PARKER CONSERVATION

Foveaux shag breeding population size

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Executive summary

Endemic to Southern New Zealand, Foveaux shag *Leucocarbo stewarti* are classified as Threatened-Vulnerable, 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 Foveaux shags. Eight current breeding sites were identified, and three sites that have stopped being used since the last breeding record.

Comprehensive surveys were conducted in targeted visits of current breeding sites. Aerial photographs for Foveaux shag counts were taken using a drone where appropriate (11 sites) or aerial DSLR photographs where a drone could not be flown (two sites). Building on animal response trials in previous work with shag species, 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 three days of each other, at the start of the breeding season in October 2022.

Photographs were counted for the number of Foveaux shags on nests. Since breeding starts earlier than October at some sites (breeding asynchronous), we expect to have missed some nesting attempts that failed before the survey, so figures should be understood as minimum breeding population estimates.

Results show breeding colonies ranged in size from two small colonies at Raratoka, with ~9 nests each, to the much larger colony at Fife Rock comprising some 275 breeding pairs (best estimate; range 273–277). The Foveaux shag population estimate—at least 1007 (1002–1012) breeding pairs at the start of the 2022 breeding season—is roughly similar to the last whole-population count in 2011. However, for assessment of population trends to be robust the population size estimate should be repeated.

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Contents

Introduction

Endemic to southern New Zealand coastal waters and harbours, Foveaux shag *Leucocarbo stewartia* and Otago shag *Leucocarbo chalconotus* are classified as 'Threatened – vulnerable' and 'Threatened – increasing' (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, most effort has concentrated on the northern part of the range. Comprehensive assessment of breeding sites for Foveaux shags has only taken place twice, in 1980/81 and in 2011 (Lalas 1983, C. Lalas unpubl. data 2015).

Both Otago and Foveaux shags are susceptible to set-net captures and breeding colony disturbance (Watt 1975; Abraham & Thompson 2015; McKinlay & Rawlence 2022). 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 Foveaux shag breeding colonies. Breeding population trends remain unknown making it difficult to assess the risk of potential impacts and inform conservation management.

Most shag colonies are located in terrain which is 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). In New Zealand, aerial counts of shags have largely used fixed-wing aircraft, but drones have been used for counts of king shag *Leucocarbo carunculatus* and Otago shags (Bell *et al.* 2022; Parker & Rexer-Huber 2022). Drones have also been explored for survey of Chatham and Pitt Island shags (*Leucocarbo onslowi* and *Stictocarbo featherstoni*) (M. Bell pers. comm. 2021). 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 via this survey method, particularly in dense multi-species colonies (Irigoin-Lovera *et al.* 2019; Rexer-Huber & Parker 2020). Preliminary animal response trials at Foveaux and Otago shag colonies in 2021 outside the breeding season, showed that drones can be flown slowly as low as 20m over the shags without causing notable disturbance (e.g. changes in incubating posture, leaving the nest pedestal), and breeding Otago shags did not react to overflight as low as 20–30m (Parker & Rexer-Huber 2021; Parker & Rexer-Huber 2022). Because animal responsiveness can vary, however, drone overflights of breeding Foveaux shags must first identify the flight height that causes minimal disturbance.

The current project aim was to conduct a comprehensive Foveaux shag breeding population estimate to build on the 2021 study of Otago shag populations under POP2021-07. We detail photographic survey of all Foveaux shag breeding colonies, using drone or DSLR camera where appropriate. The

minimum number of breeding pairs at each colony is estimated from counts in images, which are summed for the estimated size of the Foveaux shag breeding population.

Methods

Breeding site locations

A comprehensive breeding population estimate of Foveaux 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). Foveaux shag breeding sites identified in Parker & Rexer-Huber (2021) were checked for any changes or new information about potential new locations. Current resources (published and grey literature, eBird, iNaturalist) were revisited again for updates, and consultation with knowledgeable experts continued.

In the 2022 breeding season we identified eight current breeding sites for Foveaux shags, three sites where breeding ceased recently (since 2011), and seven historic breeding sites where breeding ceased before 2011 (Table 1, Fig. 1). Recent and historic sites are included in surveys here to confirm that Foveaux shags still no longer breed there.

