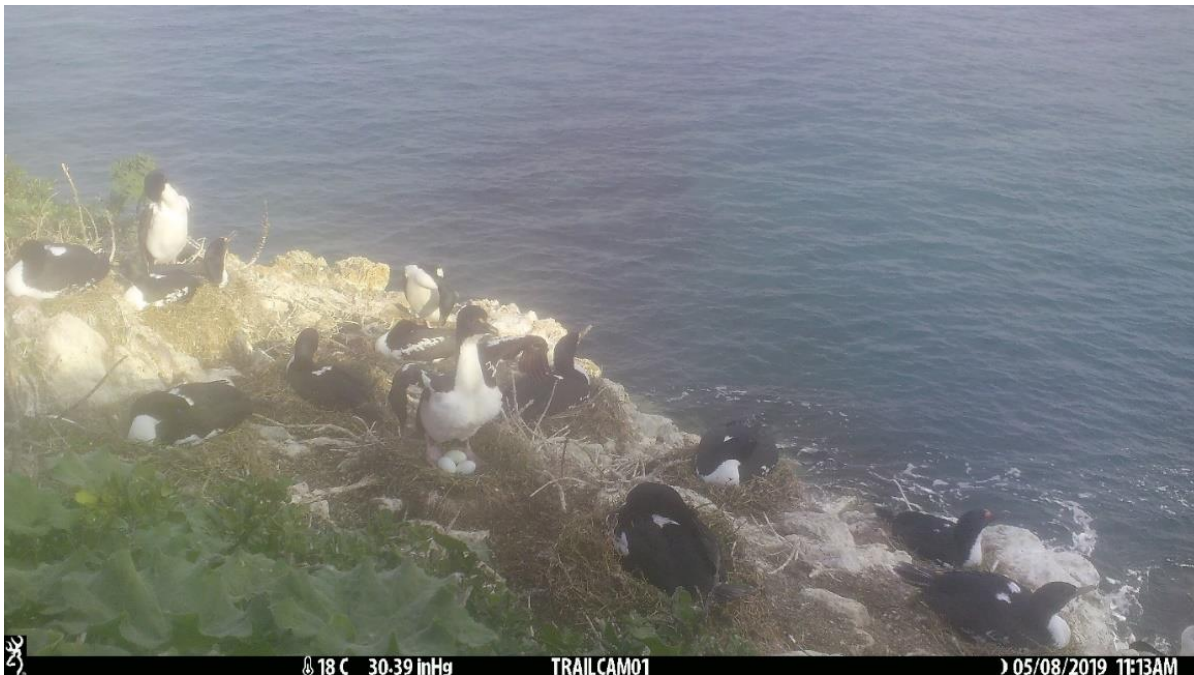


Breeding biology of King shags (*Leucocarbo carunculatus*) from analysis of field camera images



A report for the Department of Conservation

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Cover image: King shag nest with three eggs at Kuru Pongi/North Trio.

Abstract

As part of wider research on king shag (*Leucocarbo carunculatus*) biology to investigate impacts of aquaculture on the species in the Marlborough Sounds, the Department of Conservation—part of the King Shag Working Group (formed by the Marine Farming Association)—employed remote fixed camera technology and image analysis to record data on king shag breeding, colony disturbances and other threats, and to gather observations on marked individuals.

Data from 4,000 quality images captured on 10 field cameras, set at a range of angles and image frequencies at four locations—Duffers Reef, Kuru Pongi/North Trio, Tawhitiui and White Rocks—, captured a sample of the king shag breeding population in 2018 and 2019, from early nest-building in the late (austral) summer/autumn to juvenile disappearance in spring, as well as bird movements through the off-season. White Rocks was the only colony viewed in its entirety so productivity could be calculated—41% young fledging (but not yet independent) from 27 breeding pairs—and breeding activity here could be compared to aerial breeding census results.

Sexes appeared distinguishable by comparing the white plumage patterns on the upper backs of incubating king shags and relating findings to observed copulations and egg-laying events. Males tended to have larger white markings than their mate, and evidence suggested inter-colony variations in markings. Movements of some males and females were basically documented at various stages through incubation and chick rearing, supporting previous suggestions of gender role.

Nesting territories were retained year-round but not strongly defended by December. Pairs started to sit on nests by day as soon as nest-building commenced in February-April, and only at night once eggs had been laid in March-May. Nest-building extended over many months, particularly at exposed, low-lying nesting areas vulnerable to wave surges. Peripheral nest sites at all locations seemed to be occupied by less experienced pairings, with uncoordinated nest attendance, later and more frequent nest-building, and more courtship postures, some described for the first time.

Eggs were mostly laid over a 5-7-week period in 2019, but 10 weeks at Tawhitiui. Clutch size was 2-3 eggs, taking as long as 13 days to lay, and incubation was 28-32 days. Staggered hatches were predicted to account for the loss of many nestlings. Replacement clutches were only occasionally laid after failure at either egg or young nestling stage and were unsuccessful.

Chicks were unguarded for the first time around 1 month, leaving the nest soon after, and showed strong creche behaviour at most colonies. Loss of downy, mobile chicks was mainly attributed to bad weather and/or disappearance, particularly following human disturbance. Chicks reached adult size by 6 weeks and were fully feathered at 2 months, fledging between late July and early October in groups, and venturing further away from natal nests when on land. Thereafter, juvenile sightings decreased, with disappearance of many juveniles at around 4.5-5 months, their actual fate—dispersed or perished—unknown in this study. Some 2018 juveniles remained at all colony sites into the next year, departing during the 2019 breeding season, with two present in full adult plumage at 18 months and still associating with parents. Thirty-six banded juveniles (and six adults) were re-sighted in images at two colonies; data complemented re-sightings recorded in the field from boats.

Productivity per pair monitored—zero, single or two chicks—varied between colonies and between nesting sites at the same location. Success rates were clearly influenced by height above sea-level and site exposure to wind, rain, and wave surges during the viewing period, and to boat/landing disturbance. The type of response seen by king shags in severe weather depended on the stage in the breeding cycle. Accessibility to large mammals was also seen as a real vulnerability at three locations. Gulls were considered a lesser threat, most likely scavengers rather than predators.

The benefit of continuing to use cameras to monitor king shag nesting colonies is likely to outweigh any negative effects on roosting behaviour at night. Observations made in this study can be used to interpret the breeding status of attended nests captured in aerial photographs in the annual census.

Introduction

The New Zealand king shag (*Leucocarbo carunculatus*) is a marine cormorant endemic to New Zealand, restricted to the Marlborough Sounds. With a count of 839 birds—including 187 pairs at predominantly five breeding colonies—using aerial surveys in 2015 (Schuckard et al., 2015), the species has a small, relatively stable population and a conservation status of Nationally Endangered (Robertson *et al*, 2017). King shags breed in winter on rock plateaus, ridges, or faces on small, exposed islands up to 33 m above sea-level (Schuckard, 2017). The species remains highly vulnerable to a range of environmental and human-induced threats.

Protection of king shags requires knowledge on population dynamics and breeding biology, and while these research priorities were identified in the Action Plan for Seabird Conservation in New Zealand (Taylor, 2000), few studies have been conducted in these areas because the species is extremely sensitive to human disturbance. As a result, the potential impact of aquaculture in the region on king shags was also unknown, leading to opposition to industry resource consents.

The Marine Farming Association (MFA) formed a King Shag Working Group to investigate these concerns, which included representatives from the aquaculture industry, the Ministry for Primary Industries (MPI), Iwi, Marlborough District Council, and the Department of Conservation (DOC) (marinefarming.co.nz/king-shag-project/).

In 2019, MFA partnered with Seafood Innovations Ltd to fund an extensive king shag research project, implemented by Wildlife Management International (WMIL) and a sibling company Toroa Consulting Ltd. The three-year project included chick banding to facilitate life history studies, and GPS tracking of adult birds to follow movement and foraging behaviour at sea (Bell, 2019).

In parallel to the marking of young birds and tracking of adults, a study on king shag breeding biology was initiated by DOC and facilitated through advances in remote camera technology. As well as recording biological data on the breeding cycle at key colony sites, fixed field cameras also showed potential to capture disturbances and any other events that could help further define threats to the species, as well as gather observations on marked individuals visiting or nesting at these sites. This report details the results of this project.

Methods

Study sites

Field (trail) cameras were placed at five different king shag colony sites in the Marlborough Sounds by personnel from DOC and WMIL/Toroa Consulting (Fig. 1). These breeding locations were primarily marine rock plateaus and steep rock faces.

Duffers Reef, Kuru Pongi/North Trio (Trio Islands) (both in Pelorus Sound) and White Rocks (Queen Charlotte Sound) were chosen because they were the largest known breeding colonies (Schuckard et al. 2018)—all have Wildlife Sanctuary status, but Kuru Pongi/North Trio is privately owned (D. Palmer, DOC, pers. comm. 2021). Nesting time at Kuru Pongi/North Trio was known to be later than other sites, and birds there were thought to use a different foraging area to those at other locations. The main colony Duffers Reef, along with Tawhitinui (also within Pelorus Sound) were sites where the marking of birds could be achieved; the use of images to record bands was designed to work in

parallel with the banding programme. Tawhitinui, the most accessible and only mainland colony location (part of Kenny Isle Scenic Reserve) was the first study site to test out this project concept.

Nesting areas at Kuru Pongi/North Trio and Tawhitinui were more elevated at approximately 10-15m above sea-level, while the White Rocks nesting site was estimated to be 5-10m, and Duffers Reef the lowest lying at <5m above sea-level (D. Palmer, DOC, pers. comm. 2021).

Eleven still image cameras were deployed in the five locations – Duffers Reef (3 cameras), Kuru Pongi/North Trio (2) (hereon referred to as Kuru Pongi), Moturaka/The Haystack (1), Tawhitinui (3), and White Rocks (2) – at different periods between 10 August 2018 and 15 January 2020, although most image files were collected by 26 November 2019.



Fig 1: Location of king shag colonies in the Marlborough Sounds where cameras were deployed.

NB Moturaka/The Haystack (-40.90679, 174.09164) is not mapped as there were no camera images available for analysis from this Nature Reserve.

Deployment of trail cameras

Two different camera models were used: Swift Enduro and a Browning Dark Ops Pro XD (D. Palmer, DOC, pers. comm. 2021). Both models showed advantages and disadvantages. The Swift Enduro units required up to 12 AA batteries, were limited in image capacity by their SD card size (maximum 32GB), had a screen on the inside door of the camera (difficult to use when positioning), and lacked flexibility in the camera mount meaning additional packing was needed to point the camera down. However, they were reported to have worked well and were durable in the hostile environment. The

Browning Dark Ops Pro XD had a lower power output, running on 6 AA batteries, and the SD card capacity was up to 500GB allowing for longer periods between servicing and the ability to use video as well as still photos. A screen on the face of the Browning made aiming the camera much easier and a movable hinged attachment bracket, although rusting up over time, allowed for pointing down. The downside of this unit was a series of internal software issues whereby the operating parameters, such as time and date, would reset. Eight cameras were ultimately lost over the project: five to water/rock damage, and three to internal software issues.

Placement of multiple cameras at a single site aimed to cover different angles and views of each nesting area, although limited vantage points restricted coverage at some locations e.g., Duffers Reef. Personnel aimed to cover wide angles covering many nests at some locations, and close-up views of a smaller number of nests at others; and, they had to consider sun direction and height above sea-level regarding storm surges. Often there was little choice where cameras could be installed: two cameras were lost at White Rocks in storm surges, and sun strike could not be avoided for one unit on Tawhitinui.

In most instances, cameras were cable-tied to a steel waratah post hammered into the ground. On the rocky White Rocks and Duffers Reef, a 12mm hole was drilled, and a threaded bar glued into the rock, with the camera attached to this using a custom-made right-angled bracket screwed to the camera mounting and then fixed to the threaded bar with nuts/washers. At Tawhitinui, one camera was attached to a tree using cable ties.

Files were stored on SD cards which had to be retrieved and replaced at intervals, influencing dates of deployment. There were 48 files of images captured, along with 22 video files from an additional camera placed at White Rocks.

Study objective

Viewing and analysis of images was required to find the following information for king shags:

- Breeding biology—including timing of breeding events (nest building, egg laying, chick hatching, and fledging), clutch and brood size, breeding success rates, and juvenile dispersal.
- Banded bird sightings—to follow growth, behaviour, and survival of chicks/juveniles, that were banded at two sites: Tawhitinui (2018 and 2019) and Duffers Reef (2019) (Bell, 2019). In addition, sightings of any of six banded adults fitted with back-mounted GPS devices in July 2019 were to be noted.
- Bird behaviours—including that of breeding pairs (during incubation and rearing), chicks and juveniles, banded birds, first-year birds, and all birds outside breeding months. Reaction of birds to disturbances or potential threats was also a focus.
- Threats—to identify any events seen to negatively impact on birds, including bad weather, wave surges, human-induced disturbances (boats, landings, etc.), interference by seals or other wildlife, and presence of avian/mammalian predators.

Data and observations were to be recorded and documented for each camera view at each colony. This report aims to detail findings so they can be available to the King Shag Working Group.

Analysis of camera images

To manage the task of image viewing and analysis, and monitor viewing and data collection progress, the following methods were employed:

1. All image files were sorted and labelled as sets within camera numbers; a single camera may have been deployed several times through the study period.
2. Using thumbnails, all images that were not usable were identified (fallen camera, fogged lens, view obscured by vegetation etc.) and eliminated from viewing.
3. An Image Library Index was created containing colony site, camera number (1-3), set (i-v), start and end dates of each deployment, camera setting notes, and number of usable images, viewed images, and images with data recorded.
4. A master image was selected for each camera view for reference (refer Appendices 1-5). Sometimes, several masters were required for a single camera if the angle/view changed considerably with time (e.g., camera knocked out of position), but data could still be collected.
5. Nests were assigned alphabetical labels in each master image so that they could be followed easily. The best master image to use was usually one found during incubation time, when nest sites were well-defined.

Important note: For most sites, it was initially not always clear if the same nests were represented in each camera view, so nests were labelled from the beginning of the alphabet at each view. For example, there are three different nests labelled A at Duffers Reef, for each different camera view but these will not actually represent the same nest. Therefore, it is important that any interpretation of data for a labelled nest is associated only with the labelled nest in that specific camera view. (In retrospect, a different nest labelling system could have been devised, however they can be distinguished from each other if camera number is included in the nest number, e.g., D_C1_A; D_C2_A; and, D_C3_A)

6. Nest label overlays were applied to all relevant images within a file using appropriate software, so that all images viewed featured nest labels.
7. Image data from every camera file was exported into Excel spreadsheets (one workbook per camera set), so that image number, and date/time shot were listed. This enabled data and observations to be entered directly next to the relevant image/date/time. (All other image data such as settings was retained but hidden on the spreadsheets.)
8. Priority was given to viewing all images taken around the core breeding season at all colony sites first, and to the images that were the easiest to gather data from, i.e., higher quality and closer proximity of nests to cameras. Thereafter, files were viewed according to time of season, to look at nest building leading up to the breeding season, follow fledglings in the spring, and final viewing time was allocated to the off-season.
9. Images were coded for quality: D = data collected from viewed image, Y = image viewed but no data collected, or N = image not usable (poor quality) and not viewed. This allowed images to be sorted after data had been collected, to facilitate analysis.
10. Summary data tables and observation reports were created for each camera set, from which this report has been compiled.

