waitaki River mouth, Seacliff, Long Beach, Aramoana, Boulder Beach, Papanui Beach, Allans Beach, Nugget Point (Rawlence *et al.* 2014; Rawlence *et al.* 2016). Note roosting sites and breeding colonies not distinguished in those works, so this list may include some breeding sites

Table 3. Breeding sites of Foveaux shags

	eBird 2021	**DOC database (1911-2005)**	**Crossland (1996-07) 2012**	**Lalas & Perriman 2005**	**Marchant & Higgins 1990**	**Lalas 1983**	**Watt 1975**
Kanetetoe Island	-	breeding	-	-	breeding	-	breeding
Whero Rock	breeding	breeding	-	-	breeding	breeding	breeding
Centre Island and Kuru-kuru rocks	-	breeding	-	-	breeding	breeding	breeding
Whenua Hou / Codfish Island (Sealer's Bay)	breeding	breeding	-	-	breeding	-	breeding
Papa-Kaha Rocks (Bluff Harbour entrance)	-	breeding	-	-	breeding	breeding	breeding
Islet off Rabbit Island Bluff Harbour		breeding					
Tiwai Rocks		breeding					
Tihaka / Pig Island		breeding					
Zero Rock	-	breeding	-	-	breeding	-	breeding
Ulva Island (The Snuggery)		breeding					
Pukeokaoka / Jacky Lee Island	-	-	-	-	breeding	-	breeding
Omaui Island	breeding	breeding	-	-	-	-	-
Breaksea Isles	-	-	-	-	-	breeding	-
High Rock off Codfish	-	-	-	-	-	breeding	-
Fife Rock	-	-	-	-	-	breeding	-

- : no information provided in reference; NA: not applicable
DOC database records provided by Ros Cole, DOC Murihiku

Roosting sites: Te Waewae Bay, Muttonbird Island, Ruapuke Island, Seal Rocks (off Ruapuke), Paterson Inlet, Easy Harbour (Rakiura), Shag Rock, Port Pegasus (Rawlence *et al.* 2014; Rawlence *et al.* 2016). Note roosting sites and breeding colonies not distinguished in those works, so this list may include some breeding sites

From 4995 records in eBird (Sullivan *et al.* 2009), only 56 mentioned evidence of breeding that could be interpreted with confidence. iNaturalist did not prove to be a helpful resource for identifying breeding locations.

Taken together, these resources point to ten known historic or contemporary breeding colonies of Otago shags and 15 breeding sites for Foveaux shags (Tables 2, 3). Other definite or probable roost sites (13 for Otago shags, eight for Foveaux; footnotes, Tables 2, 3) may include some breeding sites, since roosting sites and breeding colonies were not always distinguished in those sources. Knowledgeable experts would likely be able to refine that roost sites list, but we have not yet received information from all relevant experts.

Trail cameras

Hourly photos of shag colonies at Sumpter Wharf and Taiaroa Head showed that roosts were attended between 1630 and noon each day (median departure and arrival times), with departures reliably occurring 1130–1230 (Fig. 3). However, at Whero roost attendance each day was much shorter, with birds present ~1330 to 1930 (Fig. 3). From 21 April to 12 May the colony was generally empty all day. At all sites, shag returns to the colonies were less predictable than departures, with greater spread (Fig. 3 right), particularly at Whero. Departure and return times shifted earlier as days got shorter from March to May, as illustrated at Sumpter (Fig. 3 mid).