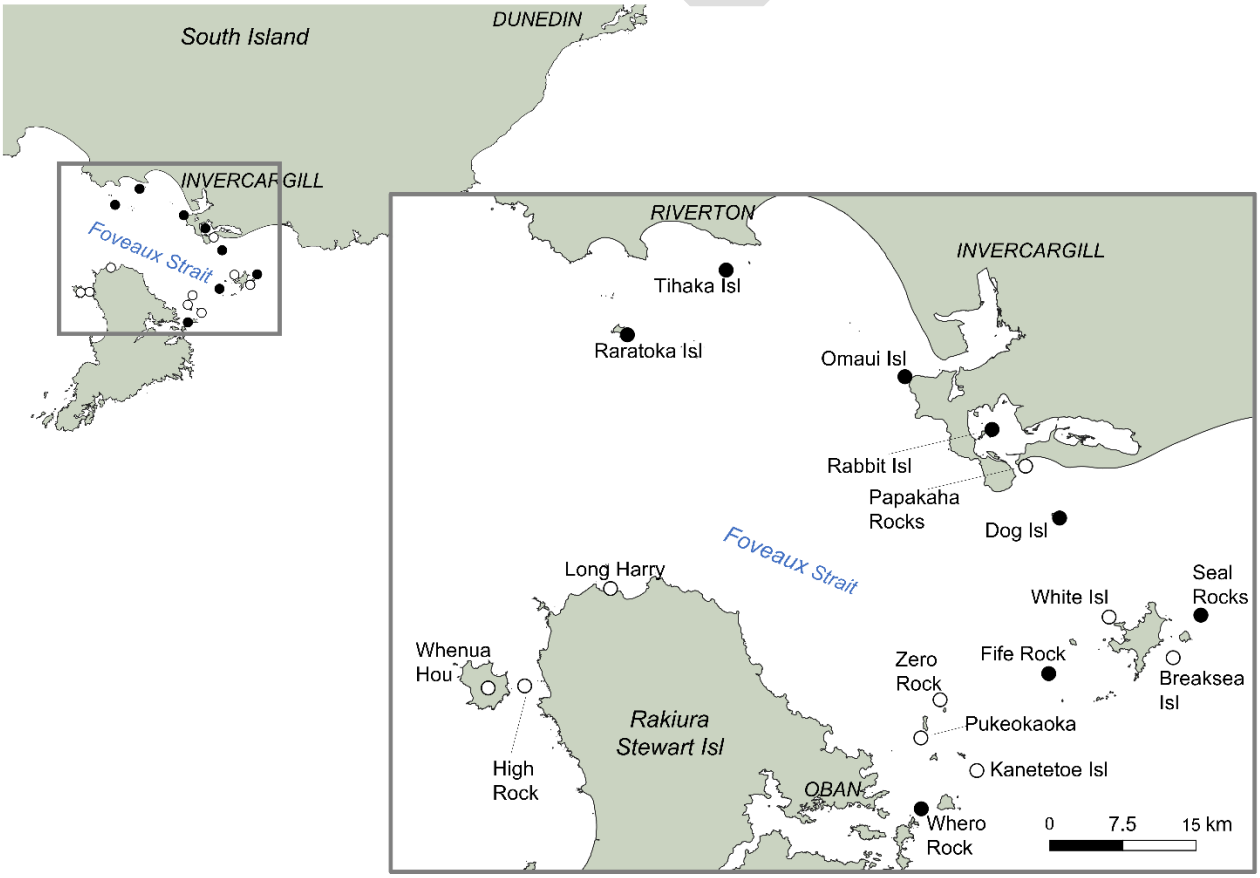

Figure 1. Distribution of Foveaux shag breeding colonies. Current breeding colonies (filled circle) are distinguished from historic breeding sites (open circle)

Table 1. Breeding sites used by Foveaux shags in 2022, and the abandoned breeding locations where breeding ceased before 2022.

Breeding site	Site details †	Manager †	Year nesting started	Last year nesting recorded	Max no. nests
Raratoka / Centre Isl	SSE of Oraka Pt (10.5km)	Ōraka Aparima Rūnaka	<1954	present	>600 in 1955 [a]
Rabbit Isl islet (Bird Isl locally)	Bluff Harbour, NE of Greenpoint Reserve (1.8km)	Invercargill City Council	1980-92 [b,c]	present	96 in 2022
Tihaka / Pig Isl	S of Taramea beaches (2.8km)	DOC Murihiku	~1998 [e]	present	139 in 2022
Omaui Isl	New River mouth	Invercargill City Council	1981-91 [b,d]	present	65 in 1991 [d]
Dog Isl	SE of Bluff (5.6km)	Maritime NZ	< 2001 [h]	present	84 in 2022
Whero Rock	In Carter Passage, betw the Neck and Bench Isl	DOC Rakiura	~1950 [a]	present	400 in 1980
Ruapuke: Fife Rock	W of Ruapuke (7km)	Awarua Rūnanga	<1980 [b]	present	334 in 2011
Ruapuke: Seal Rocks	E of Ruapuke (3.6km)	Awarua Rūnanga	<1979 [b]	present	117 in 2022
Rakiura: Long Harry	N Rakiura	DOC Murihiku	<2016	2016	~20 in 2016
Papakaha Rocks / Tiwai Rocks	S of Tiwai Pt (225m)	DOC Murihiku	~1953 [h]	2011 [b]	90 in 1955 [a]
High Rock	E of Whenua Hou (1.75km)	DOC Rakiura	<1980 [b]	2011	77 in 1980 [b]
Whenua Hou: islet off Sealer's Bay	Sealer's Bay	DOC Murihiku	<1934 [h]	~1970	64 in 1966
Whenua Hou: the Knobbies	NW corner Whenua Hou	DOC Murihiku	<1966 [h]	< 1971	colony in 1966
Ruapuke: Breaksea Islands	SE of Ruapuke	Awarua Rūnanga	unknown ~1980?	1980	5 in 1980 [b]
Ruapuke: White Isl (Shit Rock locally)	NW of Ruapuke	Awarua Rūnanga	unknown ~1970s?	<1979 ‡	20 <1979
Kanetetoe Isl	Outer Rakiura SE of Bunker Islets/Haumaiteraki	Rakiura Titi Islands Admin Body	<1911 [i]	1960s [a]	400-500 in 1911 [a]
Zero Rock	Titi Islands northmost	DOC Murihiku	Early 1960s?	1968	19 in 1968
Islet off Pukeokaoka / Jacky Lee Isl	Titi Islands	Rakiura Titi Islands Admin Body	1950s [h]	1955	22 in 1955

Important roost site: Te Waewae Bay, Muttonbird Isl, Ruapuke Isl, Shag Rock, Port Pegasus [f,g]; Tamihau Isl (Paterson Inlet, off Ulva) [b,h] was year-round roost site but is no longer used (Phred Dobbins pers. comm.).
Other roosting sites: islet off Easy Harbour, islet off south Red Head Point [b]; Pipi Rock (Paterson Inlet, between Ulva and the Neck), rock at the Neck (head of Paterson Inlet), between Horseshoe Bay and the Mucks (Matt Atkins pers.comm); Hay Stacks, Flat Rock (Ian Wilson pers. comm.)
† Site access and approvals are described in Appendix A
‡ White Island* ≈20 old nest mounds but no breeding in 1980 [b]
References: [a] (Watt 1975) [b] (Lalas unpubl. data 2015) [c] (W. Cooper in O'Donnell & West 1995) [d] (Cooper & McClelland 1992) [e] (W. Cooper in O'Donnell 2001) [f] (Rawlence *et al.* 2014) [g] (Rawlence *et al.* 2016) [h] (DOC database 1911-2005, extract provided by Ros Cole, DOC Murihiku) [i] (Guthrie-Smith 1914)

Some of the 15 breeding sites identified in the desktop exercise in 2021 (Parker & Rexer-Huber 2021) have stopped being used by Foveaux shags since the last record of breeding, but the list also changed as new information came to light. In summary: Dog Island and Seal Rocks (Ruapuke) were added (C. Lalas unpubl. data 2015, DOC database). In original sources, Papakaha Rocks and Tiwai Rocks refer to the same site so are merged here. Several sites that were abandoned before 2011 (Kanetetoe, Breaksea, Jacky Lee and Zero; Lalas unpubl. data 2015) were moved to the ex-breeding site category. Following discussion with local experts, two sites off Whenua Hou (Knobbies and islet off Sealer's Bay) where Foveaux shags no longer breed were moved to the ex-site class, and two recorded breeding sites are incorrect (the Snuggery on Ulva Isl, and Big Rock in Halfmoon Bay) so removed entirely. Several reliable roost sites were added (Matt Atkins, Phred Dobbins, Ty Jenkinson, Ricky Topi, Ian Wilson, pers. comm. 2022). Finally, two records that were understood as indicating breeding (fledglings present) in fact just referred to roosting birds in sub-adult plumage so have not

been included as breeding sites (Omaui Beach, eBird record Dec 2013, The Rocks at Taramea / Howell's Pt, eBird record Dec 2019).