Results

A total of 131,946 usable images were viewed, and data was collected from 3995 images (Table 1). Images that were discarded were unusable for various reasons: loss of view due to camera drop—likely caused by severe weather conditions—occurred at Duffers Reef (Cam1) and the single Moturaka/The Haystack camera; nests obscured by growing vegetation in spring at Kuru Pongi (both cameras) and Tawhitinui (Cam1); operation malfunction of one of the White Rocks cameras a month into deployment. Only eight of 22 videos were watched due to time constraints; no significant information was gained from watching these as they were a distant, partial view of a site.

Camera deployment date ranges are summarised in Table 1; within these periods, cameras were serviced and not operating continually (refer table footnotes).

Image frequency also varied between cameras and in some cases was experimental. Mostly cameras were set to take still images at set intervals throughout the day (e.g., every 30 mins) and turned off for a period in the middle of the night to conserve battery power. Motion sensor settings were unintentional (D. Palmer, pers. comm., 2020) and represented 4 days of activity at Duffers Reef and 5 days in at Tawhitinui in December 2018 (17,472 of the usable images).

Table 1: Summary of images sourced from cameras deployed at five king shag colony locations.

Note: For every camera there were multiple files of images (see table footnotes), and there was sometimes a range of image frequency programming on a single camera.

Colony	Cams used	Date range cameras deployed	Total usable images viewed	Total images with data	Image frequency summary (all cameras at a site)
Duffers Reef	3	13/12/2018-26/11/2019 ¹	63,916	1,280	<i>Motion sensor setting (approx. 12 frames/min); or</i> Approx. half-hourly and less frequent through night; or Approx. half-hourly with no night shots; or Multiple (8) frames/every 30 mins.
Kuru Pongi/ North Trio	2	04/04/2019-26/11/2019 ²	11,642	701	Half-hourly by day and less frequent through night.
Moturaka/ The Haystack	1	12/03/2019-15/01/2020	136	2	Poor view for most images due to camera drop. No analysis could be undertaken.
Tawhitinui	3	10/08/2018-26/11/2019 ³	40,561	1,191	<i>Motion sensor setting (approx. 12 frames/min); or</i> Half-hourly by day from pre-dawn (dark) up to mid-evening (dark); or Quarter-hourly by day from pre-dawn (dark) up to mid-evening (dark).
White Rocks	2	25/08/2018-31/10/2019 ⁴	15,691	821	Half-hourly by day from pre-dawn (dark) up to mid-evening (dark), with more night shots in winter as days shorten.

¹ Dates Duffers Reef cameras deployed: Cam1: 13-17/12/2018 and 12/03–26/11/2019; Cam2: 13/12/2018–23/05/2019 and 24/07–26/11/2019; Cam3: 12/03–8/06/2019 and 24/07–26/11/2019.

² Dates Kuru Pongi cameras deployed: Cam1: 4/04–19/10/2019; Cam2: 4/04–21/06/2019.

³ Dates Tawhitinui cameras deployed: Cam1: 10/08–15/11/2018; 13/12/2018–15/06/2019; and 18/07–26/11/2019; Cam2: 28/08/2018–19/10/2019; Cam3: 13-17/12/2018 and 12-27/03/2019.

⁴ Dates White Rocks cameras deployed: Cam1: 25/08-25/11/2018 and 11/03-2/04/2019; Cam2: 25/08-21/12/2018 and 11/03-31/10/2019.

Population sample monitored by cameras

Maximum head counts of birds in camera view, nests labelled, and breeding outcome is captured in Table 2 so the reader can understand sample sizes of birds/nests monitored and numbers of chicks that could be followed through rearing to independence in 2018 and 2019.

The greatest number of king shags head-counted in any single image was 80 (adults, chicks, and juveniles) at White Rocks, which would have included birds from nests or loafing areas normally out of view, i.e., beyond the photographed area. Less emphasis was placed on head counts in images from cameras with smaller fields of view such as Kuru Pongi. 'Floating' non-breeding adults and first-year birds were the hardest demographic to count in the breeding season because they were usually only seen sporadically on the edges of or beyond the main nesting area at all sites.

The number of nests followed was usually less than the number labelled, because some nests ended up being hidden behind other birds on nests closer to the camera. Sometimes, unlabelled nests were loosely followed if they were discovered after the labelling process and featured interesting observations. The maximum number of nests followed in any one field of view was 27 at White Rocks, and the smallest number followed in detail over the breeding season was nine at Kuru Pongi.

Table 2: Details on bird and nest numbers in camera view at four king shag colony locations.

(C) = seen on camera 1, 2 or 3; (B) = determined by band sighting

Year	Duffers Reef		Kuru Pongi /North Trio	Tawhitinui		White Rocks	
	2018	2019	2019	2018	2019	2018	2019
Max. head count (adults and juveniles)	-	50 (Dec 2018) (C1)	-	-	56 (Mar) (C3)	-	80 (Jul) (C2) 75 (Aug) (C2)
No. 2018 juveniles seen as first-year birds in early 2019	-	4 (Jan) (C2) 3 (Feb) (C2) 2 (Mar) (C2) 1 (Apr) (C2)	5 (Apr) (C2) 10 (from mid-May) (C2)	-	5 up to Apr (C2)	-	Few, not followed past Mar
Estimated min. no. nests	-	16 (C2) ¹	11 (C1)	21 (C1)	-	-	31 (C1) ⁴
No. nests labelled	-	15 (C2) ¹	10 (C1)	20 (C1)	15 (C1)	28 (C2)	28 (C2)
No. nests followed through season	-	15 (C2) ¹	9 (C1)	20 (C1)	12 (C1)	27 (C2)	27 (C2)
No. breeding attempts	-	-	8	Min.10	Min.10	-	26
No. non-breeding pairs	-	-	1	-	1	-	1
No. unknown status	-	3	-	10 ³	1	-	-
Nest failures at egg or small chick stage	-	-	1	-	1	-	10
Nest failures downy, mobile chick stage	-	-	-	-	2	-	3
Nest failures at fledging	-	-	-	-	-	-	1-3
No. chicks in July	-	12 (C2)	11 (C1)	-	-	-	15 (C2)
No. juveniles in August	-	-	≥8 (C1)	11 (C2)	14 (B)	-	12 (C1,2)
No. juveniles in September	-	18 (B)	≥8 (C1) ²	9 (C1)	12 (B)	10 (C2)	11 (C1)
No. juveniles in October	-	11 (C2) 17 (B)	≥7 (C1)	10 (C2)	10 (B)	7 (C2)	8-10 (C2)
No. juveniles in November	-	10 (C3) 14 (B)	-	10 (C2)	9 (B)	5 (C2)	-
No. juveniles in December	5-6 (C1)	-	-	9 (C3)	-	3 (C2)	3 (C2)

¹ There were 20 nests (eight at C1, 12 at C3) that could only be monitored for short segments of the breeding season. While these provided detail on breeding biology, the C2 nests provide an overview of the Duffers Reef colony 2019 productivity.

² Advancing vegetation obscured views of two nests at Kuru Pongi from August 2019, and all nests by October. Juveniles viewed after this were grouped just beyond the vegetation.

³ Contents of Tawhitinui nests in 2018 could not be seen, so nests of unknown status include those belonging to non-breeders, or pairs that failed earlier on.

⁴ Maximum count at White Rocks in March/April 2019 only and includes small deposits of nest material.

Distinguishing sexes

A significant discovery part way through the viewing process was a plumage feature, seen best during incubation, which distinguished male from female at each nest. All 10 pairs in Duffers Reef Cam3 view comprised one bird with a white saddle (nests B-G and I-K) or two large, almost merging, white spots (nest H) on its upper black back, and at all nests the partner had two separate relatively smaller white patches or spots (Table 3). This feature could only be seen from above when the adults were sitting on nests and/or with wings slightly relaxed (Figs 2-4 in this report).

The birds with the saddle were deduced to be males (Fig 3): they were slightly larger, and one was seen on top during a copulation at Duffers Reef. The birds with two spots here were deduced to be female (Fig 4): they were slightly smaller, and one was underneath during copulation. Another piece of evidence used to assign gender to these birds was noted when an egg was seen to be laid in the afternoon on a nest rim (Nest K, Duffers Reef, 2019) when the bird with two spots was attending the nest; its mate was known to have a saddle and was not present at the time.

After noticing this plumage feature at Duffers Rock, data on this upper back marking was then collected for 25 presumed males and 21 presumed females while incubating at White Rocks (Cam2) in 2019, because this camera view also looked down on the birds (Table 3).



Fig 2: 'Saddled' and 'spotted' adults in pairings (top left and centre pair) at Duffers Reef (18/04/2019).

At White Rocks, presumed males (sitting from early morning through to middle of day) exhibited the following range of upper back patterns when sitting on nests: a saddle (that could be described as two large fully merged white spots); or two large almost merging white spots; or, two big, medium-sized, or small, clearly separated white spots. As at Duffers Reef, these birds seemed marginally larger than their partners in body size, but this was not always clear to see.



Fig 3: Incubating presumed ‘males’ in morning rain at Duffers Reef (05/06/2019).

Table 3: King shag upper back, white plumage features in breeding pairs at nests in 2019.

Adult 1 = presumed male; Adult 2 = presumed female; Med = medium

Duffers Reef Cam3 Nest	Adult 1 white plumage feature	Adult 2 white plumage feature	White Rocks Cam2 Nest	Adult 1 white plumage feature	Adult 2 white plumage feature	White Rocks Cam2 Nest	Adult 1 white plumage feature	Adult 2 white plumage feature
B	Saddle	Two spots	A	Big spots, almost merging	Small spots	O	Big spots, separate	Med spots
C	Saddle	Two spots	B	Big spots, separate	Small spots	P	Big spots, separate	Small spots
D	Saddle	Two spots	C	Saddle	Small spots	Q	Saddle	No data
E	Saddle	Two spots	D	Big spots, separate	Small spots	R	Saddle	Med spots
F	Saddle	Two spots	E	Saddle	Small spots	S	Saddle	No data
G	Saddle	Two spots	F	Saddle	Med spots	U	Med spots, separate	Med spots (same as mate)
H	Big spots merging	Two spots	G	Med spots, separate	Small spots	V	Med spots, separate	Med spots (same as mate)
I	Saddle	Two spots	H	Saddle	No data	W	Med spots, separate	Med spots (same as mate)
J	Saddle	Two spots	I	Big spots, separate	No data	X	Big spots, almost merging	Small spots
K	Saddle	Two spots	K	Med spots, separate	Med spots	Y	Saddle	Small spots
			L	Med spots, separate	Tiny spots *	Z	Big spots, separate	Small spots
			M	Small spots, separate	Tiny spots	@	Big spots, separate	Small spots
			N	Big spots, separate	Tiny spots *			

*Tiny spots at Nests L & N were barely visible.

Presumed females (sitting through afternoon into early evening) exhibited the following range of upper back patterns when sitting on nests: two medium-sized, or two small, or two tiny, separated white spots (the latter barely visible, i.e., mainly black back only seen).

Significantly, a much smaller proportion of males at White Rocks had a clear saddle than those at Duffers Reef, where this plumage feature was first identified. At Duffers Reef, nine of 10 monitored males had saddles, while at White Rocks less than half the males (10 birds) had spots that were merged, or almost merging, and more birds (15) had two distinct white spots.

At Duffers Reef, and in nearly all cases at White Rocks, females showed smaller white spots than their male partners. Females never seemed to have spots that were big, or almost or fully merging. Their spots were medium-sized or smaller and always distinctly separate.

There was just one pairing in all the images/files viewed to date (banded adult White18 and mate at Tawhitinui Cam3) where the upper back markings did not fit the general observed pattern for the sexes. The presumed male, based on relative body size and daytime movements, had distinct medium-sized spots while his mate had a small-medium patch of slightly merged spots. White18 was later confirmed as a male (Bell, 2020).

There were three adjacent nests at White Rocks where the two birds in each pairing were almost indistinguishable as their white spots appeared virtually the same medium size. None of these three pairings produced chicks; in fact, no chicks were ever seen at these nests, hatches could only be implied. One of these pairs is thought to have laid two clutches.

There was no time to analyse wing markings, specifically the white wing (alar) patches. From limited observations, it is likely that the male had a more extensive patch than the female in a pairing. Images taken in April 2019 were viewed after those taken in later core breeding months at Duffers Reef Cam3 and revealed that females tended to have the slightly larger caruncle. There was no time to examine either of these features—alar markings and caruncle size/colour—in any more detail.

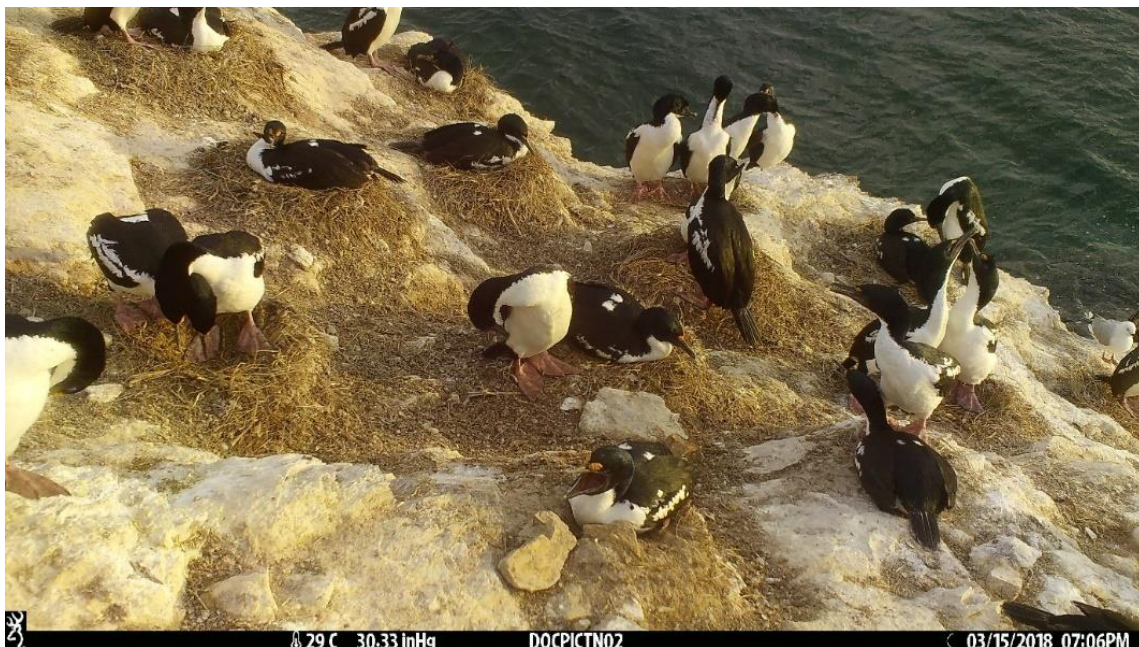


Fig 4: 'Spotted' adults, presumed females, at nest sites in early evening, during nest-building phase at Duffers Reef (15/03/2019). 'Neck-crossing' (left pair) and 'sky-pointing' (centre right) courtship displays.

