PARKER CONSERVATION

Otago shag breeding population size

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Executive summary

Endemic to Southern New Zealand, Otago shag *Leucocarbo chalconotus* are classified as threatened, but there is little recent information on their population status and trends to inform conservation management. The aim of this project was to conduct a breeding population census of Otago shags.

Comprehensive surveys were conducted in targeted visits of current breeding sites. Aerial photographs for Otago shag counts were taken using a drone where appropriate (six colonies) or vantage-point DSLR photographs where a drone could not be flown (one colony). Building on animal response trials in previous work, these drone overflights during the breeding season first determined the drone flight height appropriate at each site to cause minimal disturbance. Survey flights were all taken within a week of each other, at the start of the breeding season in September 2021.

Photographs were stitched and counted, recording the number of apparently nesting Otago shags. To correct counts of apparently nesting shags (apparently on nest, or AON), we collected ground-truthing data assessing nest contents at one colony (Pukekura), finding that 0.74 of apparently nesting Otago shags were actually breeding at the start of September. The size of the breeding population is then calculated as the raw count of apparently nesting pairs multiplied by the nest-contents correction. Since surveys took place at the very start of the breeding season, we expect to have missed some birds yet to lay, so figures should be understood as minimum breeding population estimates.

The breeding colonies ranged in from the small southern colony at Kinakina Isl (estimated 32–33 breeding pairs) to the very large colony at Sumpter Wharf comprising some 504 breeding pairs (best estimate; range 496–511). The Otago shag population estimate—at least 1,275–1,332 breeding pairs at the start of the 2021 breeding season—is roughly similar to the last whole-population count in 2007. Despite different methods used, we believe this comparison is reasonable because independent counts of five colonies in 2021, using the vantage-point methods of earlier work, gave comparable numbers to our estimates from aerial photographs. However, for re-assessment of population trends to be robust the population size estimate should first be repeated, considering the 15-year interval since the last regular colony counts and the unknown population dynamics in that interval.

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Introduction

Endemic to Southern New Zealand coastal waters and harbours, Otago shag *Leucocarbo chalconotus* and Foveaux shag *Leucocarbo stewartia* are classified as 'Threatened – increasing' and 'Threatened – vulnerable' (Robertson *et al.* 2021). 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 Otago shag breeding colonies was published in 2009 and for Foveaux shags in 1983 (Lalas 1983; Lalas & Perriman 2009).

Both Otago and Foveaux shags are susceptible to set-net captures and breeding colony disturbance (Watt 1975; McKinlay 2013; Abraham & Thompson 2015). Emerging threats to population stability arise from indirect fisheries pressures; in particular, 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).

Shag colony distributions are known to change over time (Watt 1975; Lalas 1983; Lalas & Perriman 2009), so changes to distribution patterns of colonies may go undetected without up-to-date published literature on the location and size of Otago shag breeding colonies. Breeding population trends have not been updated for more than a decade, making it difficult for the risk of potential impacts to inform conservation management.

Most shag colonies are in terrain difficult to access on foot and shags can be sensitive to investigator disturbance, so aerial photographs appear to be the best way to estimate population numbers (Lalas & Perriman 2009; Schuckard *et al.* 2018; Oosthuizen *et al.* 2020). Compared to aerial photographic counts, boat-based counts and counts on foot tend to underestimate shag numbers (Chilvers *et al.* 2015): simultaneous counts over widespread colonies are difficult when boat-based or ground counting, and topography, vegetation and even conspecifics obstruct the field of view to an unknown degree (Chilvers *et al.* 2015; Schuckard *et al.* 2015). Aerial survey platforms can include fixed-wing planes, helicopters and drones. Drones are increasingly used for shag population assessment and monitoring worldwide (e.g., Oosthuizen *et al.* 2020; Dunn *et al.* 2021; Pfeifer *et al.* 2021). In NZ aerial counts of shags have largely used fixed-wing aircraft, but drones have been used for counts of king shag *Leucocarbo carunculatus* (Bell *et al.* 2022). Drones have also been explored for survey of Chatham and Pitt Island shags (*Leucocarbo onslowi* and *Stictocarbo featherstoni*) (M. Bell pers. comm. 2021). 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; Mustafa *et al.* 2018; Weimerskirch *et al.* 2018). Before assuming drones are a suitable tool for a given species, it is important to 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). Preliminary animal response trials at Otago and Foveaux shag colonies, outside the breeding season, showed that drones can be flown slowly as low as 20m over the shags without causing notable disturbance (Parker & Rexer-Huber 2021). Because animal responsiveness can vary, however, drone overflights during the breeding season must first identify the flight height that causes minimal disturbance.

For the resulting population size estimate to be useful and accurate, planning must carefully consider sources of error and how to manage or quantify those errors. For aerial photographic counts, the only unavoidable error is *visual obstruction bias* (italicised terms defined in sidebar, from ACAP 2011). Other inherent biases of aerial counts can be avoided, managed or quantified: *nest-failure error* is best avoided by timing the surveys to the very start of the breeding season, before many failures have had a chance to occur. When early survey timing is not possible, raw counts could be corrected using nest survival rates (where available), otherwise nest numbers are underestimated (Oosthuizen *et al.* 2020; Pfeifer *et al.* 2021). We avoid issues around *sampling error* by including every known colony, as close together in time as possible for comparability. *Detection errors* can be minimised by careful counting but detection rates should be quantified (multiple counts of the areas by e.g. independent counters, repeat counts at time interval, repeat photographs over a day are all ways to get a measure of the precision or repeatability of the counts) (Chilvers *et al.* 2015; Wolfaardt & Phillips 2020; Pfeifer *et al.* 2021). *Occupancy error* occurs when birds that appear to be incubating are not in fact breeding. Because it is generally not possible to see the contents of nests in aerial photographs, and therefore distinguish birds sitting on an empty nest from breeding birds (e.g., Schuckard *et al.* 2018), ground survey of nest contents is needed.