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. The timing of surveys 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 Foveaux shags, egg laying starts in September (McKinlay & Rawlence 2022) but is not very synchronous between sites, varying more than for Otago shags (Lalas 1983). Ideally colonies are each visited at the start of breeding at that site, but colony-specific breeding timing data are not available so the timing of best fit across all colonies is sought. Wildlife cameras deployed to check breeding timing during the pilot study in 2021 recorded images at a colony that moved out of view for nesting, so unfortunately no timing or nest contents data were acquired. Considering the breeding stage documented in a range of resources (Lalas 1983; Cooper 1991; DOC database 1911-2005; Lalas unpubl. data 2015; records in ebird), most colonies must start egg lay in early October, with a few colonies laying early in September. Surveys in September would therefore be too early, just recording nest building at most colonies, while October surveys would already see chicks at early colonies but egg-laying at most others. The timing of previous work is also relevant, for comparability. The last surveys were conducted 9 October 2011 (Lalas unpubl. data 2015).

Surveys of all Foveaux shag breeding sites were therefore targeted to the week of 9 October, around the assumed end-of-lay timing at most colonies and during chick rearing for early colonies, and for best comparability with the most recent survey. The first window where conditions were suitable (sea state and flying conditions) was 12–14 October.

Surveys

Approval for site visit and/or overflight are detailed in Appendix A, along with relevant notes about access (method, landings, conditions required). Sites were first circumnavigated by boat or on foot (Fig. 2) to identify whether colonies were present and, if so, where on the site since colonies move over time. At sites with areas not visible from our ground/sea-level survey, we used a drone to complete survey coverage photographically (DJI Mavic 2 Pro, Hasselblad camera with 20MP 1" sensor).

At sites where landing was possible and permitted (Dog Island, Tihaka, Omaui), the drone was launched from the island. At sites within 2km of an accessible mainland point (Papakaha Rocks, Rabbit Isl) the drone was flown from the nearest point (Appendix A). At Raratoka, Fife Rock, Seal Rocks, the drone was flown from a boat (MV *Hananui*) (Fig. 2).

The breeding colony at High Rocks and ex-colonies around Whenua Hou (the Knobbies, islet off Sealer's Bay) could not be inspected by drone, so observers with binoculars inspected the sites for shags from helicopter flying at low altitude. During that helicopter survey, the entire Whenua Hou coastline was overflown to confirm that Foveaux shags have not started new colonies along the coast (Fig. 2). DSLR photographs were taken where needed for later check and confirmation (Canon 7D MkII camera, 20MP APS-C size sensor, lens 18–55mm EFS f 3.5–5.6 IS STM).

Three further sites where Foveaux shags have nested in the past (Long Harry, islet off Pukeokaoka Isl and Zero Rock) were checked as part of other work in October 2022 (P. Dobbins, R. Cole pers. comm. 2022).

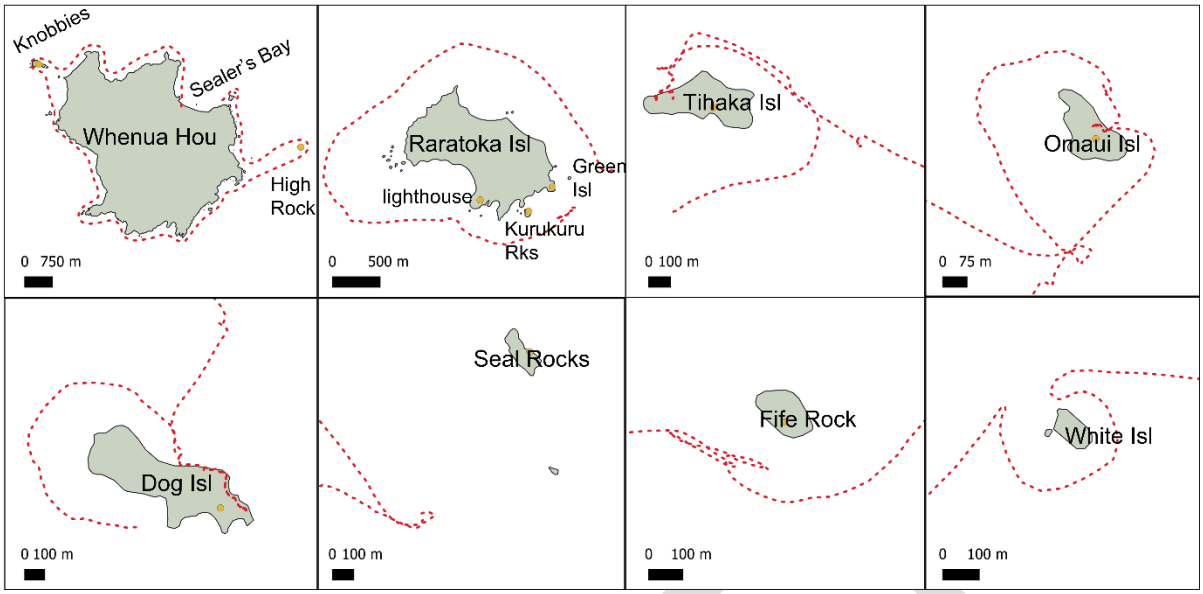

Figure 2. Survey for Foveaux shag breeding colonies. Tracks (dashed red line) show survey route by helicopter (top left) or boat and on foot (all other sites).

Aerial photography

Animal response trials showed that drones can be flown slowly as low as 20m over Otago shags without causing notable disturbance in both non-breeding and breeding seasons (Parker & Rexer-Huber 2021; Parker & Rexer-Huber 2022), but comparable Foveaux shag data are only available 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 was lowered slowly from 50m in 10m intervals (to a minimum height of 20m) 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, or nearest point a boat could safely approach the shoreline), to ensure the pilot and spotter had the best possible field of view to monitor animal responses.

Once we were confident that drone overflight could occur without notable disruption at a given height, we focused on colony photographs at that height. Colonies were mostly overflown directly overhead to take nadir images, but at steep-sided sites (Green Isl and Kurukuru Rocks off Raratoka) oblique images into the sides were needed. Colonies were not large enough to require programmed grid flights. Careful monitoring of animal responses continued throughout grid and manual flights to enable swift removal of the drone from the area if needed.