Courtship and nest building

Muddy mounds at nest sites seen early in 2019 were considered the dried-on remains of previous seasons' king shag nests (guano, decomposed nest material); these were particularly obvious at Duffers Reef (Cam1) and Tawhitinui (Cam1). At Duffers Reef, old nests started to wash away, back to bare rock, with the onset of autumn weather. In contrast, at Tawhitinui, some of the mounds from 2018 remained through to the 2019 breeding season when they were added to with fresh material. At White Rocks (Cam2), the rock was stained indicating the presence of nests at most of the nesting sites in the previous season, but there were no mounds at all.

Distinct sites were occupied by birds and nest material was already present by late summer/early autumn when cameras at most sites were deployed, although the pattern of occupation at nests early in the season was a little sporadic. Only two sites had cameras running earlier than March 2019, through the end of 2018, and January/February 2019: Duffers Reef (Cam2) and Tawhitinui (Cam1). From these, it could be deduced that in the off-season (late spring/summer), a pair might leave their site unoccupied during the day, but roost loosely there or nearby at night.

The first pair nest-building in 2019 started on 30 January at Tawhitinui (Cam1). At this time, established nest mounds were occupied sporadically by pairs even through to March, and some first-year birds were still regularly seen with pairs (presumed parents) at these sites by March. From April onwards, breeding nest sites were rarely left unattended. Where there was no muddy nest mound, staining or nest material present in March, pairs started nest-building much nearer to egg-laying time, e.g., Nest M on 7 April and Nest L on 7 May (both sites nearest to camera).

Distinct nest sites were occupied in January 2019 at Duffers Reef (Cam2). Shifts commenced around February/early March when the nest site was occupied by at least one bird in the day. Nest-building was underway in early March 2019: nest material was obvious at some of the sites on 12 March (day of camera service), and by 13 March more nests were being built, and notably adults began to sit during the day. In the Cam3 view, only two nest sites (Nests H and I nearest to the camera) had little or no nest material in early March; pairs here were the slowest to start nest-building.

At White Rocks, recent material had been added to 23 of 27 viewable nests by 11 March 2019; this was easy to see while the camera was being set up and there were no birds present. Only four nests in this colony view were started at later dates: Nest D on 13 March; Nest @ on 4 May; and Nests H and M on 17 May 2019. Three of these nests were on the edge of the nesting site (D on the far edge, M and @ on the edge nearest the camera). There was no staining on the rock at sites D, H and @.

Nest material was already present at distinct nest sites at Kuru Pongi (Cam2) when the camera was deployed on 4 April 2019. Fresh nest material was notably added to sites mid-late April. Movements for all pairs were closely monitored for a whole day on 19 April, revealing that by this stage there was always at least one bird present at each nest. Nests were only left completely unattended during disturbances, e.g., all adults moved 1-2 m away from nests on 25 April 2019 when alerted.

Nests were made of land vegetation or seaweed, depending on location. At Duffers Reef (Cam3), nests were mainly made of grasses, but occasionally flax was seen in nests, and on one occasion seaweed appeared in a few nests. At White Rocks they mainly comprised different seaweeds.

The timing of pairs starting to sit at nest sites by day tended to coincide with the start of nest-building in many pairs. As soon as birds began to sit, nest material remained at sites, and nests began to grow (Fig 4). Interestingly, all the birds would then stand to roost at night at this time before egg lay. When birds were not often seen sitting at nest sites by day, they were recorded

trying to establish nests multiple times with no success. While the disappearance of nest material from all nests was known to coincide with bad weather at exposed sites, often nest material would disappear soon after adults had positioned it. Image frequency was not enough to reveal in these instances if material was being blown away by wind. Where wind was not suspected—birds not standing in postures associated with strong, directional wind—, and where conditions were dry—no rain to wash material away—, it was suspected that nest material might be stolen from nests by other birds. However, this behaviour was only captured on camera on two occasions, once at White Rocks (two neighbouring pairs making nests on 1 day only in late September 2018), and a single bird suspiciously carrying material across the Duffers Reef (Cam 3) nesting site during a disturbance when most other birds were absent on 17 April 2019. Aggressive postures to neighbours at Cam1 during nest-building in April 2019 led to the suspicion that nest material might be stolen.

A pattern emerged at most sites: pairs occupying certain nest sites (often central in the nesting area, buffered by other pairs/nests) seemed to be more successful in building longer-lasting nests. They sat much more than some of the peripheral nesters that made multiple attempts to build nests.

One site where nests were rebuilt repeatedly was one of the lowest lying nest areas subject to some of the most adverse conditions at Duffers Reef (Cam1) (Fig 5). Pairs at central nest sites and those further away from a small ravine in the rock were generally more successful in building longer lasting nests—nests started from scratch 2-5 times in 2 months from 12 March 2019 (Table 4). These pairs were rarely seen in courtship display postures during this time. Three pairs at peripheral nest sites (two closest to the camera) and all along the edge of the small ‘ravine’ had multiple attempts to build nests—nests started from scratch 11-15 times in 2 months from 12 March—and were more frequently observed in courtship display and copulation postures during this time. With no successful breeding at any of the nests, pairs were still building nests through to October.

Nest sites were unattended during adverse weather and many nests were washed away, e.g., severe conditions recorded on 29 April 2019 at Duffers Reef Cam1 caused adults to vacate nest sites during the night—roosting in front of the camera—and the following morning. Immediately after a bad weather event, all adults would typically interact with neighbours (probably re-establishing territories) and adults resumed nest-building at the next suitable opportunity. Otherwise, pairs were not often seen in aggressive postures with neighbours.

Table 4: Nest-building behaviour by king shag pairs on images taken at Duffers Reef Cam1 in 2019.

Note: Bad weather washed nests away on 27/03, 1/04, 29/04, 10/05 (camera knocked), and 20/08/2019. No usable images between 10/05 and 24/07/2019.

Nest	Nest location relative to rest of nest site area	No. of times nest built from scratch 12/03-10/05	Courtship displays seen to 10/05	No. of times nest built from scratch 24/07-29/10	Copulation Seen
A	Far edge of nests, next to ‘ravine’	11	0	1	0
B	Far edge of nests	3	0	2	0
C	Near to camera, next to ‘ravine’	15	5	6	2 (18/03, 21/04/2019)
D	Far edge of nests	5	0	2	0
E	Central, buffered by others	2	0	2	0
F	Central, buffered by others	4	1	4	0
G	Central, buffered by others	4	0	2	0
H	Nearest to camera, next to ‘ravine’	13	9	3	2 (24/03, 5/04/2019)



Fig 5: Waves washing over Duffers Reef Cam 1 nesting area (27/03/2019).

At Tawhitinui (Cam1), pairs that showed multiple nest rebuilding attempts from March 2019 onwards were at nest sites nearest the camera (J, L and M). Nest J was completely washed or blown away four times in 6 weeks between 12 March and 29 April. Nest material stayed in place as the pair increased sitting time on the nest; and continual sitting commenced 27 May. In contrast, birds were far less often seen carrying nest material or arranging nests at Duffers Reef Cam3, because the site appeared to be quite elevated and sheltered with nests remaining intact.

Nests thickened up (breeding pairs only) just before egg laying and throughout incubation. At Kuru Pongi (Cam2), nest building appeared to happen at clusters of nests simultaneously—multiple nests were added to, with the same type of material, on a particular day—as well as on an individual basis. This was also easy to see at White Rocks, e.g., on 23 April 2019, five nests in two clusters (R, S, X, Y and Z) all had fresh bright green seaweed appear at their nests in the same image.

There was usually at least one nest site in most camera views where there was limited or no nest-building activity at the start of the breeding season, and with one or maybe two adults sporadically visiting with limited activity (no breeding) at site through rest of season (e.g., Nest I at Kuru Pongi, Nest L at Duffers Reef [Cam3]). At Nest @ at White Rocks, an unpaired bird in March (roosting alone) acquired a mate in late April (two birds roosting together), and nest-building commenced in May. The site was not always occupied, and a nest not always present. This newly established pairing continued to occupy the nest site right through to end of October (end of camera operation). All these nests were peripheral to the established breeding pairs.

Duffers Reef (Cam3) images featured a variety of courtship displays including gargling, mutual head lowering, and gaping (all described in Marchant & Higgins, 1990), as well as 'sky-pointing', and 'biting' (head or nape), and 'neck-crossing' (often after the 'biting') (Fig 4). The two pairs here seen courtship displaying most often were likely to be less established pairs; they were also slow to nest-build, not always roosting at the site at night.

Copulations were recorded whenever seen at Duffers Reef (Cam3), Kuru Pongi (Cam1&2) and White Rocks (Cam2) which was not all that often (Table 5 notes). The earliest copulation observed was on

14 March at Duffers Reef. Copulations were seen over a month before some first eggs were laid, or as close as the day before the first egg was laid in two pairs (with two and three-egg clutches).

Egg laying and incubation

Observing the standing and sitting behaviour of birds at night—2-3 hrs after dark and the same before dawn was sufficient—proved to be the fastest method of establishing when a pair was laying (Fig 6). Both birds in a pair stood at night right up until the night or night before first egg laying. Birds tended to sit at nests continuously from the time the first white egg was laid, with limited standing (if any, it was at night only) until incubation commenced when adults were observed sitting all night.

If nesting areas were illuminated by the camera light, observations right up to 2230h and from 0500h onwards were important in helping to ascertain first egg lay dates, along with egg sightings. Most first egg lay dates at White Rocks were thought to be within 1-3 nights/days accuracy.

Eggs were rarely captured being laid in images, but generally it was suspected from behaviour at nests that most eggs were laid in the early morning hours (i.e., after midnight and before dawn). However, some eggs were seen to be laid during daylight hours too.

Clutch sizes in 56 nests where data could be collected on egg laying—Duffers Reef (10 nests), Kuru Pongi (16), Tawhitinui (4), White Rocks (26)—ranged from one to three eggs (Table 5). Four eggs were never seen in any one nest at a time. At least 40 of the 56 monitored nests (71%) were confirmed to have two- to three-egg clutches (17 two-egg, 15 three-egg clutches, and eight with at least two eggs). A further 15 nests could have contained up to three eggs, but no data could be recorded after the first egg was seen. A single egg was laid (then predated) on bare rock at one site.

The egg-laying period for first clutches covered 5-6 weeks at Duffers Reef (Cam3) in 2019, with the earliest egg laid 21-23 April and the latest known egg laid 3-5 June (Table 5). It was noticeable that pairs at the top of the slope in camera view laid first, and those at the bottom laid later, with the pair at the very bottom of the nesting area in view not laying. Replacement clutches were laid at Duffers Reef (Cam1); see later.

At Kuru Pongi (Cam1 & Cam2), eggs were laid over a similar 5-6-week period: earliest egg laid 2 May and latest known on 9 June, although another egg may have been laid after that between then and 14 June. There were no recorded replacement clutches at Kuru Pongi.

Only four egg-lay dates were recorded at Tawhitinui as there was a lack of images showing the detail required at the appropriate time of year. However, these records contain the likely earliest egg lay date at this colony of 19 March (high up the nesting area near to Cam3), and a possible latest date of 31 May, spanning a period of 10 weeks. The later lay date was undoubtedly a first clutch as the pair were in front of Cam 1 (at the bottom of the nesting area) and slow to settle at the site, only roosting there all night from 7 May on which date the first nest-building was also observed.

At White Rocks in 2019, eggs in first clutches were laid over 7 weeks from 30 March to 22-26 May. Replacement clutches were suspected at this colony; see next section.

Robust data from just three nests where accurate lay dates were recorded showed females laying each egg within a first clutch at roughly 3-4-day intervals. A clutch of three eggs took 8 days for the Nest H female at Duffers Reef (Cam3) to lay, 7 days for the Nest G female at Kuru Pongi (Cam1) and 6 days for the Nest G female at Kuru Pongi (Cam2) to lay (cover image). One of the longest three-egg clutches to be laid was at White Rocks (Cam2) Nest O: 13 days between the latest lay date of the first egg and earliest lay date of the third egg.

Table 5: Egg lay dates (first clutches) at labelled nests on field camera images at four king shag colonies in 2019.

D = Duffers Reef; K = Kuru Pongi/North Trio; T = Tawhitinui; W = White Rocks

Note: Where \geq symbol is used, the minimum number of eggs per clutch is listed based on later views into the nest, but it was impossible to confirm if any more had been laid (no further views into nest, or part of nest obscured by bird).

Colony_Camera	Nest	Egg 1 earliest lay	Egg 1 latest lay	Egg 2 earliest lay	Egg 2 latest lay	Egg 3 earliest lay	Egg 3 latest lay	Clutch size	Notes
D_C3	A	21/04	23/04	25/04	28/04			≥ 2	Only the bottom of nest visible (bowl and adults' feet). Behind another nest, it was not visible in later footage when camera dropped slightly.
D_C3	B	25/04	25/04	29/04	1/05	n/a	n/a	2	First chick known to hatch on 25/05. Second chick hatched 26-28/05 (the only hatches captured at Duffers Reef).
D_C3	C	11/05	11/05	14/05	15/05	n/a	n/a	2	Seen copulating on 14/03 and 19/04.
D_C3	D	12/05	12/05	14/05	17/05	n/a	n/a	2	
D_C3	E	No data	No data	No data	No data	No data	No data	No data	No clear view into nest (behind another). Pair likely commenced incubation 7/06 (adult sits at night).
D_C3	F	23/05	24/05	25/05	31/05	n/a	n/a	2	
D_C3	G	11/05	11/05	14/05	15/05	n/a	n/a	2	Seen copulating on 9/04.
D_C3	H	22/05	22/05	25/05	29/05	30/05	30/05	3	Seen copulating 15/04 and 18/04.
D_C3	I	27/05	28/05	30/05	31/05	1/06	5/06	3	Seen copulating on 9/04. Nest I was the last nest to be built.
D_C3	J	21/05			25/05	26/05	28/05	3	
D_C3	K	25/05	25/05					>1	Seen copulating on 3/06. First egg appeared on nest rim during afternoon, immediately rolled out of nest, and was predated by a red-billed gull. Pair likely commenced incubation 7/06 (adult sits at night). A less-experienced pair?
D_C3	L	n/a	n/a	n/a	n/a	n/a	n/a	0	Non-breeding pair.
K_C1	A	No data	No data	No data	No data	No data	No data	No data	Nest out of camera view for most of analysis.
K_C1	B	14/05	15/05			n/a	n/a	2	Seen copulating on 7/05.
K_C1	C	2/05	2/05		7/05	n/a	n/a	2	Seen copulating on 1/05.
K_C1	D	6/05	6/05		11/05	n/a	n/a	2	
K_C1	E	5/06	6/06	8/06	14/06	n/a	n/a	2	
K_C1	F							3	Seen copulating on 7/05 and 10/05.
K_C1	G	2/06	2/06	3/06	5/06	9/06	9/06	3	Seen copulating on 12/05. Possibly a dead chick (or large fully developed embryo) outside nest on 15/07.
K_C1	H	15/05	15/05	n/a	n/a	n/a	n/a	1	Pair not regularly occupying site; sporadically visiting in April/May; rarely staying at site at night. No nest building. Egg laid on bare rock, left unattended. Egg predated by red-billed gull on 17/05.
K_C1	I	n/a	n/a	n/a	n/a	n/a	n/a	0	One adult sporadically visiting in April. No nest building.
K_C1	J					n/a	n/a	2	Nest J partly obscured behind another pair/nest.
K_C2	A	3/05	4/05	5/05	7/05	n/a	n/a	2	Nest hidden by vegetation early June.
K_C2	B	14/05			2/06	n/a	n/a	2	Nest hidden by vegetation early June.
K_C2	C	No data	No data	No data	No data	No data	No data	No data	No good view of nest contents (behind other birds). Incubation behaviour. Nest hidden by vegetation early June.
K_C2	D	No data	No data	No data	No data	No data	No data	No data	No good view of nest contents (behind other birds). Incubation behaviour. Nest hidden by vegetation early June.
K_C2	E	11/05	11/05					≥ 1	No view in nest after first egg laid. Nest hidden by vegetation early June.
K_C2	F	12/05	16/05	17/05	18/05	19/05	20/05	3	Nest hidden by vegetation early June.
K_C2	G	2/05	2/05	5/05	5/05	7/05	8/05	3	Seen copulating on 22/04. Nest hidden by vegetation early June.