Error sources in aerial-photographic counts

detection errors—the probability of not detecting a bird despite its being present during a survey
nest-failure error—the probability of not counting a nesting bird because the nest had failed prior to the survey, or had not laid at the time of the survey
occupancy error—probability of counting a site as active despite it's not being used for nesting by birds during the season
sampling error—error associated with counting sites from photographs
visual obstruction bias—the obstruction of nest sites from view

From Methods Rating Matrix for Species Assessments, Agreement on the conservation of Albatrosses and Petrels (e.g. ACAP 2011, p.11)

The current project aim was to conduct a comprehensive Otago shag breeding population estimate. We detail photographic survey of all Otago shag breeding colonies, using drone or DSLR camera where appropriate, and describe ground-truthing to assess nest contents. Raw counts of apparently nesting shags from image analysis were compared with those from five colonies counted independently, using existing vantage-point methods. Raw counts had a nest-contents correction applied, giving estimates of the minimum number of breeding pairs at each colony and the estimated size of the Otago shag breeding population.

Methods

Image collection

Breeding site locations

A comprehensive breeding population estimate of Otago shags requires all colonies be included, since a known feature of shag breeding is that they occasionally desert well-established colonies and create new breeding colonies (Watt 1975; Lalas 1983). Otago shag breeding colony locations identified in Parker & Rexer-Huber (2021) were checked for any changes or new information. Current resources (published and grey literature, eBird, iNaturalist) were checked again for updates, and consultation with knowledgeable experts continued.

The ten breeding sites identified in 2021 were refined as follows. Reports of Timaru harbour having breeding birds (Stuff 2021) were incorrect; the ornithologist involved confirmed that Otago shags were just roosting and have not yet been seen breeding there (A. Crossland pers. comm. Aug 2021). Two sites had several names in various original sources, so each was effectively included twice in

2021 (Otago Harbour referred to Pukekura/Taiaroa Head, and Goat Isl referred to Maukikie); these double-ups have been merged. Heyward Point, Puddingstone Rocks and the Nuggets were added (C. Lalas unpubl. data June 2022). This leaves nine current breeding sites for Otago shags, and one historic breeding colony (Table 1), with the historic colony retained here for surveys to confirm that Otago shags still no longer breed there.

Table 1. Breeding sites of Otago shags. Status: C=current H= historic

Breeding colony	**Colony site details**		**Status**
Sumpter Wharf	Oamaru Harbour	Council	C
Maukiekie Isl	Moeraki Point	Te Rūnanga o Moeraki	C
Heyward Point	stacks off point		C
Taiaroa/Pukekura	NW side of Head, Otago Harbour	Nature Reserve	C
Puddingstone Rocks	N of Cape Saunders, Otago Peninsula	Council	C
Wharekakahu Isl	off Allans Beach, Otago Peninsula	Nature Reserve	C
Gull Rocks	off Sandfly Beach, Otago Peninsula	Council	H
Okaihe/Green Isl	off Brighton Beach, Otago	Nature Reserve	C
the Nuggets	two northeastern islets off Nugget Pt	Wildlife Reserve	C
Kinakina Isl	off Waipati Beach, Chaslands	Public conservation land	C

Important roost site: Shag Point, Oamaru, The Sisters (west of Chaslands Point) (Lalas & Perriman 2009), Waitaki River mouth (Crossland 2012; Crossland 2021).
Other roosting sites: Okahau Point (between Moeraki and Katiki Points) (Lalas & Perriman 2009), Wainono Lagoon, Seacliff, Long Beach, Aramoana, Boulder Beach, Papanui Beach, Allans Beach (Rawlence *et al.* 2014; Rawlence *et al.* 2016), Timaru harbour, Ashburton River mouth (Crossland 2021)

Timing

Population size estimates will be most accurate when as many of the breeding birds as possible are attending nests. This will be at the start of the breeding season, when the majority of pairs have finished lay and few nest failures have yet occurred. This is typically at the peak of the egg laying curve, termed 'peak lay', rather than at the end of the laying period when all breeding pairs have finished laying, because for many seabirds early nest failures (up to the end of the laying period) can be substantial. In the absence of detailed nesting chronology and daily nest failure rates for Otago shags, peak lay strikes a balance between underestimating breeding numbers because birds yet to lay are missed, and underestimating them because nests that had already failed are missed.

For Otago shags, egg laying starts in September (McKinlay 2013) although this can vary between years (Lalas 1983). Breeding timing this year was confirmed by observations from albatross rangers at Pukekura/Taiaroa Head (no eggs 30 Aug, first eggs 1 Sept; T. Thompson pers. comm. Sept 2021). Assuming that timing at Pukekura is similar to that at other colonies (but see *Discussion*), aerial photography was therefore targeted to 9–15 Sept around the assumed peak laying period.

Aerial photographic surveys

Images were taken with the high-quality Hasselblad camera (20MP 1" sensor) on a DJI Mavic 2 Pro drone at six sites. At Pukekura drone use was not permitted so photographs were taken from a vantage point near the colony using a Canon 7D MkII camera (20MP APS-C size sensor) with a 18–55mm lens (EFS f 3.5–5.6 IS STM).