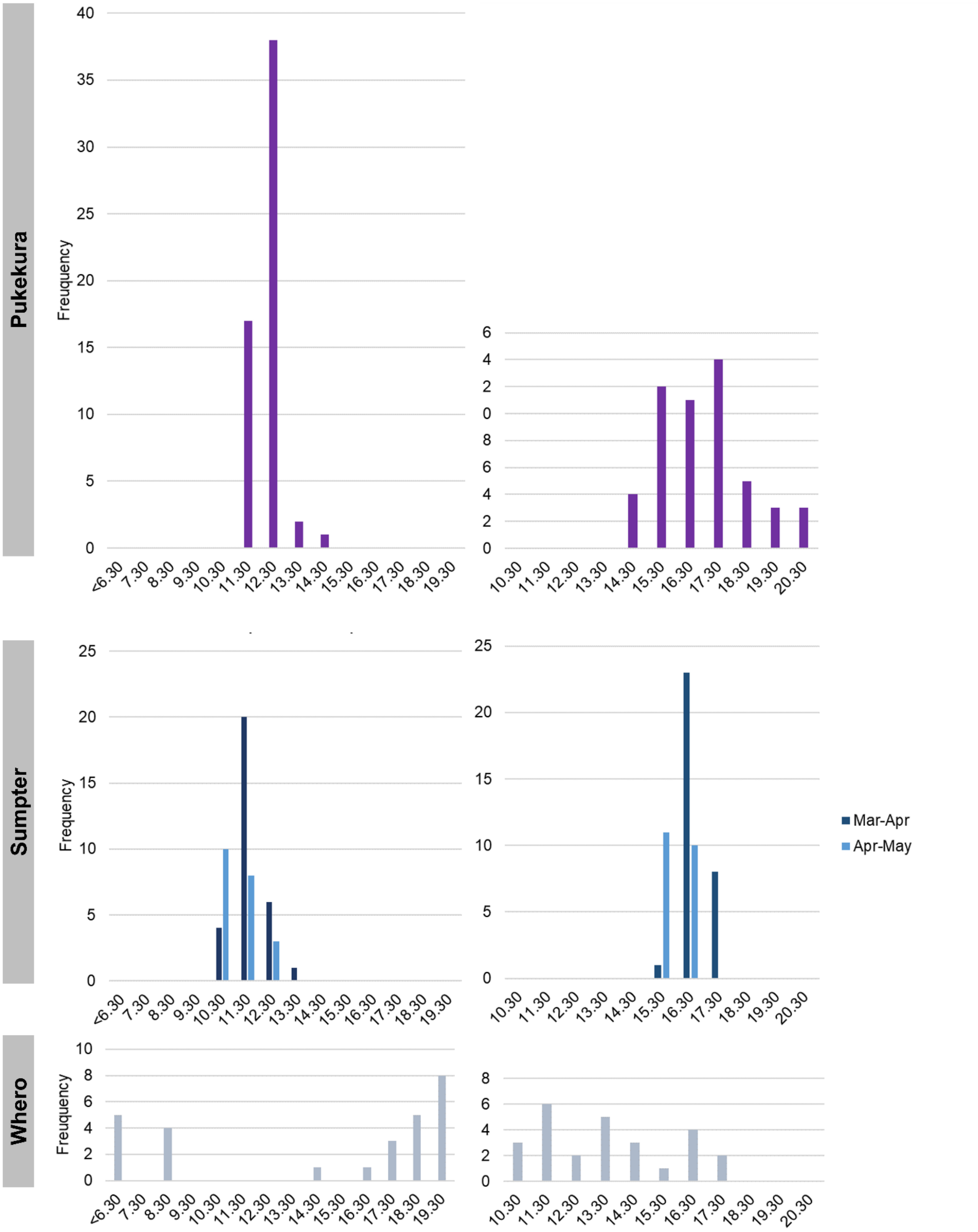

Figure 3. Colony attendance patterns at Pukekura Sumpter Wharf and Whero Rock shag colonies. Departure time frequencies are at left and return time frequencies at right; times along the x-axis from morning to evening.

Colony attendance patterns are expected to differ during the breeding season within and between colonies (McKinlay 2017). An early indication of this was that shags were present at the colony full-time from 22 April (Pukekura) and 4 May (Sumpter), with courtship beginning and import of nesting material apparent. This was not seen in the Whero camera, where the colony was empty all day from 21 April to 12 May; these birds were either at a nesting site (different to the roost site) out of view of the camera on Whero, or at a different island entirely.

Cameras were not useful for detecting if roosts were intermixed (and at what proportions Otago vs Foveaux shags) in this non-breeding season trial. This is largely because a key feature—extent of facial carunculation—is only present during the breeding period. The Foveaux shag has scattered dark orange papillae, while the Otago shag has equal frequencies of dark orange scattered papillae and small bright orange facial caruncles (Rawlence *et al.* 2014; Rawlence *et al.* 2016). Otago shags also have 20–30% pied morphs but pied comprise 50–60% of the Foveaux group (Rawlence et al. 2014). Species ID being based on proportions, it would be difficult to detect the proportion of intermixing in a colony; only at Foveaux colonies might we detect intermixing (if small caruncles are visible, not papillae, then we are seeing Otago birds). Despite setting cameras to take the highest-quality images, the extent of carunculation cannot be seen clearly on enough birds (e.g., Fig. 4). We do note that pied and bronze morphs can be distinguished in drone images from 20 m flight height, albeit not from every bird.

Since we lack data for the breeding season, cameras at all three sites were left running. This project will not benefit from the data, but an extended camera deployment (estimated 1-year deployment) will provide important information on colony attendance during the breeding season. Counts will be more accurate if a time of day can be identified with fewest loafing birds, and fewest birds of other species (e.g., spotted shags *Stictocarbo punctatus* absent at 12.30pm, so very few in May drone trial images). Further, enough nests should be visible on camera to determine nest survival rates, informing aerial photographic counts.