Colony_Camera	Nest	Egg 1 earliest lay	Egg 1 latest lay	Egg 2 earliest lay	Egg 2 latest lay	Egg 3 earliest lay	Egg 3 latest lay	Clutch size	Notes
K_C2	H	11/05	12/05	13/05	17/05	18/05	23/05	3	Seen copulating on 10/05. Nest hidden by vegetation early June.
K_C2	I	8/05	9/05				20/05	3	Nest hidden by vegetation early June.
K_C2	J	n/a	n/a	n/a	n/a	n/a	n/a	0	No incubation behaviour. Nest hidden by vegetation early June.
K_C2	K	n/a	n/a	n/a	n/a	n/a	n/a	0	No eggs laid by 12/06.
K_C2	L	13/05	14/05		21/05	n/a	n/a	2	Nest hidden by vegetation early June.
T_C1	J	27/05						≥2	Date based on adult sitting day/night. Eggs not seen; two chicks July.
T_C1	L	31/05						≥2	Date based on adult sitting day/night. Eggs not seen; two chicks July.
T_C1	M	22/05						≥1	Date based on adult sitting day/night. Nest contents could not be viewed.
T_C3	?	19/03						≥1	One egg only still on 23/03; no further eggs seen. Camera stopped on 27/03.
W_C2	A	1/05	3/05					≥1	Suspect first clutch failed during or soon after hatch (no brooding) and second clutch of two eggs laid soon after. Sitting tight from late April to late July.
W_C2	B	14/04					27/04	3	
W_C2	C	2/05	2/05			n/a	n/a	≤2	Distant nest, detail not discernible.
W_C2	D	4/05	4/05					≥1	Distant nest, detail not discernible.
W_C2	E	1/05	2/05	4/05	10/05	n/a	n/a	2	
W_C2	F	24/04	25/04	26/04	4/05	n/a	n/a	2	Suspect first clutch failed during or soon after hatch (no brooding) and second clutch of two eggs laid soon after. Sitting tight from late April to late June.
W_C2	G	9/05	10/05	11/05	19/05	n/a	n/a	2	
W_C2	H	18/05	21/05					≥1	Distant nest, eggs never seen, lay dates based on sitting behaviour at night.
W_C2	I	9/05	10/05					≥1	Distant nest, no eggs seen but pair sitting tight day and night from 9/05.
W_C2	J	27/04	28/04					≥1	Distant nest, no eggs seen until July; pair sitting tight day and night from 28/04.
W_C2	K	18/04	18/04					≥1	
W_C2	L	15/04			19/04			≥2	
W_C2	M	18/05	18/05	19/05	21/05	22/05	26/05	3	Small amount of nest material on 11/03; nest blown away, rebuilt nearer laying.
W_C2	N	16/04	18/04	19/04	24/04	n/a	n/a	2	
W_C2	O	15/04	16/04	17/04	28/04	29/04	11/05	≥2	Laying of first clutch may have been staggered (details unclear). Brooding in early June, then pair incubating a likely second clutch in mid-June with two eggs seen clearly on 13/07.
W_C2	P	9/04	9/04	26/04	26/04	26/04	3/05	3	First egg laid during day, rolled out of nest, and was missing by evening.
W_C2	Q	8/05	9/05					≥1	
W_C2	R	5/05	9/05					≥2	
W_C2	S	22/05						≥1	
W_C2	T	No data	No data	No data	No data	No data	No data	No data	Nest hidden behind another in most images; not followed.
W_C2	U	22/04	22/04		30/04			≥2	Suspect first clutch failed during or soon after hatch (no brooding), second clutch of at least two eggs laid by mid-June.
W_C2	V	27/04			8/05			≥2	
W_C2	W	30/03	30/03					≥1	Suspect first clutch failed during or soon after hatch (no brooding), second clutch of at least one egg laid mid-June.
W_C2	X	12/04	13/04				24/04	3	
W_C2	Y	25/04	25/04				3/05	3	
W_C2	Z	24/04	24/04					≥1	
W_C2	&	11/05	13/05	14/05	16/05		24/05	3	An egg rolled out of this nest on 16/05; it was missing soon after (unlikely to have been moved back into nest).
W_C2	@	n/a	n/a	n/a	n/a	n/a	n/a	0	Non-breeding pair.



Fig 6: Adults sitting on nests at night incubating; adults standing at night on or next to nests yet to lay. A group of first-year birds roost on edge, to the left, of White Rocks nesting site.

Replacement clutches

No king shag pairs at any of the colonies were seen to re-nest after successfully rearing young. However, at least seven replacement clutches were known or suspected at two colonies—Duffers Reef and White Rocks—in 2019 following failure of first breeding attempts around the hatching/early nestling stage. None of these second breeding attempts was successful.

Adults at most nests in Duffers Reef Cam1 view were observed to be still nest-building in late July 2019, 2 months after the last of four recorded nest washouts between March and May following severe weather. It seems highly likely there were more nest washout events in the interim period between 10 May and 24 July when the camera was not operating, i.e., most pairs probably laid in June with all, but two attempts foiled by late July. Of the two attempts still underway in late July, one was a late-breeding pair (closest to the camera) with two nestlings in early August that both died, the last one on 20 August in another wave washout event. This pair re-laid two eggs on 21 and 27 September, 6 days apart, but both eggs disappeared soon after lay. They seemed inexperienced from the start of the season, based on site occupancy, nest-building behaviour, and the adult did not sit on the egg at night after it was laid.

One other pair nest-building through August, laid two eggs on 11 and 17 September. This was likely to be a second breeding attempt, with a likely first attempt between May and July when no images were available. This pair still incubated into mid-October, but colony disturbance on 17 October, when eggs were due to hatch, caused both eggs to be left unattended for 1.5 hours. These eggs were almost certainly predated (nest ruffled); so, it remains unknown if these late eggs were viable.

Five pairs (Nests A, F, O, U, and W) at White Rocks are thought to have double-clutched following a first failure as some birds that had initially laid in mid-April 2019 were seen incubating 3 months later. Pairs that double clutched are suspected or known as failing at late egg, hatching or early nestling stage in the first attempt. Observations of brooding behaviour (adult sitting with loosely held wings) around 1 month after first seen incubating support the fact that some eggs had hatched. Replacement clutches at four nests were all likely to have been laid between late May and late June (exact dates were not ascertained) based on the hatching event at one nest at the end of June, and the timing of the abandonment of eggs in the other three nests in early, mid, and late July. At Nest W, the pair failed between 13-15 May and began to stand again at night and sit sporadically by day for just less than 1 month when they commenced sitting again day and night on 12 June and a single egg was just discernible on 15 June (28-33 days after failure of the first clutch).

King shag pairs failing later than early nestling stage were not seen to re-lay at any of the colonies in 2019. For example, the second nest at Duffers Reef (Cam 1) that had survived potential bad weather events between May and July, lost a downy, standing, but not yet mobile chick on 20 August in bad weather. This pair resumed nest-building promptly on 22 August, as did all the other pairs soon after all their nests had been washed away, but none of the pairs were seen to produce any more eggs despite this behaviour.

At Duffers Reef (Cam 3), a pair that lost a chick in late July were observed engaging in courtship behaviour in early to late August and was the only pair nest-building in this camera view throughout September but did not re-lay. (They were also the first pair to be suspected of commencing moult on 11 October 2019—white feathers seen in their nest bowl.)

At Tawhitinui, two sets of parents of approximately half-grown, downy, mobile chicks that went missing following a major (human-induced) disturbance did not re-lay in 2019. And two pairs known to lose downy, recently mobile chicks at White Rocks—disappearances were unexplained with one corpse seen a few days later—did not re-nest in 2019.

Hatching

Outcome at hatching time could be observed at 34 nests at three colonies (Table 6). Exact first hatch dates were only known for two nests (one each at Duffers Reef and Kuru Pongi). Both nests also had accurate first egg lay dates recorded. The period between egg laying and hatching was 31 and 33 days, respectively.

Accurate hatch dates could not be recorded at other nests because parents were rarely standing in images. In addition, the dark grey downy nestlings were hard to see against the dark nests, particularly at White Rocks. Hatches were usually first detected by observations of clear brooding behaviour (adult sitting with loosely held wings), when chicks might already be 1 or more days old. On occasion, hatches were ascertained when eggshell suddenly appeared on or just outside a nest rim, sometimes seen in just a single image.

Hatch dates to within 1 day were known for two nests only (one each at Kuru Pongi and White Rocks). These nests also had first egg lay dates recorded to within 1 day. The period between egg-laying and hatching was 31-33 days for the Kuru Pongi pair. (For the White Rocks pair, the period was 41-43 days, but one egg failed at the nest, so the hatch recorded may not have been that of the first egg laid.)

Six other pairs with accurate first egg lay dates and latest first hatch dates only showed a maximum period of 29-39 days between first egg lay and latest possible hatch dates. Date ranges larger than this were disregarded in any analysis.

The shortest period between egg lay and hatch—29 days—was recorded at a nest where the egg was laid between 1530 h on 17 April and 0630 h on 18 April (most likely during the night) and the white egg was no longer apparent in the nest by 1500 h on 16 May. Note that a chick could not be confirmed at this point because the dark nestlings would not have been discernible against the dark nest material in this camera view; the first clear sighting of a chick here was not until June.

From the above limited data, it can be deduced that the incubation period for king shag eggs is likely to be 28-32 days if not counting the actual day of hatch.

Two of the seven known pairs that laid replacement (second) clutches failed to hatch their first eggs (White Rocks, Nests A and J). For other nests it was hard to pin-point the exact time and cause of failure, which may have occurred before, during or very shortly after hatch. Two failures were known at nestling stage: a single, short-lived, nestling was only seen once on the day after it hatched (White Rocks, Nest O) and brooding behaviour was noted for 2 days only at another (Nest W).

Of the 29 viewed pairs that could be confirmed hatching chicks at Duffers Reef, Kuru Pongi and White Rocks, there were three that were known to hatch only single chicks. Twelve pairs clearly hatched two or more chicks. The remainder are likely to have hatched more than one chick, but initial brood sizes could not be confirmed.

While it is likely there were three-chick broods that successfully hatched and were never seen on images, the only clear evidence of this was at Tawhitinui—not included in Table 6 as cameras were not operating at hatching time—where one nest was seen to contain two large, well-developed, banded chicks (clearly siblings) on 18 July 2019 and a third smaller chick.

Chick rearing

With initial brood sizes impossible to establish because of limited opportunities to view nest contents around hatching and early nestling stage, most commonly just one or two chicks were followed per nest during the rearing period.

Dates for key events during the growth and development stage were recorded for chicks in nests at three colonies (Table 7). Chicks were followed over varying periods at 33 nests—seven nests at Kuru Pongi, nine at Tawhitinui, and 17 at White Rocks.

With very few accurate hatching dates (Table 6), it was difficult to ascertain precise ages of chicks at key development stages in the rearing period. The only nest at Duffers Reef with an accurate hatch date recorded (B, Cam3) was not captured in images during the chick rearing period. Unfortunately, other egg lay dates recorded at Duffers Reef (Cam3) were in nests that could not be matched with nests in a different camera view later in the season, so ages could not even be roughly deduced from egg lay dates and a known approximate incubation period.

At Kuru Pongi, there were just two nests with reliable hatch dates to within 1-2 days (G, Cam1) and 1-3 days (E, Cam1), and chick ages could be calculated at events in mainly one of these nests up to feather completion in juveniles. The most accurate hatch date recorded at White Rocks was within 1-2 days (E, Cam2), but this chick died at 9-10 days old. Ages of all other chicks at key development stages could only be estimated.

There were no chick hatches observed at Tawhitinui and only one first clutch hatch at Duffers Reef (Cam3), so although there were good images of chick development from half-grown, there was no way to calculate chick ages at these two colonies. (None of the banded chicks at these two colonies could be accurately aged.) Just one chick age (Nest J, Tawhitinui) could be roughly deduced from lay date (earliest egg lay date 27 May, earliest hatch date 26 June assuming an approximate incubation period of 30 days), but this downy chick disappeared on 19 July 2019 at, or younger than 3 weeks old and could not be followed through development.

Few notes were made on plumage development at Duffers Reef: with limited viewing time, and good observations collected at the other colonies, the focus at Duffers Reef was to search for and record chick bands. Development of plumage was just loosely followed here to gauge the age range of offspring and note latest dates for plumage completion.

Nestlings and downy mobile chicks

Chicks could be seen at nests (heads out when adult sitting) from approx. 1 week of age. The single known-age chick at White Rocks was visible at 6-7 days. The four known-age chicks at two Kuru Pongi nests were first visible at 12-15 days.

Roughly, chicks were at least 2 weeks old before they were no longer brooded by day (adults began standing next to nest). Exact days this happened was noted at seven nests (Table 7 Notes column). Adults would stand close to chicks to start by day and tend to brood again at night.

Four known-age chicks at the two Kuru Pongi nests were 20-21 and 27-29 days old when they were first left alone by parents (Fig 7). It is estimated that most other chicks were unguarded for the first time at roughly 1 month old. Parents would tend not to leave chicks unattended for long; commonly to start a chick might only be alone in between one and three images (i.e., up to 2hrs at most). Chicks at Kuru Pongi were unguarded for several hours at a time by mid-July 2019.



Fig 7: Chicks in front nest unguarded for first time 26 July 2019. Both have also moved out of the scrape, i.e., sitting next to nest. Note three chicks from two nests in creche top right.

Table 6: Egg hatch dates (first clutches) at labelled nests on field camera images at three king shag colonies in 2019.