Animal response trials showed that drones can be flown slowly as low as 20m over Otago and Foveaux shags without causing notable disturbance (Parker & Rexer-Huber 2021), but those data were collected outside the breeding season. For breeding-colony surveys in this study, we therefore started every overflight by first checking drone flight heights. To find the flight height producing minimal disturbance at that colony, the drone descended slowly during manual/unprogrammed flight (DJI Go4 interface software) while monitoring animal responses closely. To assess shag responses before, during and after drone flight, a dedicated observer with binoculars or spotting scope supported the drone pilot. We flew from as close to the colony as possible (nearest point on land to island/colony), to ensure the pilot and spotter had the best possible field of view to monitor animal responses.

Once we were confident that drone overflight at a given height could occur without notable disruption, we flew programmed grids to capture images over the whole island/colony. Grid flights were possible at five out of the six sites where drones could be flown. The exception was Gull Rocks, which is a tall, steep-sided rock stack requiring manual flight to get oblique images into the sides. Programmed grid flights (Pix4D Capture software) were set to take nadir images, directly overhead, with generous 80% front and 72% side overlap to ensure good coverage of the whole island. Careful monitoring of animal responses continued throughout grid flights to enable swift removal of the drone from the area if needed. If there were no obvious issues during the first grid flight, some islands were overflown again at a lower flight height.

All drone flights were conducted with permission from the local authority/landowner, and flight plans were deposited with AirShare before each deployment. For Sumpter Wharf overflight, we also notified the local aerodrome operator (Helicopters Otago, which services Oamaru Hospital) and the Otago Regional Council harbourmaster.

Nest-contents assessment

To determine the proportion of apparently nesting shags that were actually breeding (eggs in nest) at the time of surveys, we conducted ground-truthing assessment of nest contents on 9 September at Pukekura. Pukekura was the only colony that we could view closely enough to be able to record nest contents. There we also had known breeding stage, confirmed to be the second week of egg-lay (albatross rangers provided updates in the lead-up to the breeding season; see *Timing* above). The nesting status of every apparently-incubating shag that stood up, revealing its nest contents, was recorded by observers using binoculars. A 15-min sampling cut-off was applied to minimise disturbance, and the two observers involved focused on different parts of the colony to avoid duplication. Nests sampled were spread throughout the colony, not just at the periphery, so we avoid potential edge effects. An observer's field of view is illustrated in Fig. 1, which shows mainly AON that are were only included in nest contents assessment once they stood and revealed nest contents (nest circled, Fig. 1). (Note that nest-contents sampling being limited to just one colony at the very start of breeding has consequences for interpretation; see *Discussion*).

From a vantage point into the Pukekura colony, we also counted every apparently nesting shag (apparently on nest, AON) in the colony (scan counts), to complement photo counts from the vantage point photographs described above.

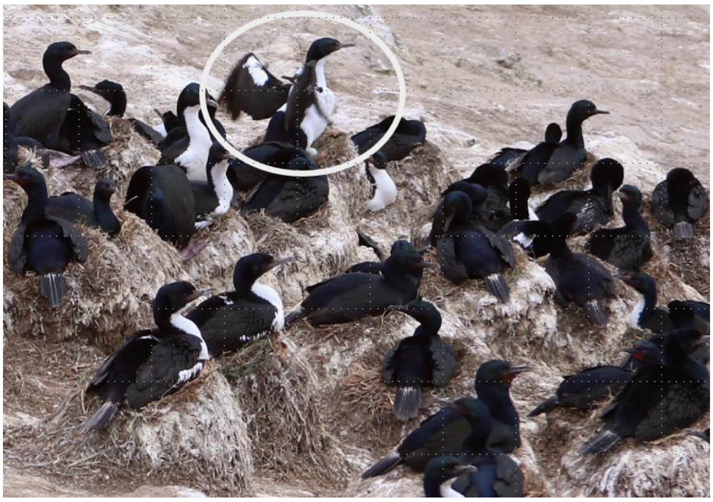

Figure 1. Otago shag nest-contents assessment of apparently occupied nests. Circled: bird that was apparently on nest (AON) that stood to reveal eggs, confirming nest contents

Population size estimates

Image analysis

Photographs were stitched into composites using the program ICE (Image Composite Editor, Microsoft) using default parameters, then projected to Transverse Mercator. Composite images were loaded into the wildlife counting application dotdotgoose (Ersts 2019) (Fig. 2). At each colony, shags were classed as

- apparently on nest (AON): one or two adults sitting horizontally on nest, thought to be incubating eggs;
- loafer: bird standing or sitting with no nest, or with visibly empty nest.