Population size estimates

Images were inspected in the wildlife counting application dotdotgoose (Ersts 2019) (Fig. 3). At each colony, shags were classed as:

- Apparent nest (AN): one or two adults sitting on nest, apparently incubating or brooding;
- Loafer: bird standing or sitting with no nest, or with visibly empty nest.

Aerial photographs were also inspected for evidence of breeding stage (nests still being built, eggs visible, or chicks visible alone on the nest or being guarded) and nest failure (recently active empty

nests had dark centres and were easily differentiated from unused nests that were a uniform white or pale brown, following Lalas unpubl. 2015) (Fig. 3).

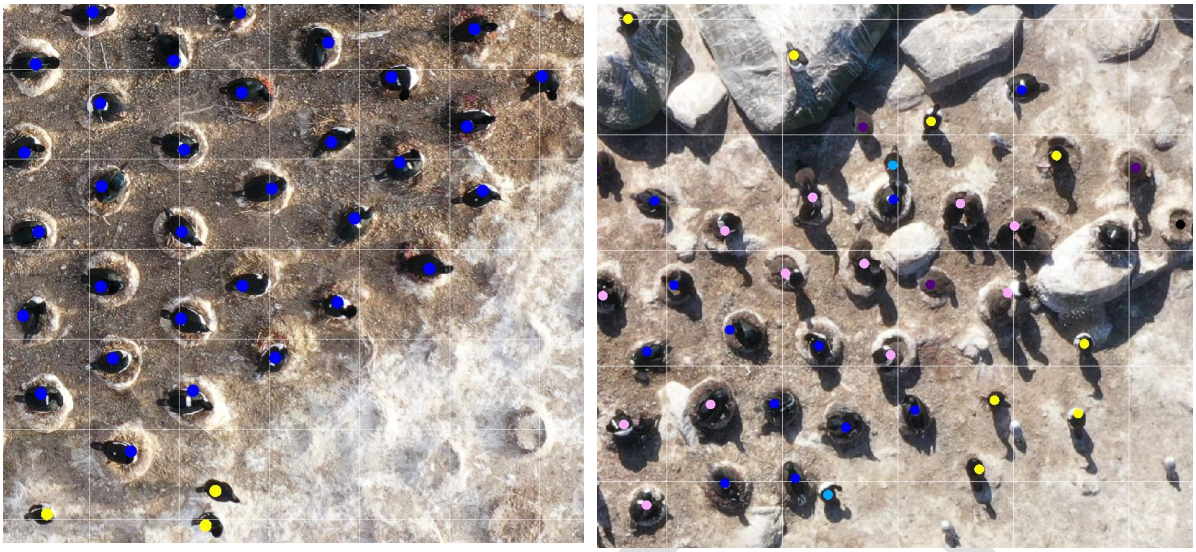

Figure 3. Foveaux shag image counting distinguished apparently on nest (AN, blue dots) from loafers not nesting (yellow dots). When chicks were visible, chicks alone on the nest (purple) were distinguished from chicks with a parent also on nest (pink). Images from Whero Isl (left) and Seal Rocks (right).

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, giving two raw counts of AN at each site. For each island/site, two estimates of the number of nests provide a range and a best estimate (mean of the two estimates) (e.g., Pfeifer *et al.* 2021).

Ideally, nest-content inspection is conducted to correct the number of AN birds in photos, but suitable data could not be obtained (see Discussion) so we do not attempt to correct numbers of AN shags for nest contents. Instead, we report simple nest counts, which allows direct comparison with the simple nest counts reported from the last survey (Lalas unpubl. data 2015). The breeding population estimate for Foveaux shags is therefore the sum of all island/site nest counts, giving an overall estimated Foveaux shag breeding population size at survey in October 2022.

Results

Shag survey photography

All colonies were photographed 12–14 October 2022, with aerial flights (drone and helicopter) conducted in good flight conditions (dry, light winds or moderate winds easing, and minimal swell for boat-based components).

Table 2. Foveaux shag colony photographic survey October 2022.

Breeding site	Colony	Date	Flight m above colony	Animal responses [a]	Image quality	Status [b]
Raratoka / Centre Isl	Raratoka/Centre Isl: notch	13/10/2022	40	No animal reactions	OK	C
	Raratoka/Centre Isl: peninsula	13/10/2022	60	None	poor	C
	Raratoka: Kuru-kuru Rocks	13/10/2022	60	None	poor	C
	Raratoka: Green Isl	13/10/2022	60	None	poor	C
Papakaha Rocks / Tiwai Rocks	Papakaha Rocks	12/10/2022	30	No response from shags. Paradise duck and 2 RBG left on first approach by drone	good	H
Rabbit Isl	Rabbit Isl: peninsula	12/10/2022	25	No response from shags. At 25m BBG started rising but no shag response	good	C
	Rabbit Isl: islet	12/10/2022	25	No animal reactions	good	C
Tihaka / Pig Isl	Tihaka / Pig Isl	12/10/2022	28	Drone: At 50m four loafing shags started walking - settle once drone unmoving hover. No further reactions at 40m or 30m. Person: crawling to 25m shags alert; at 25m standing most shags started walking. Left quickly before shags flight. Lots BBG nesting; no response to drone; but response to people landing on beach (rose en mass and calling before settling quickly).	good	C
Omaui Isl	Omaui Isl	13/10/2022	30	No shag reaction. Spoonbills reacted to people not drone (took off on people-arrival then landed among shags; no further response during drone flight).	good	C
Dog Isl	Dog Isl	13/10/2022	25	No reaction until 30m. At 25m loafing shags looking alert but not reaction from nesters. Brief response from gulls at takeoff then nothing more.	good	C
Whero Rock	Whero Rock	14/10/2022	20	No animal reactions	good	C
Kanetetoe Isl	Kanetetoe Isl	14/10/2022	—	To boat: No response from loafing shag	OK [c]	H
Ruapuke: Fife Rock	Ruapuke: Fife Rock	14/10/2022	30	No shag reactions. Gulls rose on drone launch but settled	good	C
Ruapuke: Seal Rocks	Ruapuke: Seal Rocks	14/10/2022	30	No animal reactions	good	C
Ruapuke: White Isl	Ruapuke: White Isl	14/10/2022	—	To boat: No response from loafing shags	OK [c]	H
Whenua Hou / Codfish	Whenua Hou coastline	12/10/2022	—	None	n/a	H
	Whenua Hou: islet off Sealer's Bay	12/10/2022	—	None	n/a	H
	Whenua Hou: the Knobbies	12/10/2022	—	None	n/a	H
High Rock	High Rock	12/10/2022	—	None	OK [d]	H