D = Duffers Reef; K = Kuru Pongi/North Trio; W = White Rocks

Colony_camera	Nest	First clutch size	Egg 1 earliest hatch	Egg 1 latest hatch	Egg 2 earliest hatch	Egg 2 latest hatch	Egg 3 earliest hatch	Egg 3 latest hatch	Early brood size	Notes
K_C1	B	2	10/06	18/06		22/06	n/a	n/a	2	
K_C1	C	2		16/06		Failed	n/a	n/a	1	
K_C1	D	2		26/06			n/a	n/a	1-2	A second chick possibly seen once but unclear.
K_C1	E	2	6/07	7/07	8/07	8/07	n/a	n/a	2	
K_C1	F	3		22/06				Failed	1-2	Not clear if a second egg hatched.
K_C1	G	3	4/07	4/07	5/07	5/07			2-3	Possibly a dead newly hatched chick or unhatched embryo (pink) outside nest on 15/07/2019.
K_C1	J	2		18/06			n/a	n/a	2	
D_C3	B	2	25/05	25/05	26/05	28/05	n/a	n/a	2	
W_C2	A	≥1		Failed					0	First clutch failed; no egg(s) seen on 4/06. Birds sitting tight from late April to end of July. Two eggs last seen 28/07, eggs gone 29/07.
W_C2	B	3						31/05	≥1	Dark chick against dark nest material; unclear how many chicks hatched.
W_C2	C	≤2		7/06		12/06	n/a	n/a	1-2	Distant nest, detail not discernible. Second egg or shell on nest rim on 12/06; second nestling probably died during or shortly after hatching as one chick only seen from 19/06 onwards.
W_C2	D	≥1							≥1	Distant nest, detail not discernible. One chick known to belong to this nest during rearing.
W_C2	E	2	11/06	12/06			n/a	n/a	1-2	Second egg last seen 17/06; fate unknown (failed to hatch or died around hatching time).
W_C2	F	2					n/a	n/a	0-2	First nestlings must have perished during or soon after hatch. No brooding behaviour seen when expected. Pair continued to sit tightly with two, presumably new eggs seen in June and eggshell on 28/06 indicating hatch, with chick only seen once on 29/06. Second egg incubated until 13/07 when finally rejected by pair; egg missing on 14/07.
W_C2	G	2		15/06	16/06	19/06	n/a	n/a	2	
W_C2	H	≥1		25/06					≥1	Distant nest, eggs never seen, lay and hatch dates based on incubation behaviour and first chick sighting.
W_C2	I	≥1							?	Distant nest, no eggs seen but pair were sitting tight day and night from 9/05 to middle of day 23/06 when bad weather caused adults to stand. Nest washed away by mid-afternoon (red-billed gull near empty nest site). Unclear if pair had non-viable (overdue) eggs, or small chicks at time of weather event.
W_C2	J	≥1		Failed					0	Distant nest, no eggs seen until July. Pair were sitting tight day and night from 28/04 to 24/06. Standing behaviour on 28-29/06 indicated failure? Egg not actually seen until 4/07 and presumed non-viable, egg missing by 7/07. Clutch size unknown.
W_C2	K	≥1		16/05					≥1	Chicks difficult to see in dark nest, so total hatches unknown.
W_C2	L	≥2		1/06		4/06			≥2	Chicks difficult to see in dark nest, so total hatches unknown.
W_C2	M	3		19/06		25/06		Failed	2	Clear brooding behaviour commenced 19/06 and first nestling died (corpse seen) on 24/06, probably after bad weather. Second nestling present 25/06. Unhatched egg seen on 2/07.
W_C2	N	2		30/05		Failed	n/a	n/a	1	One egg seen rolling out of nest on 24/05, missing the next day.
W_C2	O	≥2		1/06		8/06			≥2	Details unclear in Nest O but laying may have been quite staggered. Brooding seen in early June; suspect nestlings perished because of potential staggered hatch. Pair showed

Colony_camera	Nest	First clutch size	Egg 1 earliest hatch	Egg 1 latest hatch	Egg 2 earliest hatch	Egg 2 latest hatch	Egg 3 earliest hatch	Egg 3 latest hatch	Early brood size	Notes
										incubation behaviour again mid-June. Two eggs seen clearly on 13/07 and deserted on 14/07 were a likely second clutch. Failed eggs disappeared later, on 15/07.
W_C2	P	3		Failed		9/06			2-3	First egg laid during day, rolled out of nest, and missing by evening. Outcome of another egg unknown.
W_C2	Q	≥1		10/06					≥1	
W_C2	R	≥2		19/06					≥2	Early brood size determined by later sightings of two chicks.
W_C2	S	≥1		29/06					≥1	
W_C2	U	≥2		24/05					≥1?	No chicks seen. Suspect first potential nestling perished while parents continued to incubate through May; no brooding behaviour seen after first potential hatch. Seems unlikely pair sat for so long on remaining non-viable egg; alternatively, a potential second nestling also died. Pair must have re-laid sometime in June (at least two eggs by 17/06); there was no period of adults standing at night. Incubation continued into July. One egg may have rolled out of nest 5/07; other egg failed by 10/07, confirmed missing by 11/07.
W_C2	V	≥2		Failed		Failed			0	Pair likely to have failed at egg stage by 23/05; cause unknown. Pair did not re-lay.
W_C2	W	≥1		5/05					≥1	No chicks seen. Brooding behaviour first seen on 5/05, again 13/05, but no eggs or chicks in nest by 15/05. Pair re-laid by 12/06 (one egg seen 15/06) but were standing on empty nest on 16/07 (likely failure during or after hatch as no egg seen).
W_C2	X	3		Failed		24/05			2	One egg kicked or rolled out of nest on 18/05 and disappeared.
W_C2	Y	3		2/06					1-3	Chicks difficult to see in dark nest, so total hatches unknown.
W_C2	Z	≥1							1	Possible dead nestling in nest on 7/06; failure confirmed by adult behaviour.
W_C2	&	3		Failed				24/06	1-2	An egg rolled out of nest on 16/05, missing soon after (species unlikely to roll an egg back into a nest).

Table 7: Dates of key events during growth and development of king shag chicks at labelled nests on field camera images taken in 2019.

K = Kuru Pong/North Trio; T = Tawhitinui; W = White Rocks Note: Includes nesting outcomes for all Tawhitinui nests as only three observed here at egg lay (Table 5) and none at hatching.

Key events: First visible in nest = Chick sitting next to (not under) sitting adult in nest. Chicks can be seen before this only if adult is standing / First out of nest = first time chick seen sitting outside nest scrape/bowl / More mobile = chick moving away from natal nest and beyond adjacent nest / First time creche = chick joined by or joining another chick from another nest / Fully feathered = no traces of down left / First flight = absence of fully feathered juveniles from camera view then preening on return.

Colony_camera	Nest	Chick(s) first visible at nest	Chick(s) first seen unguarded	Chick(s) first out of nest	Chick(s) more mobile	Chick(s) first time creche	Chick(s) near size of parent	Juvenile1 fully feathered	Juvenile2 fully feathered	Juvenile(s) estimated first flight	Notes
K_C1	B	3/07	20/07	13/07	2/08	20/07			n/a		Only one chick seen from 8/07 onwards; mobile chick not easy to follow from 2/08.
K_C1	C	20/06	?10/07	7/07	19/07			29/07	n/a		Nest on edge of image frame during chick rearing; single chick not easy to follow from 2/08.
K_C1	D		16/07	21/07	3/08			17/08	n/a		Single chick reached fledging age.
K_C1	E	23/07	6/08			16/08					Nest obscured by vegetation before chicks (2) completed feather growth.
K_C1	F	5/07	1/08	1/08	9/08	20/07	15/07	22/08	n/a		Single chick reached fledging age.
K_C1	G	18/07	26/07	30/07	9/08	2/08		8/09	8/09		Staggered sizes of chicks in same brood. Two chicks reached fledging age.
K_C1	J	27/06	11/07	8/07	20/07	20/07	12/07	7/08	15/08		Nest J partly obscured behind another pair/nest site. Chicks fully exposed to rain 14/07. Unguarded for several hours at a time by 19/07. Chick plumage development staggered between two chicks.
T_C1	A		19/07		18/07		19/07	12/08	n/a		Nest site not in view most of March-June. Large, well-developed chick followed July onwards; often hidden by nests in front. Chick possibly banded.
T_C1	B		18/07		18/07		19/07	11/08	11/08		Nest site not in view most of March-June. Two large, well-developed chicks followed July onwards. Distant nest, so hard to see detail. Both chicks banded.
T_C1	C	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Nest site labelled but no activity here.
T_C1	D		25/07		18/07	19/07	25/07	15/08	n/a	20/08?	Nest site not in view most of March-June. Large, well-developed, banded chick followed July onwards. Chick often in creche with chicks at Nest H.
T_C1	E		18/07		18/07		19/07	7/08	n/a	20/08?	Nest site not in view most of March-June. Large, well-developed, banded chick followed July onwards.
T_C1	F	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Nest site not in view most of March-June. From July, nest site occupied all season by pair. No chick present 18/07. Non-breeding or failed breeding pair.
T_C1	G	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Nest site occupied by pair and their 2018 offspring. All three maintained a close bond through 2019, roosting together every night.
T_C1	H	-	18/07		18/07	19/07	27/07	18/08	20/08	03/09?	Nest site not in view most of March-June. Two large, well-developed, banded chicks followed July onwards. A third much smaller chick died in the nest on 19/07. Chicks often joined by chick from Nest D.
T_C1	I	-	-		18/07		n/a	n/a	n/a	n/a	Nest site not in view most of March-June. Large, well-developed mobile chick present with parent late afternoon 18/07; missing mid-morning 19/07.
T_C1	J	-	-		18/07		n/a	n/a	n/a	n/a	Big nest by 16/03, blown/washed away 18/03, rebuilt 28/03, gone 29/03, rebuilt 7/04, gone 22/04, rebuilt 23/4, mostly gone 26/4, rebuilt 29/04.

Colony_camera	Nest	Chick(s) first visible at nest	Chick(s) first seen unguarded	Chick(s) first out of nest	Chick(s) more mobile	Chick(s) first time creche	Chick(s) near size of parent	Juvenile1 fully feathered	Juvenile2 fully feathered	Juvenile(s) estimated first flight	Notes
											Continual sitting commenced 27/05. Over half-grown, banded chick present on 18/07, joined by sibling morning of 19/07; both missing by afternoon.
T_C1	K	-	8/08					20/09	20/09		Nest out of camera range (following camera movement) for bulk of images up to 15/06. Two chicks reached fledging age.
T_C1	L	-	-	-	-	-	-	-	-	-	Site nearest to camera; occupation date unclear as adults visited sporadically. Nest contents not visible March-June; nest out of camera view July onwards.
T_C1	M	-	-	-	-	-	-	-	-	-	Nest goes through cycle of disappearing and being rebuilt a few times. Nest contents not visible.
T_C1	N			18/07	18/07				n/a	-	Poor view most of March-June (looking up at nest). Chick mobile in late July and often not seen at nest. One adult and chick banded.
T_C1	O		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Poor view most of March-June (looking up at nest). Behaviour of adults indicated nestling in mid-July. Chick died by 31/07 (no rearing behaviour).
W_C2	A	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Two clutches; both failed. Pair occupied nest site to end of October.
W_C2	B		24/06	24/06	1/07	1/07	3/07	15/07	n/a	23/07	After fledging, single juvenile mostly monitored by its presence at natal nest at night, roosting with parents. From September, it seemed to be mostly in creche nearby with other juveniles but was very occasionally seen at its natal site with one or both parents, up to end of October.
W_C2	C		3/07	7/07	23/07	17/07			n/a		Chick/juvenile frequently in creche; difficult to discern growth and plumage development. A group of juveniles often in creche at site C, but single juvenile seen with parent(s) at site C at night.
W_C2	D	15/06	14/07	18/07		16/07			n/a		Distant nest. Chick/juvenile frequently in creche; difficult to discern growth and plumage development. Single juvenile seen with parents in mid-August, but mostly thought to be in creche with B and C juveniles. Thought to be alive at end of October, but not confirmed.
W_C2	E	19/06	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Dead chick next to nest 22/06; corpse missing by end of day. Pair occupied nest site to end of October.
W_C2	F	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Two clutches; both failed. Pair occupied nest site to end of October.
W_C2	G	26/06	13/07	11/07	16/07	12/07	n/a	n/a	n/a	n/a	Only one chick seen in nest by 22/06. Not brooded in day by 30/06 (adults stand next to nest). Chick probably roosting with other chicks as not always at natal nest site before dawn. Chick hard to pick out from other chicks in creche in vicinity of Nest G. From 25/07, only the pair were ever seen at site G; presumably, the chick perished between 23-25/07.
W_C2	H	1/07	15/07	16/07	n/a	15/07	n/a	n/a	n/a	n/a	Not brooded in day by 12/07 (parent stands next to nest). Chick missing by 18/07 probably related to bad weather on 16/07. Corpse was likely to be the one seen being scavenged by a black-backed gull 19/07; possibility chick was predated. Single adult only seen August to end of October. Possibly a less-experienced pairing: lack of staining on rock from previous season, late nest-building, failed breeding and only one adult remaining at site after failure.
W_C2	I	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Failed breeders. Pair occupied nest site to end of October.
W_C2	J	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Failed breeders. Pair occupied nest site to end of October.

Colony_camera	Nest	Chick(s) first visible at nest	Chick(s) first seen unguarded	Chick(s) first out of nest	Chick(s) more mobile	Chick(s) first time creche	Chick(s) near size of parent	Juvenile1 fully feathered	Juvenile2 fully feathered	Juvenile(s) estimated first flight	Notes
W_C2	K	31/05	23/06	27/06	11/07	22/06		22/07	n/a	23/07	Only one chick seen by 6/06. Not brooded in day by 14/06. Single chick/juvenile only occasionally roosting at natal site with parents at night; presumed in creche elsewhere. Juvenile never seen roosting with parents from 7/10 onwards (most other juveniles continued to roost at natal nest sites at this time). NB One of the earliest chicks to feather up and fledge.
W_C2	L		1/07		22/06	22/06		22/07	n/a	23/07	Only one chick seen by 10/06. Chick/juvenile only occasionally roosting at natal site with parents at night; presumed in creche elsewhere. Nest L often a creche site too. Juvenile still associating with parents end of October.
W_C2	M	11/07	23/07	23/07	15/08	24/07		23/08	n/a	26/08	Not brooded in day by 14/07. Youngest chick at site, with latest fledging in late August. Single juvenile still seen being fed on 4/09.
W_C2	N		8/07	20/06	1/07	1/07		19/07	n/a	23/07	Not brooded in day by 7/06. Chick often away from natal nest, in creche with other chicks, so may have been left unattended by parents earlier than 8/07. Juvenile roosting at night at nest with pair but mostly roaming in day.
W_C2	O	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Two clutches; both failed. Pair occupied nest site to end of October.
W_C2	P		24/06		30/06	24/06	14/07	27/07	n/a		Mobile chick often roosting away from natal nest with other chicks. Fledging not possible to follow as single juvenile impossible to distinguish amongst others during the day. Occasionally using natal nest site end of October.
W_C2	Q	26/06	n/a		n/a	n/a	n/a	n/a	n/a	n/a	Chick last seen at nest on 2/07. After disruption to colony (bad weather), chick was confirmed missing from nest by 10/07. Details unclear as camera was misted for many images. Pair occupied nest site to end of October.
W_C2	R	24/06	12/07	14/07	16/07		25/07		n/a		Two chicks seen on 27/06, but only one seen by 29/06. Fate of second chick unknown. Fledging not possible to follow as juvenile impossible to distinguish amongst others during the day. Occasionally discerned at natal nest site, but hard to see (cluster of close sites). Assumed alive by end of October.
W_C2	S	6/07	16/07	16/07	16/07	14/07			n/a		Nest too difficult to follow with time due to proximity of other nests and birds. Survival of single chick not known.
W_C2	U	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Two clutches; both failed. Pair occupied nest site to end of October.
W_C2	V	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Failed breeders. Pair occupied nest site to end of October.
W_C2	W	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Failed breeders. Pair last seen roosting together on 4/08; after this, only one adult seen roosting alone at night until September when a likely new mate started to regularly roost at the site.
W_C2	X		16/06	18/06	21/06	21/06	30/06	20/07			Not brooded in day by 1/06; only one chick seen from 5/06. Fledging not possible to follow as single juvenile impossible to distinguish amongst others during the day. Juvenile never roosting again with parents from 13/10 onwards (most other juveniles continued to roost at natal nest sites at this time). NB One of the earliest chicks to feather up.
W_C2	Y		24/06	28/06	30/06		12/07				Not brooded in day by 10/06; only one chick seen from 16/06. After mid-September, juvenile could not be discerned at nest.
W_C2	Z	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Failed breeders. Pair occupied nest site to end of October.
W_C2	&	30/06		11/07	16/07						Nest on edge of image; single chick difficult to follow once mobile. Clear view of juvenile still using nest site end of October.