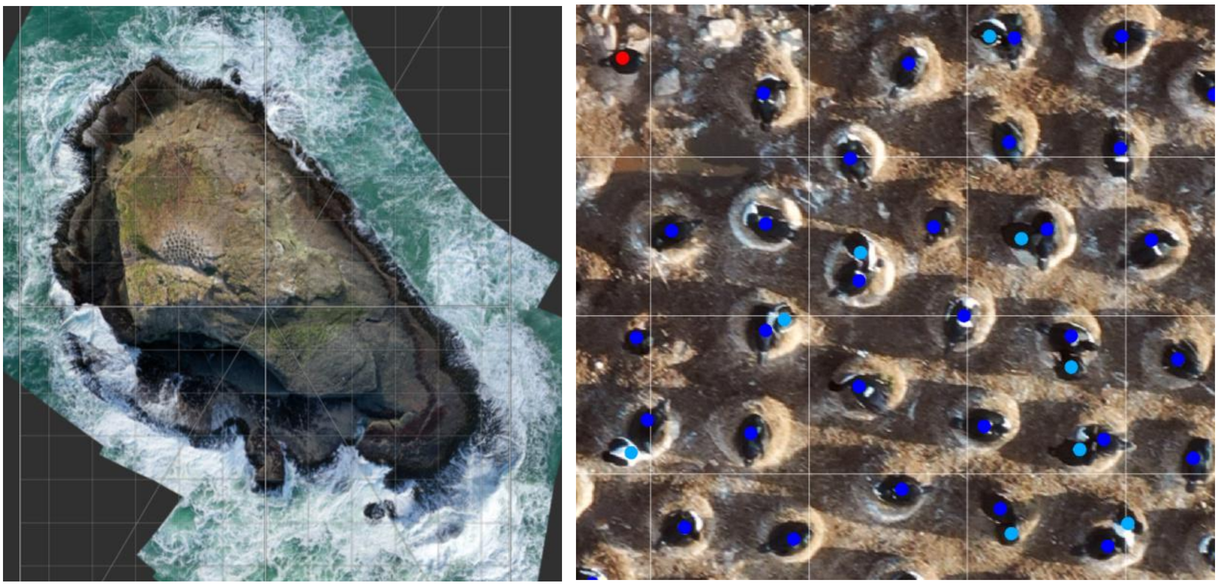

Figure 2. Otago shag image analysis. Left: process of stitching drone aerial photographs into a composite (Kinakina Isl). Right: Counts distinguished apparently on nest (AON, dark blue dots) from loafers not nesting (red dots). Light blue dots are beside-nest birds (Wharekakahu Isl)

Nests with two birds immediately beside each other (one apparently incubating and the other sitting or standing) were counted as a single occupied nest. That is, the beside-nest bird was identified but not included as a loafer (light blue dots, Fig. 2). The total of all birds present is also provided (AON, beside-nest, and loafer) for each colony/island. Poor stitching at several sites (Okaihe/Green Isl, Wharekakahu) affected the geographic accuracy of whole-island images. However, colony areas were unaffected by stitching issues (Wharekakahu), and at Okaihe the colony is visible in its entirety in several of the original drone photographs, so colony count accuracy will not have been affected.

Observer differences in photo interpretation is a known challenge for aerial photographic assessment (Schuckard *et al.* 2018), so all images were counted by the same person for consistency. Counts will be imperfect for a range of reasons (birds hidden from view in aerial image, some images more blurred than others). To reflect this and get a measure of precision (repeatability), images of each site were counted twice with a substantial interval (1–2 months) between first count and recount, giving two raw counts of AON at each site.

Data from independent counts conducted in Oct–Nov 2021 following existing methods (Lalas & Perriman 2009) were shared by Chris Lalas. Vantage-point counts were either shore-based (Sumpter Wharf, Maukiekie, Wharekakahu, Green Isl) or boat-based (Pukekura/Taiaroa, Heyward Point, Puddingstone Rock). Kinakina Isl and the Nuggets were counted from fixed-wing aircraft. Most sites were counted in the first week of October, but the latter four sites were visited as part of other work so were counted late (mid-to-late November) (C. Lalas pers. comm. June 2022).

Population size estimate

Estimates of the number of breeding pairs at each island/site were calculated from the two raw counts of apparently nesting Otago shags multiplied by a ground-truthing correction obtained via ground counts (AON * nest-contents correction of 0.74).

For each island/site, two estimates of the number of breeding pairs provide a breeding population size range and a best estimate (mean of the two estimates) (e.g., Pfeifer *et al.* 2021). To these aerial photo-counts we add for completeness the most recent vantage counts of breeding pairs (C. Lalas unpubl. data June 2022) for three further sites: Heyward Point, Puddingstone Rock, the Nuggets. The vantage-point counts are not corrected for nest contents since the counts are of breeding pairs, and also because it would be inappropriate to apply an early-Sept contents assessment to counts conducted ~2 months later (Heyward Point, Puddingstone Rock) or a year earlier (the Nuggets).

The breeding population estimate for Otago shags is the sum of all island/site estimates (aerial photo-counts corrected for nest contents, plus vantage-count breeding pairs), giving an overall breeding population size estimate for Otago shags.

Results

Breeding site locations

The breeding range of Otago shags is from the Catlins to Oamaru in North Otago, with six current breeding colonies and one historic breeding colony (Fig. 3, Table 1).