[a] BBG is black-backed gull and RBG is red-billed gull; b Colony breeding status is C currently active, H historical, no current breeding; [c] Photographs taken from boat ~30-40 m from island; [d] DSLR photographs taken from helicopter 80-100 m from island

After initial slow descent to check for animal responses (from 50m at ten-meter intervals), photographs were taken at 25–80m flight height. Flight height is measured from the launch point; taking island/site elevations into account, the drone was ~20–60m above colonies (Table 2). Animal response monitoring continued throughout. Breeding Foveaux shags did not respond visibly to drone flight as low as 20m over the colony (Table 2). Loafing Foveaux shags and other bird species (gulls, spoonbills) did not react when the drone was 30m above. At ~25m above colony, loafing shags 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). Gulls took flight at drone takeoff (3 cases) but not during drone overflight, and gulls and spoonbills both responded more to people arrival at the site than to drone activity (2 cases) (Table 2).

At Tihaka Isl we noted that all birds—including Foveaux shags—reacted markedly more to people moving around the site than to the drone; either taking off completely (BBG) or starting to walk in a massed group (breeding and non-breeding Foveaux shags). Retreating quickly out of sight of the breeding shags paused the exodus and shags did not take flight; however, the colony seems sensitised to people moving on foot around the site.

Photographs were obtained ~20–40m above nine of the 12 active breeding colonies, giving good-quality imagery for counting shags (Table 2). At three of the Raratoka colonies (peninsula, Kurukuru Rocks, and Green Isl) oblique photos into the sides of rock stacks/promontories were needed, but the drone was too distant producing images of poorer resolution.

Drone flight elsewhere (to survey other parts of a breeding site to check for colony movement; to inspect historic breeding sites for whether shags have returned; and to inspect likely locations where shags could potentially have started breeding) also had good flight conditions.

Breeding population estimate

The estimated number of breeding pairs for each colony ranged from ~9 nesting at each of the small Raratoka colonies on Kuru-kuru Rocks and Green Isl, to some 275 breeding pairs (best estimate; range 273–277) on the larger colony at Fife Rock (Table 3). (Note some breeding attempts will have already failed at early-laying colonies by the time of survey, so these should be taken as minimum breeding numbers). There was no evidence of nesting on Papakaha Rocks or High Rock, so these are now listed as ex-breeding sites.

Based on results from the current study, the estimated breeding population of Foveaux shags is a minimum of 1002–1012 breeding pairs, giving a best estimate of at least 1007 breeding pairs (Table 3). This is comparable to the last census.

Table 3. Foveaux shag breeding colony census October 2022. Status is 'C' current breeding colony or 'H' historic breeding colony; 'All birds' is the total shags present (birds loafing,or standing or roosting but not on nest; as well as birds on or attending nest); 'Nests' is birds on nest apparently breeding (nest contents unknown); 'A' and 'B' show figures from two separate photograph counts occasions.

Breeding site	Colony	Status	All birds		Nests [a]		
			A	B	Best estimate	A	B
Raratoka / Centre Isl	Raratoka: notch	C	63	62	40	39	40
	Raratoka: peninsula	C	36	33	25	24	25
	Kuru-kuru Rocks	C	14	14	9	8	10
	Green Isl	C	10	11	9	8	9
Papakaha Rocks / Tiwai Rocks	Papakaha Rocks	H	4	4	0	0	0
Rabbit Isl	Rabbit Isl: peninsula	C	117	118	67	67	67
	Rabbit Isl: islet	C	55	54	29	29	29
Tihaka / Pig Isl	Tihaka	C	179	181	139	139	139
Omaui Isl	Omaui Isl	C	36	35	26	25	26
Motu Piu / Dog Isl	Dog Isl	C	107	105	84	83	85
Whero Rock	Whero Rock	C	211	214	189	187	191
Ruapuke: Fife Rock	Fife Rock	C	363	362	275	277	273
Ruapuke: Seal Rocks	Seal Rocks	C	164	165	117	116	118
Ruapuke: White Isl	White Isl [b]	H	50	56	0	0	0
Whenua Hou / Codfish	Whenua Hou coastline [c]	H	0		0	0	0
	islet off Sealer's Bay [c]	H	0		0	0	0
	the Knobbies [c]	H	0		0	0	0
High Rock	High Rock [c]	H	0		0	0	0
Kanetetoe Isl	Kanetetoe Isl	H	1		0	0	0
Zero Rock	Zero Rock [d]	H	0		0	0	0
Islet off Pukeokaoka / Jacky Lee Isl	Islet Pukeokaoka [d]	H	0		0	0	0
Rakiura: Long Harry	Long Harry [d]	H	0		0	0	0
TOTAL BREEDING PAIRS					**1007**	**1002**	**1012**

[a] Nests should be taken as the minimum number, since some breeding attempts will have already failed by the time of survey; [b] count image from boat with DSLR camera; [c] survey by binoculars from low-altitude helicopter; [d] record from check in Oct 2022 as part of other work (P. Dobbins, R. Cole pers. comm. 2022)

Surveys of historic breeding sites at Whenua Hou (the Knobbies, islet off Sealer's Bay), Kanetetoe and White Isl (Ruapuke) confirmed that these sites remain historic breeding sites. Similarly, no shags were found breeding in October at three other sites where Foveaux shags have nested in the past (Long Harry, islet off Pukeokaoka Isl and Zero Rock; R. Cole and P. Dobbins pers. comm. 2022), and they continue to be absent from Ruapuke's Breaksea Isl (R. Topi pers. comm 2022). Because colonies move, we also checked for new colonies on Tikore and Seal Rocks in Bluff Harbour, along the south coast of Taramea / Howell's Point, and along the whole coastline of Whenua Hou. No new breeding sites were found.

Discussion

The Foveaux shag population, with an estimated 1002–1012 breeding pairs at the start of the 2022 breeding season, is similar to the 844–1,081 nests estimated when the whole population was last surveyed in 2011, and before in 1980 (834–990 nests) (Lalas thesis, Lalas unpubl. data 2015). The different platforms used for the aerial photography in the current and previous surveys—drone vs fixed-wing aircraft—are unlikely to have any marked effect on counts themselves, provided image quality is comparably suited for accurate bird counts. The Foveaux shag population appears to have

been fairly stable since 1980, unlike the Otago shag population which peaked in the late 1980s and has since declined (Lalas & Perriman 2009; Parker & Rexer-Huber 2022).