Figure 4. Example shot from trail camera from Sumpter Wharf.

UAV animal response trials

Sumpter Wharf March

The 12 March trial took place mid-afternoon, with relatively few shags present on the wharf (80–100 Otago shags). Before starting the 12 March trial (Table 4), a preliminary flight moved slowly in parallel ~20 m away from wharf at 20 m flight height (flight 1). Otago shags displayed alert behaviours, with heads cocked and looking skyward throughout the initial flight. Otago shags and spotted shags all moved to the edge of the wharf structure and maintained their alert postures. Red-billed gulls *Larus novaehollandiae* took flight in groups, wheeled and returned after one loop lasting approximately ten seconds; no shags took flight.

The flight height trial started at 50 m (flight 2), with slow overflight resulting in continued alert postures and Otago shags staying at the wharf's perimeter. When the flight altitude directly above the wharf was lowered to 30 m (flight 3) all red-billed gulls took flight, wheeled and returned after one loop lasting approximately ten seconds. Otago and spotted shags remained in alert positions with heads cocked and approximately a quarter of shags looking skyward. Shags stayed on the wharf edge where they were positioned after flights one and two.

At 20 m flight altitude (flight 4, Table 4), all red-billed gulls and five Otago shags took flight, all landed after 10 seconds. Red-billed gulls took flight a second time and landed after another 10 seconds. A few Otago shags in the middle of the wharf walked to the edge, and one shag returned to the middle of the wharf. The final flight at Sumpter wharf was at 15 m altitude and was quickly abandoned. Otago and spotted shags looked agitated, mass movement (walking although still not running or flying) but appearing poised to take flight.

Sumpter Wharf May

For the May trial, almost 800 Otago shags were present in the colony. The drone started at 50 m flight height then descended through 30 m and 25 m flight heights (flights 1–3, Table 5) without detectable reaction to the drone, nor noticeable change in shag behaviours. Spotted shags and gulls were absent.

At 20 m flight height (flight 4) there was little overall change, with four shags moving to the wharf's edge and two looking alert and skyward. 15 m overflight was quickly abandoned with mass movement of shags (walking) as the drone approached.

Table 4. Otago shag responses to drone flight, Sumpter Wharf Oamaru. 80–100 Otago shags present during trial on 12 March 2021.

Flight	Time	Flight altitude	Animal responses
1	15:35 to 15:38	10–30 m above sea level (asl) ~ 20 m from wharf edge, 20m altitude	All red-billed gulls took flight, landed after 10 seconds. Otago and spotted shags displayed alert postures with heads cocked and looking skyward, moved to wharf edge. Red-billed gulls took flight again, landed after 10 sec.
2	15:41 to 15:43	50 m above wharf	Otago and spotted shags heads cocked and approximately a quarter of shags looking skyward. Shags stayed on the wharf edge where they were positioned after flight one. Bird postures appear relaxed, but birds remained stationary.
3	15:44 to 15:48	30 m above wharf	All red-billed gulls took flight, landed after 10 sec. Otago and spotted shags heads cocked and approximately a quarter of shags looking skyward. Shags stayed on the wharf edge where they were positioned after flights one and two.
4	15:49 to 15:57	20 m above wharf	All red-billed gulls and five Otago shags took flight, all landed after 10 seconds. Red-billed gulls took flight again, landed after 10 sec. One Otago shag returned to centre of wharf
5	15:59 to 16:08	15 m above wharf	Otago shags moving about, appear agitated and about to take flight. Flight abandoned due to behaviours displayed. Spotted shags alert but not moving.

Table 5. Otago shag responses to drone flight, Sumpter Wharf Oamaru. 770 Otago shags present during trial on 6 May 2021.

Flight	Time	Flight altitude	Reaction of shags
1	14:02 to 14:03	50 m above wharf	No reaction from Otago shags, spotted shags, or red-billed gulls
2	14:04 to 14:05	30 m above wharf	Two birds had cocked heads and were looking skyward, but not clearly due to the presence of the drone
3	14:07 to 14:08	25 m above wharf	No detectable reaction to drone from any birds
4	14:09 to 14:10	20 m above wharf	Four shags moved to the edge of the wharf at the less densely occupied southern end of the wharf, two birds displayed alert postures and were looking skyward
5	14:11 to 14:14	15 m above wharf	Mass movement (shuffling and walking) of Otago shags when the drone was above the less densely occupied southern end of the wharf. Flight immediately abandoned due to behaviours displayed.

Whero Rock

At Whero Rock Foveaux shags showed no response to drone launch and ascent (Table 6). No other shag species were present at Whero. From the outset, shags were notably less watchful than at Sumpter Wharf.