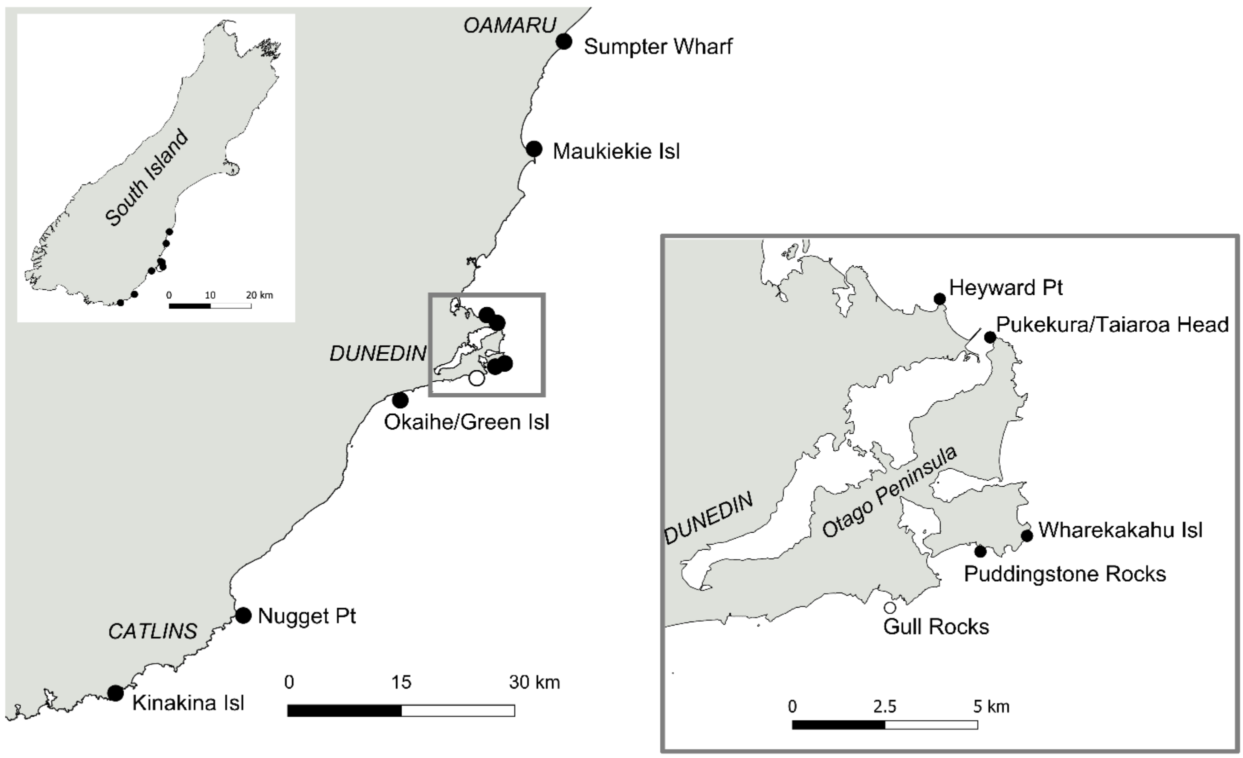

Figure 3. Distribution of Otago shag breeding colonies. Current breeding colonies (filled circle) are distinguished from historic breeding sites (open circle)

Shag survey photography

All colonies were photographed over the course of a week 9–15 September 2021, with drone flights being conducted 11–15 September in good flight conditions (dry, light winds or moderate winds easing, overcast).

After initial slow descent to check for animal responses, we started grid flights at 30–70m flight height. Flight height is measured from the launch point; taking island/site elevations into account, the drone was ~20–30m above colonies (Table 2). Animal response monitoring continued through grid flights. Breeding Otago shags did not respond visibly to grid flight at ~30m over the colony. At ~20m above colony, breeding shags showed no response, or looked more alert but did not move (one case). Although looking alert but remaining in place is clearly a reaction, we do not view this as an unacceptable disturbance (‘disturbance’ in nesting shags is widely considered to be when some birds walk or fly off the nest) (Nisbet 2000; Schuckard *et al.* 2018). Loafing Otago shags, roosting gulls and other shag species either did not react when the drone was 30m above, or moved around with a few taking flight (spotted shags, black-backed gulls). At sites where the drone flew 20m over the colony, loafing Otago shags and gulls either took flight or showed no response (Table 2).

Grid flights at 30–70m flight height were obtained at five of six active breeding colonies, giving images ~20–30m above colonies (Table 2). Manual flight at the seventh colony (historic breeding site, Gull Rocks) to check whether shags have returned to this site also had good flight conditions. Unfortunately, light rotor damage during landing partway through surveys went undetected, so subsequent images (from 13 Sept onwards) have blur that affected image quality. Nesting shags can still be distinguished from loafing shags in these lightly burred images, so counts were still possible, but with less confidence.

Table 2. Otago shag colony photographic survey September 2021.

		Grid flight m above			
Breeding colony	**Date**	**Launch**	**Colony** [a]	**Animal responses** [b]	**Image quality**
Sumpter Wharf	13/9/2021	30	30	No Otago shag reaction. <5% of spotted shags left; BBG flew toward drone	OK
Maukiekie Isl	13/9/2021	50	30	No shag or gull reaction	OK
		40	20	No gull or shag disturbance, including of loafing shags	OK
Pukekura/Taiaroa	9/9/2021	n/a [c]	n/a	None	good
Wharekakahu Isl	11/9/2021	60	20	Loafing shags and RBG rose, gulls followed drone	good
Gull Rocks	11/9/2021	mix [d]	20	RBG rose, wheeled, landed again. No fur seal response	good
Okaihe/Green Isl	15/9/2021	70	30	No shag response, BBG only around drone over water. No fur seal response	poor
Kinakina Isl	14/9/2021	50	30	No shag response. One BBG rose, flew toward drone	OK
		40	20	Shags looking more alert but did not move, 8–14 BBG rose	OK

[a] Flight height above colony calculated using estimated island elevations; [b] BBG is black-backed gull and RBG is red-billed gull; [c] DSLR photographs at Pukekura taken from vantage ~30m from colony on foot; [d] images at Gull Rocks taken at variable flight heights during manual flight

Breeding population estimate

To correct the replicate raw counts of apparently nesting Otago shags (AON) at each colony, we obtained a nest-contents correction from Pukekura at the very start of the breeding season. Ground counts defined the proportion of nests that contain eggs out of all AON nests where the contents could be checked. Ground-truthing on 9 September at Pukekura showed that 0.74 of Otago shag AON contained eggs at that time, based on 34 nests where the contents could be viewed over a 15-min period.