However, there has been substantial variability locally. At Raratoka Isl, for example, nest numbers decreased from >600 in 1955 to 25 in 1991; increased to 138 nests in 1980 and 129 nests in 2011; and have since decreased to 83 nests in 2022 (Cooper 1991; Lalas unpubl. data 2015; this study). Numbers at Tihaka / Pig Isl, Rabbit Isl and Seal Rocks have increased (see Appendix B, which collates breeding records over time from each site). For example, at Tihaka nesting was first recorded in 1998 (10 nests), quickly reaching 110 nests by 2011 and was sitting at 139 nests this season (W. Cooper in O'Donnell 2001; Lalas unpubl. data 2015). On the other hand, Foveaux shags have stopped breeding at what were relatively substantial colonies at Papakaha Rocks and High Rock. We suggest that for robust assessment of the current Foveaux shag population trend, the population size estimate should first be repeated to account for inter-annual variation.

The largest Foveaux shag colony remains that at Fife Rock, off Ruapuke, currently supporting about 27% of the Foveaux shag breeding population. The colony was first recorded in 1980 with a substantial 305 nests, suggesting it had been established for some time already. That season it was smaller than the colony on Whero; however, it has consistently been the largest colony each time counts are recorded (334 nests in 2011, 275 in 2022) (Lalas unpubl. data 2015; this study).

Sites were all surveyed over a short period of time (3 days) at the start of the breeding season. We do not consider the surveys were conducted too early in the season – no nest-building by pairs that were yet to lay was detected – and timing was consistent with the last survey (Lalas unpubl. data 2015). However, we are likely to have missed some breeding pairs that failed early, since chicks were already visible at some breeding sites (Seal Rocks and Fife Rock). Therefore, breeding numbers should be treated as an minimum. Substantial differences in breeding timing between Foveaux shag colonies have been recorded (Lalas 1983) but we lacked the data needed (on the timing of lay at each site), and resources, to survey each site at the start of lay. Indeed, at Tihaka eggs were visible in several nests, and a nest was being built, while at Fife Rock chicks were visible (5 nests or 2% had small chicks visible, being guarded) and at Seal Rocks 36% of nests contained large chicks with a parent still present and some nests even had chicks alone on the nest (7%). This season, the Seal Rocks colony appeared to have started laying earliest, with Fife Rock also an early-laying colony, and Tihaka birds started breeding latest. Other colonies showed no signs of nest-building or visible chicks, so timing must have been intermediate. Although nest failures as breeding progresses are to be expected, very few recently-used but empty nests were seen in photographs. However, in the absence of good data from regular nest checks in monitored colonies, the proportion already failed at a given date remains unknown. Therefore, our estimate—for the Foveaux shag population in early October—necessarily remains a minimum breeding population estimate, since some breeding attempts will have failed before survey took place.

To deal with the asynchronous breeding timing, each site 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 would spread census effort out over several months, which is not ideal, and this type of intensive pre-count monitoring is also not 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 tests the assumption that birds on nests are actively breeding (and quantify the occupancy error). Up to 0.25 and 0.26 of apparently nesting Otago shags were sitting on empty nests, not breeding (Lalas & Perriman 2009; Parker & Rexer-Huber 2022). Efforts to conduct similar nest-contents assessment for Foveaux shags were confounded by access and disturbance risk: the boat

was not able to safely approach islands closely enough to view nest contents, and at the three sites where we could land, the colony was sensitised to people such that approach to a vantage for viewing nests contents was not possible. As a result, no data on Foveaux shag nest contents could be obtained during photographic survey. Time-lapse cameras were also deployed in an attempt to get photos suitable for assessing breeding biology including nest contents (and nest survival rates) at Whero Rock, but the breeding colony moved which resulted in cameras being positioned inadequately to image nest contents. Therefore, simple nest counts are provided (uncorrected counts of apparently occupied nests). This has the benefit of being easily comparable with the last survey, which also recorded simple nest counts (Lalas unpubl. data 2015). Since 2011 and 2022 surveys took place at the same time (in the week of 9 October), nest counts can be compared directly.

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, and some images were more blurred than others making bird detection more difficult. 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 than they are by air (Chilvers *et al.* 2015; Oosthuizen *et al.* 2020). However, ground counts for detectability calculation conducted at one of the sites at which we could land (Omaui) are not very informative, matching aerial counts (26 nests ground, 26 nests aerial). At the other two sites (Dog Isl and Tihaka), disturbance risk of approaching a vantage point for counting was too great to justify concurrent ground-counts and aerial photography, but an unknown proportion of nests are under the shrubline edge on Tihaka and therefore obscured in aerial photographs.

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 a 2-week interval. 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; 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 all-sites population estimate at regular intervals over time to allow robust assessment of the trend of the Foveaux shag breeding population. We suggest that the most cost-effective option would be a census of the entire breeding population every five to ten years (Taylor 2000), with annual counts at a subset of Foveaux shag breeding colonies. Annual counts of Otago shags at Taiaroa Head detected subtle long-term trends in numbers not reflected in periodic whole-population census (Lalas & Perriman 2009; Lalas unpubl. data 2015). Rabbit Isl and Whero Rock colonies are numerous and comparatively easy logistically, so we recommend a census at each either annually or biennially. However, because colonies are periodically abandoned, and trends in nest numbers differ among

locations, this subset of sites may not reflect whole-population trend. Therefore, regular monitoring cannot replace periodic survey to find and count the entire breeding population.

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

- In the absence of nest-failure rate data for this species, timing photography to the start of the breeding season is important to avoid underestimating breeding numbers due to failures before survey. Survey in early October was appropriate for the latest-nesting colony (Tihaka), but survey might have been better at the end of September for Raratoka, Rabbit Isl, Omaui Isl, Dog Isl and Whero Rock, and mid-September timing would likely have produced more accurate counts of breeding numbers at Fife Rock and Seal Rocks. Preferably, colonies would be checked for status leading up to the breeding season, wherever possible, to confirm the breeding timing. This could be in person (drone flight from access point or boat), or from footage from colony cameras deployed to the nesting site beforehand.
- If surveys cannot be timed to the start of breeding, footage from colony cameras at the two annually-monitored sites should provide 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 for at least one of the annually-monitored sites, to build a dataset of occupancy error at the time of imagery

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Appendix A

Study sites: permissions and access notes

Permissions

All sites

All surveys were conducted with permission from the local authority/landowner (Table AA). We are particularly grateful to Ros Cole and Phred Dobbins (DOC Murihiku and Rakiura) for helping identify relevant landowners and land managers for each site, and to DOC's Kaitiaki Roopu for considering the wider project. Flight plans were deposited with AirShare before each deployment. For flights over Bluff Harbour and New River mouth (Rabbit Isl, Papakaha Rocks, Omaui Isl) we notified the Environment Southland harbourmaster (Table AA).