The trial started at 50 m and descended in 10 m intervals above a sub-colony of ~34 shags. At all five flight heights, the drone was flown slowly above the roost. At 20 m, as at other heights, shags watched the drone initially then ignored it and returned to relaxed postures and preening (flight 2). A water taxi pelagic tour boat with photographers was just off the colony at that point too. A circuit was flown around the island at 50 m and 30 m flight heights, and none of the shags at other roosts (a further ~51 birds) showed alarm behaviours when the drone circuited above.

Kanetetoe Island

On Kanetetoe Island, shags were mostly Foveaux but also a spotted shag, plus ~ 100 red-billed gulls. Since an island landing was not possible, the drone was flown from the boat. First approaching from the sea at ~25 m flight height, the drone ascended to 50 m then descended as before. During approach Foveaux shags were initially alert, with heads cocked, but returned to relaxed postures as the drone ascended to 50 m and throughout slow overflight at 40 m (Table 6). At 30 m flight height, the drone was flown around the island over other shags, most shags looking alert skyward. At 25 m flight height (20 m over shags), shags initially shuffled on the spot and looked at the drone, then relaxed into interacting and preening. There was no sign that shags were concerned by the drone at 20 m above.

Table 6. Foveaux shag responses to drone flight, Whero Rock and Kanetetoe Island, 19 March 2021. ~95 Foveaux shags were present for the trial at Whero and ~36 at Kanetetoe.

Site	Flight	Time	Flight altitude	Animal responses
Whero Rock, Rakiura	1	09:46 to 09:52	50 m dropping in 10 m steps to 30 metres	Red-billed gulls took flight, returned in 10 seconds. Foveaux shags alert, heads cocked at first when drone at 50 m, then returned to preening behaviours. All birds remained in relaxed postures and many preening for the remainder of flight.
	2	09:54 to 09:56	20 m	Red-billed gulls took flight, returned in 10 sec. Foveaux shags no obvious reaction to drone. Remained in relaxed postures and many preening for the duration of the flight.
Kanetetoe Island, Rakiura	1	10:59 to 11:09	50 m dropping in 10 m steps to 20 m above shags	Foveaux shags alert, heads cocked at first when drone approached from seaward and one Foveaux shag departed. At 50 m flight height shag posture relaxed, with change in postures at 40 m flight altitude. At 30 m flight altitude approximately 75% of Foveaux shags displayed alert postures with heads cocked skyward, but relaxed again. A single spotted shag was present and displayed alert and nervous behaviours. At 20 m height above shags, shuffling and looking then relaxed, no further response to the drone.

Time window needed

Drones are robust to surprisingly windy conditions (e.g. up to 20 knots for smaller drones), with good image quality obtained despite occasionally substantial winds in some of our work (Rexer-Huber & Parker 2020). However, rain, haze and fog impact image quality so should be avoided. Although drone flight itself does not take long (potentially just a few minutes for a small site), it is sensible to include time contingency for weather when planning for drone image capture.

Additional leeway must be allowed for sites where there is boat access, since sea-state conditions suitable for landing at the island (or installing camera on wharf pilings from kayak) may require substantial waits. In both March and May, the work at Sumpter wharf was planned based on a good forecast, but in March the sea-state meant it could only take place six days later than the day first identified. In May, good conditions for Sumpter were available on one day out of the 7-day window targeted. Similarly, work at Rakiura involved about one week of being on weather (sea-state) standby, with work planned for Friday 12 or Tuesday 16 eventually able to take place on Friday 19 March.

Image quality

Drone overflight at 20 m allows capture of images of sufficient quality for accurate counts of shag colonies. When overlapping images are stitched into a single composite image, the high resolution allows Otago shags to be distinguished from spotted shags and gulls (Fig. 5). Pied morph can also be distinguished from the bronze morph for many birds, although not for all as it does depend a bit on bird posture. Although images were not taken during the breeding season, it appears possible to distinguish birds sitting/standing in the colony (loafing) from birds on a nest (apparently breeding, although not possible to determine nest contents) (Fig. 5).

Discussion

Identify Foveaux and Otago shag breeding colony locations

Using all available information, we identified recorded historic and contemporary breeding sites for Otago and Foveaux shags. The list of breeding sites here—ten Otago shag breeding sites and 15 Foveaux shag breeding sites—cannot be considered complete as it most likely does not include all breeding sites currently in use, and some of the sites listed will no longer be in use. Only a handful of studies have been conducted on either species, and just 1% of eBird entries mentioned breeding, and those are biased towards the most well publicised sites where birders collecting species sightings can see the birds (Sullivan *et al.* 2009). Other knowledgeable local ornithologists may have better up to date information, and we hope to receive such records in due course.