The estimated number of breeding pairs for each colony ranged from an estimated 32–33 breeding pairs at Kinakina Isl, to some 504 breeding pairs (best estimate; range 496–511) at Sumpter Wharf (Table 3). (Note some birds yet to lay may have been missed at this early stage in the breeding season, so these should be taken as minimum breeding numbers). There was no evidence of nesting on Gull Rocks, confirming that this remains a historic breeding site.

Table 3. Otago shag breeding colony census September-October 2021. All birds is the total shags present (birds loafing,or standing or roosting but not on nest; as well as birds on nest); AON is apparently on nest (nest contents unknown); Breeding pairs is AON corrected for the proportion on empty nests in September. A and B show figures from replicate counts of photomosaics.

	All birds		**AON pairs**			**Breeding pairs[c]**		
Aerial photo-counts	A	B	Best estimate	A	B	Best estimate	A	B
Sumpter Wharf	920	938	685	675	695	504	496	511
Maukiekie Isl	536	546	415	412	417	305	303	307
Pukekura/Taiaroa[a]	299	303	254	253	255	187	186	188
Wharekakahu Isl	257	263	106	105	107	78	77	79
Okaihe/Green Isl	153	164	122	120	124	90	88	91
Kinakina Isl	69	74	45	44	45	33	32	33
Subtotal (aerial)			*1626*	*1609*	*1643*	*1196*	*1183*	*1208*
Vantage counts[b]						Best estimate	min	max
Heyward Pt						20	10	20
Puddingstone						10	5	15
Nuggets						[77]	[77]	[89]
Subtotal (vantage)						*107*	*92*	*124*
TOTAL BREEDING PAIRS						**1303**	**1275**	**1332**

[a] Photo counts at Pukekura from stitched vantage-point DSLR photographs;
[b] Vantage-point counts from boat in Nov 2021, except the Nuggets [square brackets] where most recent count in Nov 2020 from fixed-wing aircraft (C. Lalas unpubl. data June 2022);
[c] Breeding pairs should be taken as the minimum breeding numbers, since some birds yet to lay in the second week of September will not have been included

The breeding colony at Pukekura could not be imaged by drone, so DSLR photographs of the colony from a ground vantage point were stitched and counted in the same way as aerial drone photographs. Photo counts at Pukekura (253–255 AON in stitched photographs) compared well with scan counts from the vantage point by two observers, with 257 AON (mean of three counts). The Pukekura vantage-count from boat gave a best estimate of 271 nests (see Appendix; C. Lalas unpubl. data June 2022), or 5% more than from the vantage on land. It is tempting to attribute this to more birds having laid between Sept and Oct counts, but we caution that the difference may simply be one of vantage perspective (from the on-land vantage birds were overlapping, making them harder to count accurately than from a more distant but perpendicular boat-based perspective).

Our aerial-photographic counts can be directly compared to those from methods used previously (in e.g., Lalas & Perriman 2009). At the five colonies counted using both methods—aerial photo Sept 2021 and vantage photo/scan Oct 2021—AON counts largely match vantage-point nest counts (C. Lalas unpubl. data June 2022; see Appendix Table A1). Because of that agreement we think it is reasonable to add to our overall breeding population estimate (Table 3) the nest counts from three further sites identified in the contributed data: Puddingstone, Heyward Pt and the Nuggets. These further sites together had 107 nests (Table 3, Appendix). While the Nuggets count was from 2020, not

2021, we believe it is important that the overall population size estimate include this population's breeding pairs.

The estimated breeding population of Otago shags is a minimum of 1275–1332 breeding pairs (aerial photo-counts corrected for nest contents, plus vantage-count breeding pairs), giving a best estimate of at least 1303 breeding pairs (Table 3).

Discussion

The Otago shag population, with an estimated 1,275–1,332 breeding pairs at the start of the 2021 breeding season, is similar to the ~1,150 nests when the whole population was last surveyed in 2007 (Lalas & Perriman 2009). The different survey methods involved—aerial nadir vs vantage-point—are comparable: five sites counted independently by Chris Lalas in early October 2021 matched our raw counts in aerial photos from September 2021. The Otago shag population peaked at around 1,900 nests in 1987, but then declined ~30% over the two decades to 2007 (Lalas & Perriman 2009). A 2021 breeding population of some 1,300 breeding pairs remains notably lower than at the population's peak in the late 1980s, but is still about double the number recorded in the mid-1970s (Lalas & Perriman 2009). We suggest that re-assessment of the population trend would be premature, given the 15-year interval since the last regular colony counts and the unknown population dynamics in that interval. For robust re-assessment of the current Otago shag population trend, the population size estimate should first be repeated.

By far the largest colony is at Sumpter Wharf in Oamaru, which currently supports about 42% of the breeding population. Breeding only started at the wharf in 2014 (Lalas, in Crossland 2021), and the colony has since grown each year. The initial rapid colony growth at Sumpter Wharf might be stabilising, since our raw counts for 2021 are similar to counts in 2020 (C. Lalas unpubl. data 2022). It is not clear where these shags were nesting before they came to the wharf. Otago shags abandoned a historic breeding site at Gull Rocks in the early 1980s, but that colony was very small (20 nests at last count in 1983) (Lalas & Perriman 2009). We note that all colonies extant in 2007 had more shags than they do now in 2021 (Lalas & Perriman 2009). It seems plausible that the new Sumpter Wharf colony could have drawn from all other colonies to some extent. This Otago shag breeding colony on Sumpter Wharf continues the general northward expansion of breeding birds noted in the mid-1980s (Lalas 1983), with southward range expansion limited to a small number of breeding birds moving to Kinakina Isl in the early 1990s (Lalas & Perriman 2009).