Occasionally, chicks were seen leaving a nest before being unguarded, i.e., could be seen sitting next to (outside) the nest with an adult, but this was uncommon. Fairly robust data at White Rocks shows that chicks left the nest for the first time either on the same day or no more than 4 days later than the day they were first unguarded. One of the known-age two-chick broods at Kuru Pongi reflected this, leaving their nest scrape/bowl at 24-25 days old, approx. 4 days after they were first left alone.

Chicks were joined by or would join other chicks in or near one of their nests—creche behaviour (Fig 7). Generally, adults seemed very tolerant of other pairs' chicks. In fact, little obvious aggression was observed between adjacent pairs at this time, just occasional threat postures. First-time 'creching' was seen in the two known-age broods at Kuru Pongi at 26-27 days and 37-39 days old.

Creche behaviour was prevalent at White Rocks (Fig 8). All chicks showed this behaviour, either before they had left their nest (other chicks joining them in their natal nest) or within a week of leaving their nest (joining up with other groups of chicks).

Creche behaviour was also commonly observed at Duffers Reef (Cam3). This was not thought to be for warmth reasons as temperatures were often mild e.g., one chick that creched regularly at a nearby nest was roosting there at daybreak (0758h) when air temperature was 17°C on 2 August 2019, returning to its natal nest by 0828h. After losing its sibling, one downy chick (Nest O) was noted to creche overnight for the next few nights with a neighbouring chick (at M), and then later most regularly with a different neighbouring chick (S), indicating that this may have been a social behaviour. By mid-August, four offspring in this view were more often in a creche together than not.

Creche behaviour was not commonly observed with chicks at Tawhitinui (Cam1) except between the single Nest D chick, and a two-chick brood in Nest H. Nest D chick was particularly mobile and would more commonly join the Nest H chicks at their nest.

Once more mobile, leaving the vicinity of the natal and adjacent nests, chicks appeared to roam sporadically during the day, often not seen back at the natal nest until nightfall. Some chicks appeared to roost away from their natal nests at night—during the viewing hours—but would be seen back at their natal nests the next day with parents. The odd chick would have a spell (days and nights) where it was rarely seen back at the nest. It is not known if parents followed their chick to feed it, or if chicks occasionally received meals from other adults. This increased mobility occurred at 34-35 days of age, over a week after the creching behaviour, in one of the Kuru Pongi known-age broods. At some point, downy mobile chicks start standing to roost at night. All chicks were seen to stand at night by mid-August at Tawhitinui.

Roughly, chicks reached the size of their parents at around 5-6 weeks, at which point they were downy with feathers emerging. Most broods successfully reared to this stage were single chicks. However, at least two broods of two chicks were successfully raised to juvenile stage at Kuru Pongi (Cam1) in 2019; another nest with two chicks was obscured by vegetation before chicks were fully developed. At least one brood of two chicks was closely followed at Tawhitinui in 2019 after a third (smaller) chick in the nest died, and another brood of two went missing. Two juveniles were usually seen together at one White Rocks nest in 2018, but there were no two-chick broods in 2019. It required many consistent observations to determine a two-chick brood at sites where creche behaviour was prevalent, especially if camera operation started mid-season.

Plumage development and fledging

At Duffers Reef, some chicks were completely feathered by early August, but ages were unknown. They could be separated from first-year birds, by their immaculate plumage. At Kuru Pongi, two

known-age siblings hatching on 4 July were fully feathered by 8 September, with no traces of down left, at 65 days old. Two other broods hatching by mid-June at the latest were fully feathered by early August, and those that hatched by late June were fully feathered by mid-late August. At White Rocks, the first fully feathered juveniles were recorded in mid-July (Fig 8); these were birds that hatched in mid-May from eggs laid in mid-April, i.e., roughly 2 months old. The last chick at White Rocks to lose all its down was fully feathered by the end of August, again at 2 months of age.

At any one time in the breeding season, chick ages were spread across many weeks at all sites; for example, when Cam2 was deployed in late July 2019 at Duffers Reef, the youngest chick was immobile in its nest, while other older offspring were nearly fully feathered. The former chick was still a little downy in September. The timing of fledging was best observed at Tawhitinui and White Rocks in 2019 where there were wider fields of view.

At Tawhitinui, although fully feathered chicks (juveniles) were never really seen taking off, in flight, or landing in images, the first (oldest) birds were suspected to have fledged from early August, based on observations of their nests. A typical first sign was the absence of a chick from its nest for short periods, e.g., an hour mid-late morning, around the time the bird had shed all down. Another indication of a possible short excursion to water was that these birds, when next seen after being missing, would be preening.

Fledging behaviour of two of the younger chicks (siblings) at a nest closer to the camera was easier to monitor. Parents were away for much of the day in late August, leaving their fully feathered chicks at the nest site alone and returning at night, potentially attempting to force the young to fledge. Two days later, both chicks left the nest for around an hour in the middle of the day, most likely they were flying by this stage. One of the chicks left the nest again for an hour in the afternoon.

In early September, often the entire nest site area was deserted around the middle of the day for an hour or so, suggesting that all adults and juveniles were out at sea, and that all young had fledged. The pattern was repeated on other days, and so was unlikely to be attributed to disturbance. At this stage, it was unclear if adults were accompanying young on foraging trips.

In the previous 2018 breeding season, most Tawhitinui young were considered to have fledged by the end of September, with the youngest two fledging in October (after being left alone at the site on the last day of September). This was a little later than fledging time observed in 2019.

At White Rocks in 2019, the first four (oldest) juveniles are thought to have made their first excursion to sea on 23 July. These birds seemed to be missing around noon, and later in the afternoon successive images (1500-1600h) showed them at the site preening. The next day at 1000h only single adults and downy chicks (in a creche and youngest still being guarded) were at the nest site, indicating older juveniles and adults (mostly likely females) were out at sea. Adults and juveniles returned together between 1330-1430h, indicating they had perhaps been out to sea together.

A typical day of movements when both fledged juveniles and downy chicks were at White Rocks, was recorded on 30 July 2019. All birds had stopped roosting by 0830h. By 0930h, single adults (presumed males) and most juveniles were still present at the site; presumed females had departed (to sea). By 1030h, roughly half the males had departed, and all the fully feathered, flying juveniles had also gone—it is not clear if parents and juveniles departed exactly at the same time together. By 1100h, six younger chicks (some downy) and only three adults remained at the site. At noon, the young chicks were creching at the far end of the site. Mostly commonly a few adults were in attendance, but occasionally some days the chicks were 'unsupervised'. Adults and juveniles started trickling in again by 1400h, with numbers increasing over the afternoon while the younger chicks

remained in a creche. By 1800h, some of the young chicks have returned to their natal nest sites. The remaining adults were back by 1930h.

By 9 August 2019, all but one of the juveniles had fledged at White Rocks. A typical day of juvenile movements at this time was recorded on 15 August 2019 (head count 75 birds at 0500h). Adults still rearing chicks, and a scattering of other birds including a few of the juveniles, departed first. Approx. half of the older juveniles left by 0930h, around the same time as the bulk of failed breeding adults. More rearing and failed breeding adults departed by 1000h, and possibly a few more juveniles. Nearly all juveniles were missing, presumed out feeding by 1100h, and more adults had left. Most juveniles appeared to be back by noon, and all had returned by 1330h. From 1530h onwards, numbers of birds increased with each image as adults returned; the majority were back by 1730h.

The youngest chick fledged on 26 August, just 3 days after the last traces of down were observed to be gone, i.e., at just over 2 months old.

Therefore, of 26 viewed nests with confirmed breeding attempts at White Rocks in 2019, 11 juveniles (42.3%) were known to have fledged (from 11 separate nests) before September.

Juvenile movement and disappearance

Adults were spending more time away from the Kuru Pongi colony by late September 2019 and were likely to be abandoning their young to make them independent. In October, adults were occasionally seen back at the site but not seen interacting with juveniles.

Similar abandonment of juveniles occurred at White Rocks in 2019. None of the adults returned to roost at the nest site on night of 10 August; only a creche of what look like 14 juveniles seem to be roosting at the far end of the site by early morning. The weather did not look bad at all, so it is not known if this was intentional or not. However, in a different incident, adults chose to roost away from juveniles just before dark during an evening of bad weather on 12 August. Most adults had just got back to the colony by 1700h, but most disappeared again with the onset of bad weather, leaving behind what looked like the group of a dozen or so juveniles. Adults must have returned to the site during the night as they were present at 0500h.

Juveniles seemed to start wandering much further away from their natal nests after they had fledged. Most of the sightings of banded 2019 juveniles at Duffers Reef (Cam1) were made from September onwards. None of these juveniles belonged to nests within camera view—they only passed through briefly and were not seen to socialise with any birds from monitored nests. Observations in late October at Duffers Reef (Cam 3) confirmed the findings at White Rocks: that juveniles were departing independently from adults in the morning (often earlier) and arriving back at the site late morning to early afternoon. Juvenile movement away from natal nest sites peaked in November, when many different juveniles entered Cam3 view for the first time.

By late September/early October 2019, most juveniles at Tawhitinui (Cam1) were absent from nests in the morning, presumably at sea, as indicated by preening immediately on their return from late morning. By November, a typical day of movements by adults and juveniles was as follows: most juveniles departed (presumably to sea) by early morning leaving pairs at nests; last adults (presumably males, but not identified as males) departed the site by late morning; juveniles returned early to mid-afternoon; first adults returned early afternoon (likely to be the females); the remainder of adults were back by dusk.

Duffers Reef and Tawhitinui were rarely completely deserted by all shags in September/October. If they were, the most common time for a site to be vacated was around late morning and/or early

afternoon. At White Rocks, a few adults were commonly present with juveniles at the site in the middle of the day (when most other adults were away) but it was never known if these adults were supervising the group, nor if any were ever accompanying juveniles on foraging trips.

These patterns were reflected at Duffers Reef (Cam1) in December 2018. The early afternoon was the best time to count juveniles as this was when most adults were absent, after the juveniles had just returned. Adults then trickled back in over the afternoon.

White Rocks 2018 juveniles were also seen going out to sea as groups and returning together, in similar patterns. For example, after all birds vacated the nesting site during a night of bad weather on 4 September, around nine juveniles were the first birds to arrive back at the site the following late morning; there were no adults with them. After another bad weather night on 8 November causing an exodus from the nesting area, all the juveniles were notably still absent at 0530h when all the adult pairs had returned to the site in the morning, suggesting they were elsewhere as a group.

Two juveniles and their parents were followed at White Rocks on 11 and 12 October 2019 to further observe movements (of pair and young) through a typical day, providing further confirmation that juveniles at this stage in development are not accompanied to sea by either parent. On 11 October, juvenile M (known to have fledged 26 August) was seen with parents at dawn at nest site. One adult departed between 0730-0800h. Next the juvenile departed 1000-1030h. Finally, the second adult departed 1030-1100h. The first adult to return did so 1600-1630h. The second adult and juvenile were back at the nest 1730-1800h. On 12 October, juvenile N (known to have fledged on 23 July, i.e., approx. 1 month older than juvenile M) left independently between 0800-0830h. The first parent departed 0930-1000h, the second left 1200-1230h. An adult arrived back 1430-1500h. The juvenile was back at the nest next by 1630h but may have been there before this. The second adult was back 1630-1700h. Both adults left the nest for around 2 hrs just before dusk, and all three birds were roosting by 2000h.

The timing of the decline in juvenile numbers at each site is summarised in Table 2. Most juveniles were still visiting their natal sites, mainly only at night and sometimes sporadically, until they permanently disappeared. Dates were recorded (Table 8), where possible, of the last sightings of juveniles at their natal nests before camera operation ceased (or camera view was obscured).

The first two juveniles disappearing from White Rocks (Cam2) did so on 6 and 13 October 2019, some 2.5 months after fledging. They were the first to hatch at the colony (in May) and were also noted as being among the earliest to feather up. The conclusion that these birds were the first to successfully gain independence and disperse, was based on all subsequent similar observations and on the dates of fledgling disappearances at White Rocks. However, it was impossible to determine the actual fate—dispersed or perished—of juveniles that were no longer seen with parents or at natal nest sites after September, in this study.

Of 26 viewed breeding attempts at White Rocks in 2019, 10 juveniles (38.5%) were alive in October. With a similar number of nests present in the previous year (although breeding status was unknown), productivity was likely to be similar in September 2018, but may have been as low as 26% (just seven juveniles counted in October 2018 from approximately 27 nests).



Fig 8: Downy chicks and feathered juveniles showing creche behaviour, a few days before the first fledging event. Black-backed gull scavenging king shag chick corpse, and red-billed gulls foraging amongst nests.



Fig 9: Fur seal displaces several king shag pairs at White Rocks in November 2018, after breeding.

Table 8: Timing of disappearance of 2018 and 2019 king shag juveniles observed at four colonies from October 2018 to 26 November 2019.

Last dates of camera operation: Duffers Reef (D_C1, C2) and Tawhitinui (T_C1) - 26/11/2019; White Rocks (W_C2) – 25/11/2018 (no images between 26/11/2018 and 10/03/2019) and 31/10/2019; Kuru Pongi/North Trio (K_C1) - 19/10/2019 but vegetation had obscured all nest sites by 16/09/2019.