Importantly, the abandonment of breeding sites active for long periods of times (i.e. decades) and the establishment of new breeding sites is a well recorded phenomenon for Otago and Foveaux shags (Watt 1975; Lalas 1983; Lalas 1993). For example, there were no reports of breeding at the Sumpter Wharf colony before 2014, but the breeding colony then grew rapidly to some 650 nests in the 2019/20 breeding season (Lalas & Perriman unpubl. data 2020). The continued use of a breeding site may eventually cause the site to be unviable for breeding, providing the source of all these breeding shags.

Future comprehensive surveys based on information reported here should include all possible breeding sites in targeted visits. Before surveys, eBird and other resources should be checked for newly reported breeding sites.

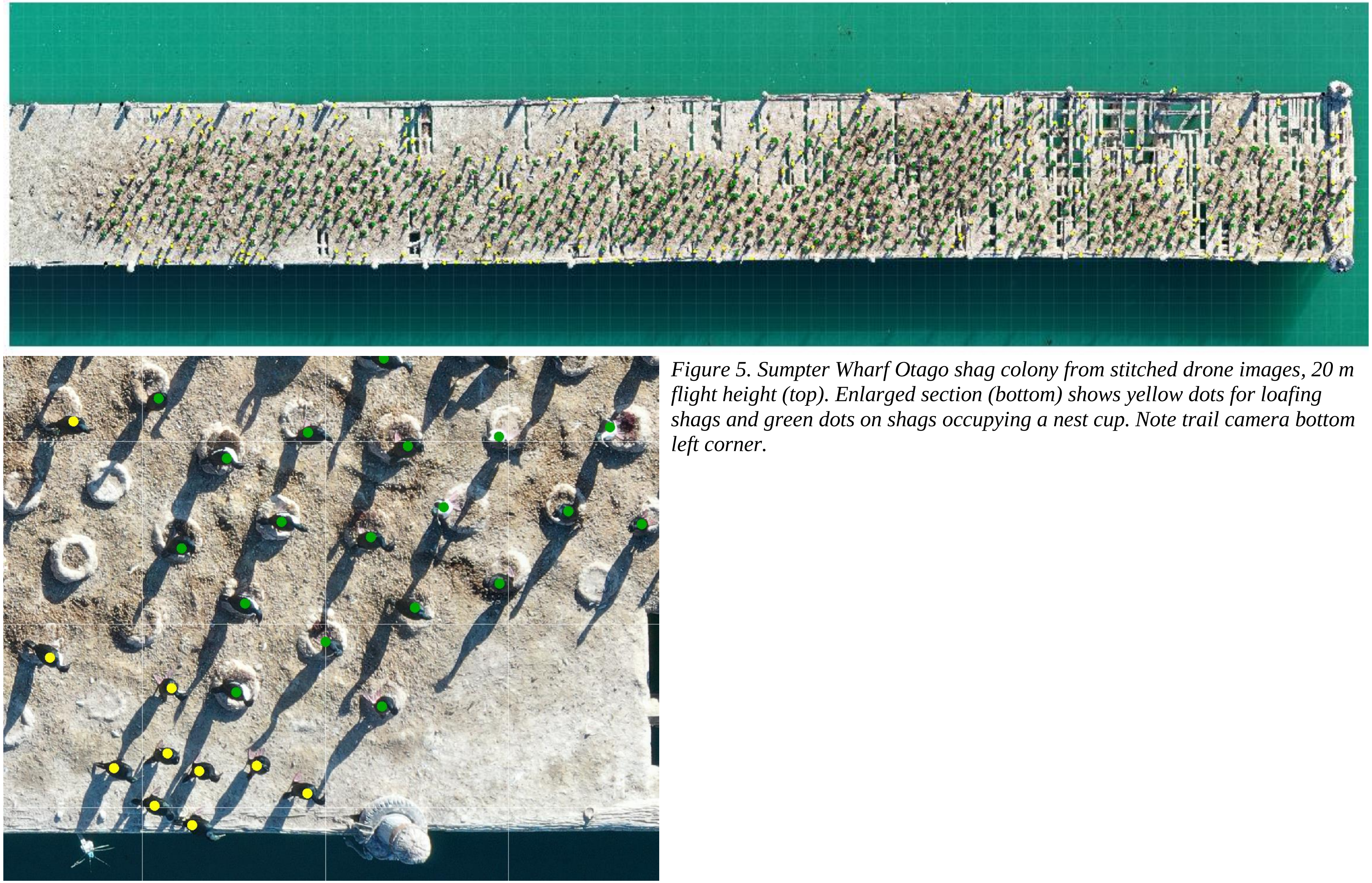

Figure 5. Sumpter Wharf Otago shag colony from stitched drone images, 20 m flight height (top). Enlarged section (bottom) shows yellow dots for loafing shags and green dots on shags occupying a nest cup. Note trail camera bottom left corner.