Site-specific permissions

Visit and drone overflight at Raratoka / Centre Isl was approved by Ōraka Aparima Rūnaka. We are grateful to Riki Dallas for facilitating this process, which included outreach to other rūnaka interests, and for putting out a panui / notice about the boat survey.

Permission to access and/or fly a drone at Papakaha Rocks, Tihaka / Pig Isl and Whenua Hou was provided by DOC Murihiku, expedited by Jenny Sycamore. Our thanks to the Tiwai Point aluminium smelter for keys to gates to access Tiwai Point.

Approval for drone use over Rabbit and Omaui islands was granted by Invercargill City Council (UAV approval 5/8/22), enabled by Kerry Bullamore and Mauricio Torres. For Omaui Isl overflight we notified Invercargill air traffic control, and the local aerodrome operator (Te Anau Helicopters) was contacted for Rabbit Isl overflight.

Access to Dog Isl and drone flight was approved by Maritime NZ; our thanks to Jim Foye.

Whero Isl and High Rock visit for survey was approved by DOC Rakiura. Ren Leppens, Kevin Carter, Sasha Smith, and Letitia McRitchie were all involved at various stages.

Permission to fly a drone over Seal Rocks, White Isl, and Fife Rock was granted by Awarua Rūnanga via Ricky and Kerri Topi. Ricky came aboard as vessel pilot and observer.

Sites visited as part of other DOC work (Long Harry, Zero Rock, islet off Pukeokaoka) were approved separately.

Table AA. Foveaux shag sites: detail of access approvals and boat-landing notes.

survey sites	survey method	Access type	Land manager/landowner	Contact name	Drone flight approvals	Access: landings
Raratoka: Centre Isl	drone	Fly from DOC boat	Ōraka Aparima Rūnaka	Riki Dallas	AirShare	Landing from boats not possible (R. Dallas)
Papakaha Rocks/Tiwai Rocks	drone	Fly from Tiwai Pt	DOC Murihiku	Jenny Sycamore	E.S. Harbourmaster for flight over waterways (Lydon Cleaver); AirShare	n/a: so close to Tiwai Point that binoculars inspection easy
Islet off Rabbit Isl	drone	Fly from mainland (public track in Greenpoint Domain)	Invercargill City Council	Mauricio Convers	Te Anau Heli aerodrome; E.S. Harbourmaster; AirShare	Easy landings possible (P. Leask)
Tihaka / Pig Isl	drone, on foot	Site visit. DOC boat	DOC Murihiku	Jenny Sycamore	AirShare	Beach landing often in dumpy beach break (R. Cole). Landing on beach on north side OK with small southerly swell (this visit)
The Rocks Howells Pt	drone, on foot	Site visit	Taramea Management Committee	Ōraka Aparima Rūnaka	AirShare	n/a: road access
Omaui Isl	drone	Site visit. DOC boat	Invercargill City Council	Mauricio Convers	Invercargill Air Traffic Control; Harbourmaster; AirShare	Good landing onto rocks midway along north-east side in small and easing southerly swell (this visit)
Dog Isl	drone, on foot	Site visit. DOC boat	Maritime NZ	Jim Foye	AirShare	Landing difficult by boat, best landing east side (R. Cole); landings are poor with little left of old rampway, safest landing heli or cessna (J. Foye). Landing midway along north-facing beach rocky but OK in moderate south swell (this visit)
Whero Rock	drone	Fly fom DOC boat	DOC Rakiura	Ren Leppens	AirShare	Good landing onto rocks on north side possible in suitable sea state (Parker & Rexer-Huber 2021, this visit)
Kanetetoe Isl	binoculars	DOC boat	Rakiura Titi Islands Admin Body	Tane Davis		Landing looks rarely possible, if at all, since site very exposed to swells (Parker & Rexer-Huber 2021, this visit)
Fife Rock	drone	Fly fom DOC boat	Awarua Rūnanga	Ricky Topi	AirShare	Landing rarely possible, if at all, since site very exposed to swells (R. Topi, P. Leask)
Ruapuke: Seal Rocks	drone	Fly fom DOC boat	Awarua Rūnanga	Ricky Topi	AirShare	Landing looks rarely possible, if at all, since site very exposed to swells (R. Topi, P. Leask)
Ruapuke: White Isl	binoculars	DOC boat	Awarua Rūnanga	Ricky Topi		Unknown but landing onto rocks appears possible (this visit)
Whenua Hou / Codfish	binoculars	Heli circuit	DOC Murihiku	Jenny Sycamore	.	
High Rock	binoculars	Heli circuit	DOC Rakiura	Ren Leppens		
Ruapuke: Breaksea Islands	visit	Awarua Rūnanga	(R. Topi pers. comm)			
Zero Rock	visit	DOC Murihiku	(R. Cole pers. comm)			
Islet off Pukeokaoka / Jacky Lee Isl	visit	Rakiura Titi Islands Admin Body	(R. Cole pers. comm)			
Long Harry	visit		(P. Dobbins pers. comm)			

Boat and helicopter support

Boat support by the MV *Hananui* was provided by DOC Rakiura. Our thanks to Ren Leppens, Kevin Carter, Sasha Smith and Letitia McRitchie for making this possible. Peter Leask (*Hananui* skipper) and Phred Dobbins (crew, small-boat operator) provided invaluable local knowledge to guide planning so surveys could occur in the best possible sea-state conditions, and to get us safely onto and back off islands wherever possible. Other specifics about sites, access and landings were added by Ros Cole, Riki Dallas, Jim Foye, and Ricky Topi (Table AA).

The Whenua Hou kakapo team generously provided a seat on their supply helicopter Bluff to Sealer's Bay return; our thanks to Bronnie Jeynes, Theo Thompson and Alyssa for organising. The Te Anau Helicopters pilot skilfully conducted slow low altitude survey around the Whenua Hou coast and out to High Rock. Tane Davis (Rakiura Titi Islands Admin Body) and Johannes Fischer (DOC Wellington) joined the Whenua Hou aerial survey as observers.

We are also grateful to Riki Dallas, Jim Foye and Ros Cole for digging up other logistics options if our first access attempt did not work out.

Our thanks to Sharon Trainor and Bronnie Jeynes for biosecurity support and quarantine inspection.