Colony_camera	Nest	Hatch year	Juvenile(s) (or chick*) last seen at natal nest	Juvenile(s) (or chick*) number last seen	Notes
W_C2	W	2018	13/10/2018	1	Juvenile seen being fed on 27/09 and 5/10. Missing mid-October 2018.
W_C2	U	2018	4/11/2018	1	
W_C2	Q	2018	14/11/2018	1	Possible presence at site on 18/11. Confirmed absent (no longer roosting) at natal site on 24/11/2018.
W_C2	O	2018	15/12/2018	1	A juvenile regularly roosted with parents until early December, but not on night of 9/12, and was not seen at nest after night of 15/12/2018.
W_C2	L	2018	20/12/2018	2	Originally thought to be a creche area (three juveniles occasionally noted), two juveniles were commonly seen together (siblings?) at Nest L right through to 18/12/2018.
W_C2	X	2018	20/12/2018	1	Juvenile roosted with parents right through to 20/12/2018, with the odd night (e.g., 19/11) not roosting at site.
T_C1	F	2018	18/01/2019	1	One of the youngest chicks in view when camera deployed late August 2018.
D_C2	F	2018	19/01/2019	1	
T_C1	O	2018	5/02/2019	1	One of the youngest chicks in view when camera deployed late August 2018.
D_C2	I	2018	23/02/2019	1	
T_C1	C	2018	11/03/2019	1	At least two of these three 2018 Tawhitinui chicks were known to be occupying natal nests still in April 2019, but April observations were made from a different camera view, so nest labels were difficult to determine.
T_C1	H	2018	12/03/2019	1	
T_C1	N	2018	12/03/2019	1	
D_C2	O	2018	2/04/2019	1	Close to being a first-year bird.
D_C2	E	2018	22/04/2019	1	Close to being a first-year bird.
K_C1	D	2019	15/09/2019*	1	*Vegetation obscures view of nests at Kuru Pongi. Juveniles still present but only upper body seen above the growing vegetation after this until view completely obscured by 19/10/2019.
K_C1	E	2019	15/09/2019*	2	
K_C1	F	2019	15/09/2019*	1	
K_C1	G	2019	15/09/2019*	2	
K_C1	J	2019	15/09/2019*	2	
W_C2	Y	2019	17/09/2019	0?	Juvenile survival unknown; possibly not old enough to be independent at time of disappearance compared to other similar aged birds at natal nests.
D_C2	G	2019	21/09/2019	1	Age unknown; unclear if independent or perished.
W_C2	K	2019	6/10/2019	1	One of the oldest chicks at colony, hatching in May and fledging in July.
W_C2	X	2019	13/10/2019	1	One of the oldest chicks at colony, hatching in May and fledging in July.
W_C2	L	2019	28/10/2019	1	
W_C2	R	2019	28/10/2019	1	
W_C2	B	2019	29/10/2019	1	
W_C2	C	2019	29/10/2019	1	
W_C2	M	2019	29/10/2019	1	
W_C2	N	2019	29/10/2019	1	
W_C2	P	2019	29/10/2019	1	
W_C2	&	2019	31/10/2019	1	
D_C2	J	2019	6/11/2019	1	Youngest chick, immobile in nest when camera deployed in late July. Still downy 21/09 (head, neck, and belly midline).
D_C2	A	2019	7/11/2019	1	
D_C1	-	2018	18/11/2019	1	
D_C2	B	2019	20/11/2019	1	
D_C2	C	2019	20/11/2019	1	The first chick to be recorded fully feathered by 8/08.
D_C2	D	2019	20/11/2019	1	
D_C2	F	2019	20/11/2019	1	Chick still downy 21/08. Band could not be read.
D_C2	I	2019	20/11/2019	1	Chick still downy 31/08.
D_C2	N	2019	20/11/2019	1	Chick still downy 25/08 (head and neck). Band could not be read.
D_C2	E	2019	22/11/2019	1	Nest often out of view behind other birds.
D_C2	L	2019	24/11/2019	1	Chick still downy 25/08.
T_C1	H	2019	24/11/2019	2	
T_C1	G	2018	25/11/2019	1	First-year bird routinely using known natal nest site with parents throughout 2019. Independency unknown.
T_C1	A	2019	26/11/2019	1	

Colony_ camera	Nest	Hatch year	Juvenile(s) (or chick*) last seen at natal nest	Juvenile(s) (or chick*) number last seen	Notes
T_C1	B	2019	26/11/2019	2	
T_C1	D	2019	26/11/2019	1	
T_C1	E	2019	26/11/2019	1	
T_C1	K	2019	26/11/2019	1-2	From July, top half of birds occupying nest seen only, nest bowl itself out of view. Not clear if chicks were banded. Only one juvenile visible after 24/11/2019.
T_C1	N	2019	26/11/2019	1	

Parental roles and nest attendance

Typical movements of male and female during courtship and prior to egg-laying in April at Duffers Reef (Cam3), were as follows: female departed after it was light (typically 0800-0900h) and returned middle of day; pair loafed together for a period (e.g., an hour) then male departed for afternoon, returning late afternoon to dusk. Sometimes, a female would disappear again in the afternoon and be back by dusk. And sometimes the male would also fit in a second excursion at the end of the day, i.e., both birds away from nest site twice in the day. Other pairs came and went a little more frequently through some days, most likely collecting nest-material, even though few images ever showed birds carrying nest material or arranging nests.

Once sexes had been distinguished at White Rocks (Cam2), it was noticed in March, prior to egg-laying, that males tended to stand at the nest in the morning, whereas females tended to sit on the nest in the afternoon.

During incubation, males were all occupying nests at daybreak while females were out presumably foraging, i.e., generally only males were at nests in the first part of the morning. Females returned from late morning to mid-afternoon, and by mid-afternoon generally only females were seen on nests while males were presumably at sea. Males then seemed to return between late afternoon and nightfall.

Good night viewing at Duffers Reef (Cam3) showed that males appeared to take over at the nest in the early hours, generally sometime between 0200-0400h, with all males ready on the nest by daybreak for the first day-time shift.

Just a few observations on feeding patterns for pairs rearing chicks were collected. One of the pair attending a nest with a small nestling at Duffers Reef (Cam3) tended to be the first to leave and return in the morning (other pairs were incubating), and both male and female squeezed in an extra foraging trip each. Once, the male was observed to feed the chick while standing next to the nest, while the female brooded it.

Movements of a male and a radio-tagged female attending their nestlings—brood size of two was ascertained later—were also documented for 2 days. The male made an extra excursion away from the nest—presumably, a foraging trip—later in the day once young had hatched. A typical day's movements in the nestling phase were as follows: male alone on nest in morning; female back mid-morning; male gone late morning, returning early afternoon; female gone just after that, returning mid-afternoon; and finally, male gone by late afternoon, returning to nest before dark.

Data on movements of males and females feeding more mobile chicks was not collected due to time constraints and a focus on collecting other data. In addition, once adults were no longer sitting at

nests there was no clear view of the upper back marking, and it was harder to find a pair where gender could be easily distinguished.

Juvenile begging behaviour, and parent-juvenile feeding events were so rarely caught on any of the cameras set to take one image per half-hour at any of the colony sites. For example, only two images taken from Tawhitinui Cam1 showed young begging, and no images showed any juveniles being fed by parents. Begging behaviour by fully feathered juveniles at White Rocks Cam2 was only noticed in a handful of images, and actual feeding of juveniles by adults was only seen twice.

However, on cameras set to motion sensor in December 2018, with multiple frames per minute, there were numerous events captured of juveniles harassing adults, and getting fed. There were several different juveniles at Tawhitinui and Duffers Reef observed exhibiting this begging behaviour.

Some interactions looked almost aggressive, with the juvenile virtually ambushing the adult as soon as it landed, and the adult fleeing afterwards. Sometimes the juvenile continued to chase the adult. Each interaction ranged from 2-5 minutes. Other similar intense incidences that did not result in a feed lasted 1-8 minutes. Ten harassments were counted on one day, half of these resulting in parental feeds. The longest time a juvenile was observed bothering its presumed parent was for over an hour (following and begging behaviour), but this was less aggressive than some of the other interactions. Actual feeding events (juveniles head inside parent's bill) lasted up to 30 seconds.

Breeding failures

Eggs failing to hatch, and the loss of young nestlings accounted for eleven breeding failures (first clutches) identified at 34 monitored nests in 2019 (Table 6). These failures at this stage were all at White Rocks (Cam2). It was impossible to deduce causes of failure at most nests, but two early losses coincided with bad weather (Nests I and Q).

At five nests (A, F, I, O and U), it was unknown if failure occurred at egg or early nestling stage as it was impossible to see nest contents around hatch time because adults so rarely stood up on nests, or images taken when birds were standing were so rare. Usually, eggs were suspected as having hatched if adults showed clear brooding behaviour, even if only for a day. Brooding behaviour was only briefly noted in one of these pairs (O), and another nest (I) was too distant to discern brooding behaviour. Four pairs went on to lay replacement clutches.

Two nests (J and V) were known to fail at egg stage. The pair at Nest J were sitting tight day and night from 28 April to 24 June. Standing behaviour over 28-29 June indicated failure; one failed egg was seen on 4 July and was missing by 7 July. This was unlikely to have been a replacement clutch as a second clutch would have been laid later in May and the pair would have been expected to continue incubation for longer before abandoning. The pair that failed at Nest V on 23 May were monitored after failure to observe behaviour and check for a replacement clutch: they immediately ceased sitting on the nest at night but continued sporadic sitting on the nest in the day, more so in the afternoon, until 14 June when neither bird sat on the nest in the day. The nest was not followed in detail after this.

Four nests (E, Q, W and Z) clearly failed at early nestling stage. A visible nestling in Nest E was seen dead next to its nest 3 days later, and one in Nest Q was missing a week after first being seen following some wet/windy weather. The nestling in Nest W was never seen, but clear brooding behaviour was noted on 5 and 13 May, and the nest was empty on 15 May. A dead nestling was seen in Nest Z.

The death of one of the two youngest nestlings at Tawhitinui (Cam1, Nest O) was likely to have been associated with the human disturbance for capture of chicks for banding on 18 July 2019. A second chick (in Nest H) perished soon after this event; however, this was the smallest chick (considerably so) in a three-chick brood and was likely to perish anyway.

A young nestling corpse was seen in Nest P at Duffers Reef (Cam3) on 24 July 2019 when the camera was reset following a similar chick banding event here, but it is unclear if this chick was already deceased when the team arrived on the island.

At White Rocks, only single chicks were raised at nests in 2019, but at least eight of the successful nests are known to have contained second nestlings that did not survive beyond early nestling stage (C, E, G, L, M, R, Y and X). There were highly likely to have been more nestlings lost soon after hatch.

There were just two losses of downy active chicks at White Rocks (Cam2) in 2019. The Nest G chick was over a month old when it disappeared 23-25 July with no explanation (no bad weather noted). The disappearance of the recently mobile Nest H chick by 18 July was most probably related to bad weather on the day it left its nest 2 days earlier. This corpse was thought to be the one scavenged by a black-backed gull on 19 July, but predation cannot be ruled out—this chick was unguarded for the first time on 15 July. A single parent only was seen August to end of October. Possible pair divorce following failure and late nest-building before laying characterise a less-experienced pairing, so exact cause of chick death remains unknown.

The three chicks that perished at the downy mobile stage at Tawhitinui (Cam1) went permanently missing on the day after the 18 July chick banding event (Nests I and J). They may have been prematurely forced off nests during the initial disturbance and/or unsettled after the stress of being banded (J), resulting in chicks being more vulnerable to misadventure or predation. (Certainly, one other banded downy mobile chick at this site was not seen at its natal nest [D] for 48-hrs on 19 July, highlighting the disruption, but it had returned by 21 July and survived.)

The impact of this type of disturbance could also be seen at Duffers Reef (Cam1). When the camera was reset on 24 July here, a creche of medium-sized downy chicks were huddled together on the far side of the nest area, and a banded downy chick was alone in the foreground. These were all displaced from natal nests that were not in camera view, most probably further up the slope. One chick displaced from Nest O (Cam3) on 24 July disappeared by 28 July, but it was the smaller of two siblings.

The loss of a half-grown chick—standing by mid-August—seen in Duffers Reef Cam1 view was attributed to bad weather; it was displaced from its nest (B) on 20 August and missing a day later. Images from the wider Cam2 angle showed a different mobile chick disappearing after 31 July.

Potential failures at juvenile post-fledging stage were investigated by observing roosting behaviour of known-aged (unbanded) juveniles with parents at natal nests and comparing with other pairs rearing young of the same age at White Rocks (Cam2). There was just one fledgling (Nest Y) that disappeared on 17 September 2019 that is considered to have done so prematurely when compared to the ages of the next birds to disperse (Table 8). Failures at this stage in development were not really assessed in the same way at the other sites as ages of offspring were unknown.

All failed breeding pairs, at all colonies were still noted to be regularly occupying their nesting sites right through to the end of the breeding season (e.g., 31 October at White Rocks). There was evidence that some White Rocks pairs may have divorced following breeding failure, e.g., Nests H and W, unless partners had perished. In the latter case, the pair (that failed in May) were last seen

roosting together on 4 August; after this, only one adult was seen roosting alone at night until September when a likely new mate started to regularly roost at the site.

One failed breeding pair was seen in courtship postures in late August. Breeding pairs rearing chicks between July and November were never spotted in images in such postures.

First-year birds

First-year birds (2018 juveniles) were distinguishable from the immaculate 2019 juveniles by their scruffier feathers, and white alar markings starting to become more defined. By August at Duffers Reef, current season (2019) juveniles seemed to have greyish feet until around October, while first-year birds had pinkish feet. After this, some first-year birds started to look more like adults in certain light, only with dark chocolate-coloured feathers instead of black (and one with dull blue eyes).

At least sixteen 2018 juveniles at three locations were known to remain at their natal colony into 2019. (White Rocks had no camera operating January to mid-March 2019.)

At Tawhitinui (Cam1), six banded 2018 juveniles stayed at the colony into 2019. In February 2019, they were often in a creche higher up the slope during the day. Four were still present at natal nests in March 2019, roosting there nightly, and interacting with parents (Table 8). By mid-April, at least one was still using the natal nest and the others were most often seen on the edge of the nesting area—after this, these first-year birds were mainly seen in front of the camera on the edge of the nesting site. One first-year bird (White03) stayed with its parents (Nest G) to November 2019; the parents were not seen to be breeding in July 2019. Interactions were never seen to be aggressive, and the three birds roosted together nightly. While this first-year bird was commonly loafing alone at the nest site, the bird was also presumed to be feeding at sea, from its patterns of movement. The feeding of this bird by parents was never captured on images.

At Duffers Reef (Cam2), four 2018 juveniles remained at the colony in 2019, dispersing between January and April. Another first-year bird was regularly seen left of Cam1 view at an unlabelled site up to mid-November 2019. This bird was sometimes seen there with an apparently non-breeding adult; the last interaction was noted on 2 August. Also, in the same location, two 2018 juveniles were seen together several times through April, sometimes allo-preening, with the last sighting of these possible 2018 siblings on 9 May 2019. A first-year bird with cut feet, muddy belly and a bloody-looking caruncle was seen on the day after a bad weather event on 20 August. It is not known how this bird sustained these injuries.

At Kuru Pongi, in early April-May 2019, only five 2018 juveniles were seen loafing right on the edge of the nesting area. Here, there was also two of these birds engaging in allo-preening behaviour in April. From mid-May, numbers increased to a group of around 10 birds. These first-year birds mostly arrived late afternoon to roost and were gone in the morning, with only a few around sporadically in the day. It is not clear why numbers swelled at this time, and if this area was potentially being used as a roost by 'floating' first-year birds from elsewhere.

Apart from interactions with parents, first-year birds were not seen associating with any of the current season breeding pairs or young at any of the colonies.

The change from first year to adult plumage was tracked for White03 at Tawhitinui (Cam1). By mid-August, plumage was generally a dark chocolate colour and the white wing bars were not extensive or well defined. The bird was suspected as being male, with two large white spots almost merging on upper back. By mid-October, the white wing patches were more defined and black feathers were

coming through, with some brown still on the wings. By mid-November, the transition into full adult plumage seemed complete.