Identify suitability of drone use for Foveaux and Otago shag aerial population census data

Four drone trials at three sites during the non-breeding season showed that at this stage, shags tolerate slow drone overflight at 20 m. Other shag species similarly show tolerance to overflight as low as 20–25 m (Weimerskirch *et al.* 2018; Irigoin-Lovera *et al.* 2019; Rexer-Huber & Parker 2020), while Chatham shags appeared tolerant to overflight as low as 10 m, and king shags tolerated 15–18 m overflight (M. Bell pers. comm. 2021). Images at 20 m are of high quality, such that other shag species (little, spotted) can be identified and excluded. At this image resolution, all occupied nests would be identifiable and loafing birds should be distinguishable from those actually on a nest. We note, though, that ground-truthing is still needed for nest contents (what proportion of apparently nesting birds are actually breeding?), as for any aerial photographic method (Schuckard *et al.* 2018). This involves checking the contents of nests and quantifying the proportion of loafing birds.

Shags at Sumpter Wharf seemed more alert and responsive to drone movements, compared to shags at Whero and Kanetetoe. This is counter to our expectation that Sumpter Wharf shags might be more used to disturbance since there is a lot more activity (people, cars, machinery) around Sumpter. Instead, it appears that birds there are sensitised to disturbance due to regularly being disturbed. At more accessible shag colonies, drone flight should therefore proceed with particular care, as shags might be more sensitised at busier sites.

For population census, drone based colony counts must take place during the breeding season, and we expect that shag responses to a drone might differ to the non-breeding season. For example, king shags appeared more tolerant to drone overflight in the breeding period than in the non-breeding period (M. Bell pers. comm. 2021), as were guanay cormorants *Phalacrocorax bougainvilli* (Irigoin-Lovera *et al.* 2019). Survey by plane elicited no obvious behavioural responses from king shags during non-breeding or breeding periods, but these were at flight altitudes from 225–460 m (Schuckard *et al.* 2015). It is promising that there was no marked difference in Otago shag responses to drone in the pre-lay/courtship phase (May) than in March, with 20 m flight height still tolerated. However, any drone overflight of breeding colonies must proceed with caution, first conducting a response trial to identify an appropriate flight height that causes least visible disturbance.

Determine temporal colony attendance, intermixing of Otago and Foveaux shags, and nest survival rates by installing trail cameras at four sites, two for each Otago and Foveaux shags

Time of day has a significant impact on shag numbers estimated (Schuckard *et al.* 2015; Chilvers *et al.* 2019). Trail cameras installed to monitor roosting birds at three breeding sites (albeit outside of the breeding season) successfully collected data to inform temporal colony attendance. In the non-breeding period, Otago shag roosts were reliably occupied in the morning before 11.30 am. Afternoon return times were more variable. This fits with typical shag attendance patterns, with maximal numbers of birds in the colonies in the mornings (e.g., Irigoin-Lovera *et al.* 2019).

Colony attendance will be different during the breeding season, with the colony constantly occupied. However, the diurnal attendance of other loafing/non-breeding birds could affect counting accuracy, so extending camera monitoring into the breeding season will help determine if there is a period when loafers (and other shags) are least likely to be present.

From our small trial we are confident that trail cameras can be used to obtain nest survival rates, and therefore be used to calibrate aerial images obtained by a drone.

Recommendations

For future census work we recommend visiting all twenty-five sites identified here to determine the population size of Otago and Foveaux shags. Egg laying starts in September, so aerial photography should take place from then, ideally around the peak laying period before there are egg losses.

Animal response trials showed that drones can be flown slowly over Otago and Foveaux shags as low as 20 m without causing notable disturbance. Since this was during non-breeding and pre-breeding seasons, we recommend that overflights during the breeding season first determine the drone flight height that causes minimal disturbance at that stage.

Drone footage from 20 m flight height is of excellent quality for counting shag numbers in colonies. Colony counts from images taken during the breeding season at 20 m flight height will be useful for estimating the size of the breeding population. To get the best estimate of numbers of breeding pairs, counts of apparently nesting shags from photographs must be corrected using ground-truthing data that assesses nest contents.

Camera monitoring during the non-breeding season showed clear diurnal patterns of colony attendance. We recommend that cameras be deployed into the breeding season as those data should provide nest survival rates, enabling correction of population size estimates.