For a whole-species population size estimate, survey timing in this study was close to ideal. Colonies were all surveyed in a short period of time right at the start of the breeding season (second week of September). This means we do not need to make assumptions about nest-failure error, since few nests would yet have had a chance to fail. However, early in the breeding season we may miss some shags yet to lay, especially if some colonies start breeding later than at Pukekura (the only site where we could get advance information on breeding stage). Although shags can have large differences in breeding timing between colonies (e.g., king shag; Bell *et al.* 2022), breeding activity at Otago shag colonies seemed closely aligned. In aerial photographs we looked for—and failed to find—evidence of earlier or later breeding start at each colony (well-developed but empty nests indicating earlier breed start, or nests being built indicating later breed start). However, Kinakina Isl shags appear to start breeding ~1 mo later than at the Otago shag colonies further north (C. Lalas pers. comm. June 2022), so we likely photographed that colony too early and therefore underestimated numbers breeding there. Otago shag breeding timing sometimes also differs between years (Lalas 1983). To account for between-site and between-year differences, colonies would ideally be monitored until nest numbers stabilise (to avoid missing any birds that have yet to lay, but also detect early failures) and only then conduct the count. However, this type of intensive pre-count monitoring may not be feasible at many sites. A suggested compromise is to visit colonies on one or more occasions before census work starts, to check breeding status at that site and minimise assumptions about timing and stage. Breeding status checks could involve using binoculars or spotting scope from a vantage point, or brief drone overflight at distant sites.

Nest contents inspection to test the assumption that birds on nests are actively breeding (and quantify the occupancy error) was also fairly optimal in terms of timing, taking place around the same time as photographic survey. Of nests where the bird appeared to be incubating, the nest contents could be confirmed for a total of 34 nests (13% of the colony), without disruption. Just over a quarter (0.26) of apparently nesting shags were sitting on empty nests, not breeding. This is not unexpected: when a small group of occupied nests (on average 17 nests) was monitored at Pukekura, on average 0.1—but up to 0.25—were actually birds sitting on empty nests (Lalas & Perriman 2009). The nest contents correction used here could be improved: occupancy error is ideally assessed at all sites, or at a representative sample of sites (not just the single site that could be visited here). This requires that observers are close enough the colony to view nest contents by binoculars. For future work, we suggest that this could be combined with drone overflight if, for example, the drone is flown from a boat that approaches an island closely enough for nest-contents checks. As discussed earlier, an important point about nest contents assessment early in the breeding season is that some of the birds on empty nests may simply not have laid yet. In the absence of good data from regular nest checks in monitoring colonies, the proportion yet to lay at a given date (and also the daily nest survival rates) remain unknown. We think it is reasonable to apply a nest contents correction to counts conducted at that same point in time, since that way we get a more accurate estimate of the size of the nesting population *at that point in time*. Importantly, though, that more-accurate corrected estimate—for the Otago shag population in early September—necessarily remains a minimum breeding population estimate, since more birds may yet lay.

Detection errors, or the probability of missing a breeding bird that is in fact present, acknowledge that counts will be imperfect for a range of reasons (Chilvers *et al.* 2015; Wolfaardt & Phillips 2020; Pfeifer *et al.* 2021). Here we expect some birds could have been hidden from view in an aerial image (*visual obstruction bias*, see sidebar p. 3), and some images were more blurred than others (*detection error*). However, detectability can be difficult to quantify. Ideally comprehensive ground-counts are conducted to complement aerial photographs (e.g., Chilvers *et al.* 2015; Pfeifer *et al.* 2021), allowing the detectability of a known population to be calculated. Comprehensive ground counts should account for visual obstruction bias (detecting birds obscured by overhangs or trees), although sometimes topography may make nests less visible from the ground thanthey are by air (Chilvers *et al.* 2015; Oosthuizen *et al.* 2020). However, ground counts for detectability calculation were not possible here, since the only site that we could access for ground counts could not be overflown, so we cannot quantify the detectability of shags in aerial photographic counts.

To get a measure of the precision (repeatability) of the counts, we took a multiple-counts approach to detection errors, with the same observer re-counting the same image after an interval long enough (1–2 months) to ensure fresh eyes. Multiple-count approaches allow a given site's nest count to be provided as a range, which is expected to contain the true breeding population. A range quantifies the precision/repeatability of the estimate, and we argue that this is preferable to a single count value which may or may not be accurate. Repeat counts to measure variability can also involve several independent counters, although this might simply address observer bias (Chilvers *et al.* 2015; Schuckard *et al.* 2018; Wolfaardt & Phillips 2020; Pfeifer *et al.* 2021). Another approach might be taking multiple colony images on the same day, or to repeat surveys on different days (Chilvers *et al.* 2015), or to repeat surveys until nest numbers stabilise (C. Lalas pers. comm.). Such multi-count approaches would iron out detection errors potentially introduced by light and shading, or by timing surveys before all pairs have yet laid, or by the presence of other non-nesting animals.