Appendix B

Summary of Foveaux shag nest records by site over time

It can be useful to compare records at various sites over time. The caveat is that methods for the records below have not been consistent, the timing has differed, and what was actually recorded is also rarely the same. Therefore, this should be considered more of a bibliography of records than an attempt to collate numbers for comparison.

Papakaha Rocks: 9 nests in 1953, ~30 in 1954, 90 nests in 1955 (Sansom 1956); 150 in 1977 (Smith in DOC database); 65 in 1980 (Lalas unpubl. data 2015); 36 nests in 1992 (W. Cooper in O'Donnell & West 1995), 45 in 2011 (Lalas unpubl. data 2015), abandoned before 2022

Rabbit Isl: 58 nests in 1992 (W. Cooper in O'Donnell & West 1995), breeding confirmed in 1993 and 1999 (W. Cooper in O'Donnell 1995; W. Cooper in O'Donnell 2002), 66 in 2011 (Lalas unpubl. data 2015), 96 in 2022 (this study)

Omaui Isl: 65 nests in Nov 1991 (Cooper & McClelland 1992), 28 in Nov 2000 (Cooper, McFarlane, Edwards & Rance in DOC database), 53 in 2011 (Lalas unpubl. data 2015), breeding in 2013 (eBird), 26 in 2022 (this study)

Tihaka / Pig Isl: none in Nov 1991 (Cooper & McClelland 1992); 10 nests in Dec 1998 (W. Cooper in O'Donnell 2001); 110 in 2011 (Lalas unpubl. data 2015), 139 in 2022 (this study)

Raratoka Isl: >600 nests on Kuru-kuru Rock in Nov 1955 (Sansom 1956), 124 nests in Dec 1975 (Wright in Cooper 1991); 138 in 1980 (Lalas unpubl. data 2015); 25 nests in 1989 (Cooper 1991), 129 in 2011 (Lalas unpubl. data 2015); ~40 nests in 2019 (J. Fischer pers. comm. 2022; 83 in 2022 (this study)

Dog Isl: nesting confirmed in 2001 (Rance, Cooper & McFarlane in DOC database), 84 in 2022 (this study)

Seal Rocks: The presence of ≈20 old nest mounds in 1980 at Seal Rocks; 94 in 2011 (Lalas unpubl. data 2015), 117 in 2022 (this study)

Breaksea Isl, Ruapuke: 5 nests in 1980, abandoned before 2011 (Lalas unpubl. data 2015)

Fife Rock: 305 in 1980, 334 in 2011 (Lalas unpubl. data 2015), 275 in 2022 (this study)

Whero Rock: breeding in early 1950s, count not recorded, and 200-300 in 1974 (Watt 1975); 400 in 1980, and 200 in Nov 1994 (ebird); 199 in 2011 (Lalas unpubl. data 2015), 350 in Dec 2017, 150 in Sept 2018, 125 in Dec 2019, 75 in Jan 2020, and 400 in Jan 2022 (eBird); 189 in Oct 2022 (this study)

High Rock: 77 in 1980 (Lalas unpubl. data 2015); 44 nests in Nov 1985 (C.M. Miskelly in O'Donnell & West 1990), 51 in 2011 (Lalas unpubl. data 2015), abandoned before 2022

Long Harry islet: ~20 in 2016 (Phred Dobbins pers. comm. 2022); abandoned before 2022

Historic sites (abandoned before 1980)

White Isl, Ruapuke: ~20 before 1979 (in Lalas unpubl. 2015)

Kanetetoe: 400-500 in 1911 (Guthrie-Smith 1914), ~300 in 1932 (Wilson in Watt 1975), possibly nesting 1968 (Adams & Cheyne in DOC database), abandoned before Jan 1975 (Watt 1975)

Islet off Pukeokaoka /Jacky Lee Isl: breeding first noted early 1950s (R.H. Traill in Watt 1975), 22 in 1955 (R.H. Traill in DOC database), colony nest building in August 1964 (Bell in DOC database)

Zero Rock: colony nest building in Aug 1964 (Bell in DOC database), 19 in 1968 (J. Cheyne in Watt 1975)

Whenua Hou, extreme NW promontory: 11 in September 1978 (Nilsson, Imber, Garrick & Crouchley in DOC database)

The Knobbies, Whenua Hou: colony 1966 (Blackburn 1968), abandoned by 1972 (R. Nilsson in Watt 1975)

Islet off Sealer's Bay, Whenua Hou: ~60 in 1934 (E.F. Stead in DOC database); nesting confirmed in 1948 (Dell in Blackburn 1968), 64 in 1966 (Blackburn 1968), abandoned by 1972 (R. Nilsson in Watt 1975)

Table AB. Chronology of Foveaux shag nesting records by breeding site. Maximum nest numbers from surveys in 1980 and 2011 (Lalas unpubl. data 2015) and from 2022 (this study) are supplemented by other records available. Seal Rocks ≈20 old nest mounds but no breeding in 1980.*

Breeding location	Before 1980	1980	1981-2010	2011	2012-2021	2022
Papakaha Rocks	9 (1953), 30 (1954), 90 (1955), 150 (1977)	65	36 (1992)	45		0
Rabbit Island		0		66	58 (1992)	96
Omaui Island		0	65 (1991), 28 (2000)	53	Breeding (2013)	26
Tihaka / Pig Island		0	10 (1998)	110		139
Raratoka Island	>600 (1955), 124 (1975)	138	25 (1989)	129	~40 (2019)	83
Dog Island			Breeding (2001)			84
Ruapuke: Seal Rocks		0 *		94		117
Ruapuke: Breaksea Islands		5		0		0
Ruapuke: Fife Rock		305		334		275
Whero Rock	Breeding (early 1950s), 200-300 (1974)	400	200 (1994)	199	350 (2017), 150 (2018), 125 (2019), 75 (2020), 400 (Jan 2022)	189
High Rock		77	44 (1985)	51		0
Long Harry, Rakiura					~20 (2016)	0
Ruapuke: White Isl	20 (< 1979)					
Kanetetoe	400-500 (1911), ~300 (1932)					
Pukeokaoka/Jacky Lee Isl: islet off	Breeding (early 1950s), 22 (1955), breeding (1964)					
Zero Rock	Breeding (1964), 19 (1968)					
Whenua Hou extreme NW promontory	Breeding (1978)					
Whenua Hou: the Knobbies	Breeding (1966)					
Whenua Hou: islet off Sealer's Bay	~60 (1934), 64 (1966)					