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References

Abraham, E.R.; Thompson, F.N. 2015. Captures of gulls, terns, shags, and gannets in setnet fisheries, in the New Zealand Exclusive Economic Zone, from 2002–03 to 2017–18. Retrieved from https://psc.dragonfly.co.nz/2019v1/released/gulls-terns-shags-gannets/setnet/all-vessels/eez/2002-03-2017-18/, May 3, 2021.

Adame, K.; Pardo, M.A.; Salvadeo, C.; Beier, E.; Elorriaga-Verplancken, F.R. 2017. Detectability and categorization of California sea lions using an unmanned aerial vehicle. *Marine Mammal Science 33*: 913–925.

Borrelle, S.B.; Fletcher, A.T. 2017. Will drones reduce investigator disturbance to surface-nesting seabirds? *Marine Ornithology 45*: 89–94.

Chilvers, B.L.; Baker, G.B.; Hiscock, J.A.; McClelland, P.J.; Holdsworth, M.; Jensz, K. 2015. Comparison of breeding population survey methods for the Auckland Island shag (*Phalacrocorax colensoi*). *Polar Biology 38*: 1847–1852.

Chilvers, B.L.; Curtis, H.; Zintzen, V.; Wakelin, L.; Geange, S.W. 2019. A survey of four shag species in the outer Queen Charlotte Sound, New Zealand. *Notornis 66*: 37–40.

Cox, F.; Horn, S.; Jaques, P.; Sagar, R.; Ware, J. 2019. *Maukahuka - Pest free Auckland Island - 18/19 Summer trials Operational Report. Department of Conservation internal report DOC-5911275*. Invercargill, Department of Conservation.

Crossland, A.C. 2012. A review of the current range of Stewart Island shag (*Leucocarbo chalconotus*) and two records from Lake Ellesmere, Canterbury. *Notornis 59*: 71–73.

Dunn, M.J.; Adlard, S.; Taylor, A.P.; Wood, A.G.; Trathan, P.N.; Ratcliffe, N. 2021. Un-crewed aerial vehicle population survey of three sympatrically breeding seabird species at Signy Island, South Orkney Islands. *Polar Biology 44*: 717–727.

Guthrie-Smith, H. 1914. Mutton Birds and Other Birds. Christchurch, Whitcombe and Tombs.

Heather, B.; Robertson, H.R. 2015. The Field Guide to the Birds of New Zealand. Auckland, Penguin, 464 pp.

Hodgson, J.C.; Mott, R.; Baylis, S.M.; Pham, T.T.; Wotherspoon, S.; Kilpatrick, A.D.; Raja Segaran, R.; Reid, I.; Terauds, A.; Koh, L.P. 2018. Drones count wildlife more accurately and precisely than humans. *Methods in Ecology and Evolution 9*: 1160–1167.

Hughes, A.; Teuten, E.; Starnes, T. 2018. *Drones for GIS – Best Practice. Conservation Data Management Unit*. Sandy, UK, Royal Society for the Protection of Birds.

Irigoin-Lovera, C.; Luna, D.; Acosta, D.; Zavalaga, C.B. 2019. Response of colonial Peruvian guano birds to flying UAVs: effects and feasibility for implementing new population monitoring methods. *PeerJ e8129*:, https://doi.org/10.7717/peerj.8129.

Korczak-Abshire, M.; Zmarz, A.; Rodzewicz, M.; Kycko, M.; Karsznia, I.; Chwedorzewska, K.J. 2019. Study of fauna population changes on Penguin Island and Turret Point Oasis (King George Island, Antarctica) using an unmanned aerial vehicle. *Polar Biology 42*: 217–224.

Lalas, C. 1983. Comparative feeding ecology of New Zealand marine shags (Phalacrocoracidae). PhD, University of Otago, 288 pp.

Lalas, C. 1993. *Status and monitoring of marine shags in Otago Conservancy, with recommendations on research needs. Conservation Advisory Science Notes No. 13*. Wellington, Department of Conservation.

Lalas, C.; Perriman, L. 2009. *Nest counts of Stewart Island shags / mapua (*Leucocarbo chalconotus*) in Otago. DOC Research & Development Series 314*. Wellington, Department of Conservation.

Marchant, S.; Higgins, P.J. 1990. Handbook of Australian, New Zealand and Antarctic birds. Vol. 1: Ratites to Ducks, Part A - Ratites to Petrels. Melbourne, Oxford University Press, 736 pp.

Mattern, T.; Rexer-Huber, K.; Parker, G.; Amey, J.; Green, C.-P.; Tennyson, A.J.D.; Sagar, P.M.; Thompson, D.R. 2021. Erect-crested penguins on the Bounty Islands: population size and trends determined from ground counts and drone surveys. *Notornis 68*: 37–50.