Recommendations

Repeat the population estimate to allow robust re-assessment of the current trend status in the Otago shag breeding population size.

For monitoring, we recommend planning for an Otago shag population size estimate to be repeated at regular intervals over time to monitor the population's trend.

To improve the accuracy of estimates, and reduce potential biases and reliance on assumptions, we recommend that:

- Photographic timing should be at the very start of the breeding season, when most eggs have been laid and before many have yet had a chance to fail.
  - Where possible, check colonies for status leading up to the breeding season, in case breeding is asynchronous at some sites.
  - If surveys cannot be timed to the start of breeding, footage from colony cameras should be assessed for potential nest survival data. Daily survival rates could be used to correct the number of nests counted partway through the breeding season (when a colony's lay dates are known), giving a more accurate estimate of the actual number of breeding pairs.
- Occupancy rate: Nest contents should be recorded at any colony where close enough to view nest contents with binoculars, to quantify occupancy error at that point in time
- Detection rate: ground counts should conducted at at least one of the aerial photography sites, allowing detection error to be assessed.

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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.

ACAP. 2011. Species assessments: White-capped Albatross *Thalassarche steadi*. Agreement on the Conservation of Albatrosses and Petrels. Available at: http://www.acap.aq.

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.

Bell, M.; Frost, P.; Schuckard, R. 2022. Breeding population assessment of kawau pāteketeke/New Zealand King Shag in the Marlborough Sounds: 2021 breeding season. Unpublished client report CSP BCBC2020-05 for Marine Species Team, Biodiversity Group. Department of Conservation.

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.

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.

Crossland, A.C. 2021. Northward expansion of the non-breeding range of Otago shag (*Leucocarbo chalconotus*) along the Canterbury coast towards Banks Peninsula, eastern South Island, New Zealand. *Notornis 68*: 166–169.

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.

Ersts, P.J. 2019. DotDotGoose (version 1.2). American Museum of Natural History, Center for Biodiversity and Conservation. Available from https://biodiversityinformatics.amnh.org/open_source/dotdotgoose.

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

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.

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.

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

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.

McKinlay, B. 2013. Stewart Island shag. *In* Miskelly, C.M., *ed. New Zealand Birds Online. www.nzbirdsonline.org.nz*.

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.

Nisbet, I.C.T. 2000. Disturbance, habituation, and management of waterbird colonies. *Waterbirds 23*: 312–332.

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. 2021. *Foveaux and Otago shag population census methods: drone and camera trials. 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.; Elliott, G.; Hitchmough, R.; McArthur, N.; Makan, T.; Miskelly, C.; O'Donnell, C.F.J.; Sagar, P.M.; Scofield, R.P.; Michel, P. 2021. Conservation status of birds in Aotearoa New Zealand, 2021. Wellington, Department of Conservation. Available at: https://www.doc.govt.nz/globalassets/documents/science-and-technical/nztcs36entire.pdf.

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.

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.

Wolfaardt, A.; Phillips, R. 2020. Guideline census methodologies for albatrosses and petrels. Agreement on the Conservation of Albatrosses and Petrels. Available from https://acap.aq/en/resources/acap-conservation-guidelines.

Appendix

In the 2021 Otago shag breeding season, vantage-point breeding pair counts matched independent aerial photo-counts (raw counts of apparently on nest, AON) (Table A1), despite some differences in timing (aerial photos taken Sept, while vantage counts conducted Oct–Nov).

At the five colonies that were counted using both methods in 2021, the best estimates summed differed by 1% (total best estimates 1562 pairs vantage and 1582 AON aerial photo). At each of those five sites, counts differed by <1% (Sumpter) up to 12% (Maukiekie). This is partly because of the quality of the vantage view: the vantage at Sumpter is excellent with full view into the colony, while at Maukiekie the vantage point perspective means birds overlap and counts are more difficult (C. Lalas pers. comm. June 2022).

Table A1. Otago shag counts in 2020 and 2021, comparing different methods in 2021 (vantage-counts cf aerial photocounts). Vantage counts were conducted Oct–Nov (vantage 2020, 2021) and are the best estimate of breeding pairs. Aerial photo-counts were conducted Sept 2021 (aerial photo 2021) and are raw counts of AON (apparently on nest) to reflect that in aerial photos nest contents are unknown. Low count and high count are from replicate analysis of photomosaics.

	vantage 2020†			**vantage 2021†**			**aerial photo 2021**		
	best estimate	min	max	**best estimate**	min	max	**best estimate**	low count	high count
Sumpter Wharf	**737**	737	750	**683**	673	732	**685**	675	695
Maukiekie Isl	**392**	392	439	**370**	306	408	**415**	412	417
Heyward Point	**5**	0	5	**20**	10	20			
Pukekura/Taiaroa Hd	**302**	302	307	**271**	255	271	**254**	253	255
Puddingstone Rock	**5**			**10**	5	15			
Wharekakahu Isl	**65**	61	88	**114**	114	128	**106**	105	107
Okaihe/Green Isl	**134**	134	149	**124**	124	133	**122**	120	124
the Nuggets‡	**77**	77	89						
Kinakina Isl‡	**56**	54	58				**44**	44	45

† Unpublished data shared by Chris Lalas (June 2022). Vantage counts conducted from shore in October (Sumpter, Maukiekie, Wharekakahu, Okaihe) or from boat in November (Heyward Pt, Pukekura, Puddingstone).
‡ Kinakina and the Nuggets counted in photos from fixed-wing aircraft flown 20 November 2020 as part of other work