McKinlay, B. 2017. Stewart Island shag. *In* Miskelly, C.M., *ed. New Zealand Birds Online. www.nzbirdsonline.org.nz*.

Muller, C.G.; Chilvers, B.L.; Barker, Z.; Barnsdale, K.P.; Battley, P.F.; French, R.K.; McCullough, J.; Samandari, F. 2019. Aerial VHF tracking of wildlife using an unmanned aerial vehicle (UAV): comparing efficiency of yellow-eyed penguin (*Megadyptes antipodes*) nest location methods. *Wildlife Research 46*: 145–153.

Mustafa, O.; Barbosa, A.; Krause, D.J.; Peter, H.-U.; Vieira, G.; Rümmler, M.-C. 2018. State of knowledge: Antarctic wildlife response to unmanned aerial systems. *Polar Biology 41*: 2387–2398.

Oosthuizen, W.C.; Krüger, L.; Jouanneau, W.; Lowther, A.D. 2020. Unmanned aerial vehicle (UAV) survey of the Antarctic shag (*Leucocarbo bransfieldensis*) breeding colony at Harmony Point, Nelson Island, South Shetland Islands. *Polar Biology 43*: 187–191.

Parker, G.C.; Rexer-Huber, K. 2020. *Drone-based Salvin's albatross population assessment: feasibility at the Bounty Islands. Report to the Conservation Services Programme, Department of Conservation*. Dunedin, Parker Conservation.

Parker, G.C.; Rexer-Huber, K. 2021. *Foveaux and Otago shag population census methods: drone and camera trials. DRAFT Final report for BCBC2020-24 for the Department of Conservation*. Dunedin, Parker Conservation.

Pfeifer, C.; Rümmler, M.-C.; Mustafa, O. 2021. Assessing colonies of Antarctic shags by unmanned aerial vehicle (UAV) at South Shetland Islands, Antarctica. *Antarctic Science 33*: 133–149.

Rawlence, N.J.; Scofield, R.P.; Spencer, H.G.; Lalas, C.; Easton, L.J.; Tennyson, A.J.D.; Adams, M.; Pasquet, E.; Fraser, C.; Waters, J.M.; Kennedy, M. 2016. Genetic and morphological evidence for two species of *Leucocarbo* shag (Aves, Pelecaniformes, Phalacrocoracidae) from southern South Island of New Zealand. *Zoological Journal of the Linnean Society 177*: 676–694.

Rawlence, N.J.; Till, C.E.; Scofield, R.P.; Tennyson, A.J.D.; Collins, C.J.; Lalas, C.; Loh, G.; Matisoo-Smith, E.; Waters, J.M.; Spencer, H.G.; Kennedy, M. 2014. Strong phylogeographic structure in a sedentary seabird, the Stewart Island shag (*Leucocarbo chalconotus*). *PLOS ONE 9*: e90769, 10.1371/journal.pone.0090769.

Rexer-Huber, K.; Parker, G.C. 2020. *Bounty Islands drone trials: feasibility for population assessment of NZ fur seal. Final report to the Conservation Services Programme, Department of Conservation*. Dunedin, Parker Conservation.

Robertson, H.A.; Baird, K.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C.M.; McArthur, N.; O'Donnell, C.F.J.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. 2017. *Conservation status of New Zealand birds, 2016. New Zealand Threat Classification Series 19*. Wellington, Department of Conservation.

Schuckard, R.; Bell, M.; Frost, P.; Taylor, G.; Greene, T. 2018. A census of nesting pairs of the endemic New Zealand king shag (*Leucocarbo carunculatus*) in 2016 and 2017. *Notornis 65*: 59–66.

Schuckard, R.; Melville, D.S.; Taylor, G. 2015. Population and breeding census of New Zealand king shag (*Leucocarbo carunculatus*) in 2015. *Notornis 62*: 209–218.

Stuff. 2021. Threatened shags take up shelter in Timaru's Evans Bay. Article 8 March 2021 at https://www.stuff.co.nz/timaru-herald/news/124469889/threatened-shags-take-up-shelter-in-timarus-evans-bay.

Sullivan, B.L.; Wood, C.L.; Iliff, M.J.; Bonney, R.E.; Fink, D.; Kelling, S. 2009. eBird: a citizen-based bird observation network in the biological sciences. *Biological Conservation 142*: 2282–2292.

Watt, J.P.C. 1975. Notes on Whero Island and other roosting and breeding stations of the Stewart Island shag *Leucocarbo carunculatus chalconotus*. *Notornis 22*: 265–272.

Weimerskirch, H.; Prudor, A.; Schull, Q. 2018. Flights of drones over sub-Antarctic seabirds show species- and status-specific behavioural and physiological responses. *Polar Biology 41*: 259–266.