This plumage transition was loosely followed in a first-year bird at Duffers Reef (Cam1) but was not the focus of viewing. Plumage in March 2019 was very worn and there were no white wing bars. White back patches were visible but not clearly defined in May. In August, the eye was noted to be a dull blue. Between August and mid-October, the white in the wing bar was becoming more obvious. In late October, there was a brownish tinge to otherwise adult plumage, and the transition seemed to be almost complete by mid-November.

Non-breeding birds

Apart from the single non-breeding pair at Nest @ in 2019, there were a few other non-breeders using the White Rocks (Cam2) area over the breeding months, but not committed to a nest site. 'Floating' adults were only ever seen on the edge or beyond the nesting area.

Two nests at Tawhitinui (Cam1) did not contain eggs or chicks on 18 July 2019; at least one (G) had an earlier failed breeding attempt (Bell, 2019), and the previous season's young still residing here.

Three nests (K, M and O) at Duffers Reef (Cam2) did not contain eggs or chicks on 24 July 2019; pairs at these nests were either failed breeders or non-breeders. A pair (L) in Cam3 low down the slope did not attempt to breed in 2019. There may have been non-breeding pairs at nest sites at Cam1, but the camera was not operating between May and July to confirm this.

Bird band sightings

A total of 329 readings were confidently made of 42 bands: 208 bands were clearly viewed on 22 birds at Tawhitinui in 2018 and 2019, and 121 bands were clearly viewed on 20 birds at Duffers Reef in 2019 (Table 9). Blurred sightings were noted but not included in totals.

Most bands were worn by chicks/juveniles when sighted. However, six bands were identified on adults: four at Tawhitinui and two at Duffers Reef. One of these adults was also radio-tagged.

Radio-tagged adult

The radio-tagged adult was a breeder at Tawhitinui (near Cam1 at bottom of image frame) that successfully reared two chicks in 2019 which were both still alive in late November. This bird was almost certainly a female identified by two small white spots on back and the bird's feeding pattern.

The tag, deployed on 18 July (Bell, 2019), was last seen on the bird on 29 July when the tape appeared frayed, and the tag was drooping slightly to one side. It was almost certainly absent by 31 July (confirmed missing by 7 August).

Movements were monitored for this pair on 27-28 July to check for any potential impacts on the female carrying the device: pair were present 0700h, tagged female gone by 0730h, female back by 1200h (male then departed), male back by 1415h (presumably to feed chicks although no image to show this), male gone again and female stayed at nest, male back by 1800h, tagged female gone by 0530h the next morning (definitely gone by 0630h), female apparently not back until 1515h (male then departed), male back 1800h.

Pair movement was monitored again on 8 August, after the tag had fallen off: pair together 0700h, female gone by 0715h, male also gone by 1100h (chicks unguarded), both back by 1315h, male gone again by 1415h, and male back by 1815h (dusk).

Table 9: King shag plastic numeric band sightings recorded in static images taken at Tawhitinui and Duffers Reef in 2018 and 2019.

Band colour	Band no.	Location seen	Cam	Date first seen	Date last seen	Images seen in	Age when seen	Notes
White	03	Tawhitinui	1	10/08/2018	22/11/2019	33	Chick/juvenile/1st-year	Bird maintained a close bond with parents at its natal nest right through 2019. Parents failed to breed in 2019. Possible male (two large white spots almost merging on upper back). Plumage changed into full adult by late Nov 2019.
White	04	Tawhitinui	1	24/12/2018	17/01/2019	2	Juvenile	Clear band reading.
White	07	Tawhitinui	1	11/08/2018	13/12/2018	2	Chick/juvenile	
White	10	Tawhitinui	1	10/10/2018	7/06/2019	23	Juvenile/1st-year	Still at natal nest when seen in Mar 2019 (but band not read on this date). Thereafter, seen roosting in foreground (near camera) at night.
White	11	Tawhitinui	1, 3	11/08/2018	28/10/2018	5	Chick/juvenile	
White	12	Tawhitinui	1, 2, 3	18/09/2018	1/11/2019	27	Juvenile/1st-year	Still at natal nest when seen in Mar 2019 (but band not read on this date). Thereafter, seen roosting in foreground (near camera) at night. Seen in multiple successive images in June and July 2019.
White	13	Tawhitinui	1	2/11/2018	2/11/2018	1	Juvenile	Single clear band reading.
White	14	Tawhitinui	1, 2, 3	15/10/2018	14/03/2019	13	Juvenile/1st-year	Last seen at natal nest 05/02/2019 (but band not read on this date). Thereafter, seen roosting in foreground (near camera) at night.
White	15	Tawhitinui	1, 2	3/09/2018	17/08/2019	38	Chick/juvenile/1st-year	Still at natal nest when seen in Mar 2019 (but band not read on this date). Thereafter, seen roosting in foreground (near camera) at night.
White	17	Tawhitinui	1	22/07/2019	8/08/2019	2	Adult	Radio-tagged breeder in 2019. Likely female, based on plumage and behaviour. Leg out of view for majority of images as nest on edge of image frame.
White	18	Tawhitinui	3	14/12/2018	25/03/2019	2	Adult	In Dec 2018, seen feeding a juvenile near camera. In Mar 2019, seen a minimum of 12 times with only five reasonable but not definitive readings.
White	19	Tawhitinui	1, 2	5/09/2018	5/10/2019	19	Juvenile/1st-year	Mostly seen roosting in foreground (near camera) at night up to Jun 2019.
White	20	Tawhitinui	1	18/07/2019	17/11/2019	3	Adult	Successful breeder in 2019. Smaller white alar patch than mate.
White	25	Tawhitinui	1	25/08/2019	24/11/2019	4	Chick/juvenile	
White	26	Tawhitinui	1	3/10/2019	24/11/2019	3	Juvenile	Often seen at nest but limited opportunities to read band.
White	27	Tawhitinui	1	6/09/2019	6/09/2019	1	Adult	Single sighting near camera.
White	28	Tawhitinui	1	18/08/2019	27/09/2019	3	Chick/juvenile	On nest distant from camera.
White	29	Tawhitinui	1	10/11/2019	22/11/2019	3	Juvenile	Presumed to be from a nest outside camera view.
White	30	Tawhitinui	1	19/07/2019	22/11/2019	6	Chick/juvenile	Band seen multiple times but not recorded every time.
White	32	Tawhitinui	1	18/08/2019	24/11/2019	7	Chick/juvenile	Band seen multiple times but not recorded every time.
White	33	Tawhitinui	1	21/09/2019	21/09/2019	1	Juvenile	Single slightly blurred band reading.

Gummer, H. 2021. Breeding biology of King shags from analysis of field camera images.

Band colour	Band no.	Location seen	Cam	Date first seen	Date last seen	Images seen in	Age when seen	Notes
White	34	Tawhitinui	1	18/08/2019	23/11/2019	10	Chick/juvenile	
Red	01	Duffers Reef	1	29/07/2019	29/07/2019	1	Adult	Adult plumage.
Red	02	Duffers Reef	1	12/08/2019	12/08/2019	1	1 st year?/adult?	Small white alar on wing? Difficult to age this bird at night in a single sighting.
Red	03	Duffers Reef	1	25/11/2019	25/11/2019	1	Juvenile	
Red	04	Duffers Reef	2, 3	30/07/2019	22/11/2019	17	Chick/juvenile	
Red	05	Duffers Reef	1	25/09/2019	19/11/2019	2	Juvenile	
Red	06	Duffers Reef	3	9/11/2019	9/11/2019	1	Juvenile	
Red	10	Duffers Reef	1	30/09/2019	16/11/2019	4	Juvenile	Also 2 blurred readings on Cam 2 (3/10 and 5/11/19).
Red	11	Duffers Reef	1, 3, (2)	8/11/2019	24/11/2019	5	Juvenile	Also 1 blurred reading on Cam 2 (30/10/2019).
Red	12	Duffers Reef	1, 3	25/07/2019	24/11/2019	8	Chick/juvenile	Also 1 blurred reading on Cam 2 (10/11/2019).
Red	14	Duffers Reef	3	21/09/2019	21/09/2019	1	Juvenile	
Red	16	Duffers Reef	1, 3	31/08/2019	11/11/2019	5	Juvenile	
Red	17	Duffers Reef	1	16/09/2019	3/10/2019	2	Juvenile	
Red	18	Duffers Reef	1	20/10/2019	16/11/2019	2	Juvenile	
Red	19	Duffers Reef	1, 3	17/10/2019	17/10/2019	2	Juvenile	Seen once at each camera.
Red	20	Duffers Reef	1, 2, 3	26/07/2019	26/11/2019	41	Chick/juvenile	
Red	21	Duffers Reef	1, 3	31/10/2019	20/11/2019	2	Juvenile	
Red	22	Duffers Reef	1	18/10/2019	17/11/2019	2	Juvenile	
Red	23	Duffers Reef	1	24/10/2019	21/11/2019	3	Juvenile	
Red	24	Duffers Reef	3	24/07/2019	20/11/2019	20	Chick/juvenile	
Red	25	Duffers Reef	1	19/10/2019	19/10/2019	1	Juvenile	

Human-induced disturbances

Trail camera setting/servicing/removal and the capture of chicks for marking were clearly the most disturbing human-induced events. The time it took for birds to return to sites was dependent on time of year.

After camera service on 13 December 2018 at Tawhitinui, birds did not come into view until over 3 hrs after the disturbance, but at this time of year all birds tended to be out feeding anyway, so the disturbance was minimised. Following camera set up and the departure of staff on 11 March 2019, birds took over 2 hrs to return to the White Rocks nesting area. Single adults or pairs returned by 1302h, with more partners returning by 1532h. A pair was recorded at all sites by 1803h, except Site @ (refer Non-breeding birds).

After chick banding at Tawhitinui on 18 July 2019, adults had returned to all nests within 15-30 mins of people leaving, and after that a banded first-year bird returned. Chicks only started to return to natal nests 1 hr after people had left, but it took 3.5 hrs for the last chicks to be seen back at their natal nest sites on this day, and 24 hrs for one chick (Nest J) to be reunited with its parents and sibling on the morning of 19 July. Disturbance associated with this event almost certainly caused the permanent disappearance of three downy chicks, i.e., two nest failures (I and J), and the 48-hr disappearance of another chick (Nest D) that survived (refer Breeding failures).

At Duffers Reef (Cam3) after a similar chick banding event on 24 July 2019, most chicks moved out of camera view except a small-medium chick (Nest S) which remained in its nest when people were at the colony and survived. There was also one nest containing an unattended egg, and one with a small, unattended chick corpse. Single adults (including the incubating adult) and mobile chicks had returned to most nests within approx. 1 hr of people leaving. Failure of the egg to hatch and the loss of the nestling may have been attributed to this disturbance if adults were displaced from nests for hours. In addition, the disappearance of a more mobile chick by 28 July (the smaller or two siblings) may have been linked to the banding event.

Adding weight to the fact that some downy chicks may have been forced prematurely from nests was that one chick (Nest N) in Duffers Reef Cam 3 view was absent from its nest in the first image following the chick banding event, but once it had returned (within half an hour) it was not seen outside its nest again until a week later, on 2 August.

At several colonies, the birds at sites nearest the camera seemed quite restless at night before the breeding season. The following behaviour is likely to have been caused by some form of 'light' emitted from the camera. Pairs seemed to accept the 'light' as the season progressed.

In December 2018, birds nearest Duffers Reef Cam1 tended to move away from the camera when roosting at night and move back near it in the day when loafing. At Duffers Reef Cam3, only one of each pair at two nests (H and I) nearest the camera roosted there in March 2019; partners were missing at night and returned at daybreak. Another pair in the foreground (unlabelled site) left their site nightly, returning before daybreak. Birds at the site nearest to Tawhitinui Cam1 (L) tended to move away during the night in April and early May 2019 and return before dawn. After this, the pair stayed there at night and other birds also roosted in front of the camera. Birds at nest sites closest to Kuru Pongi Cam1 tended to move away from their sites during the night and return before dawn and birds visiting by day did so sporadically. It is unclear if this behaviour was caused by camera disturbance, or if the sporadic behaviour was because less established pairs chose sites on the edge of the colony, near the vegetation line.

Table 10: Impact of boat activity recorded in static images taken at three king shag colonies between September 2018 and August 2019.

D = Duffers Reef; T = Tawhitinui; W = White Rocks

Colony_Camera	Date of incident	Time of incident	Boat activity	King shag response
D_C2	12/10/2019	1230h	One boat approached the site	Site mostly empty; birds had returned by 1300h
T_C1	3/08/2019	0600h	Boat lights before daybreak shone directly at colony and camera	No response at time image taken
T_C2	14/09/2018	1945h	Boat lights passing at night (1 image)	No response at time image taken
T_C2	8/10/2018	0715h	One boat passing in early morning (1 image)	No response at time image taken
T_C2	12/11/2018	0915h	One boat passing in morning (1 image)	No response at time image taken
T_C2	27/12/2018	1045h	One small boat passing through (approx. 4-person size)	No response at time image taken
		1515h	Two boats present, one small (2-person) possibly approaching	No response at time image taken
T_C2	30/12/2018	1945h	One small boat present (approx. 4-person size)	No response, site quite full of birds
T_C2	31/12/2018	1015h	One boat passing	No response, site quite full of birds
T_C2	1/01/2019	1615h	One boat present (approx. 4-person size), c.10-20m to land, facing island (not passing through)	No response, only four birds at site in previous image
T_C2	8/01/2019	1515h	One small leisure(?) boat, c.10-20m to land	Site empty from 1315h, with first two birds back 1515h and rest returning 1715h onwards (movements not unusual for date)
T_C2	25/01/2019	1645h	One boat present (approx. 4-person size), fairly c.10-20m to land	No response at time image taken, most nest sites occupied by one bird
T_C2	3/02/2019	1315-1415h	One small inflatable present 1315h, 1345h and 1415h (3 images), c.10-20m to land to land	No response at time images taken, no alert postures
T_C2	26/02/2019	1345h	One boat present	No response at time image taken
T_C2	2/03/2019	1215-1315h	One small fishing boat present 1215h, 1245h and 1315h (3 images)	No response at time images taken, no alert postures
W_C2	15/03/2019	1030h	Two boats moored near to the island	Site was empty (no birds)
		1100h	One boat much closer to island	Site still empty
		1130h	Boats gone	Most birds returned between 1130-1200h
W_C2	27/08/2019	1200h	Small motorboat entering view (passing)	Approx. 1 dozen birds (mostly juveniles) in alert posture, but no further impact noted

Not all camera views were useful for monitoring boat activity. Boats were seen near or approaching three sites on several occasions with no major impact (Table 10). If birds were displaced from the site—unclear if they flew off or stayed on land and moved out of camera view—, they were usually back in the next image or two. The longest times birds were kept away from the site was 1-2 hours (White Rocks) in March 2019 before egg-lay, when normally the nest sites were occupied by at least one bird during the day, and up to an hour at Duffers Reef in October 2019.

Boat sightings at Tawhitinui (Cam2) were more common with some very distant sightings not recorded. Most boats were not close to the island, so were probably just passing, and there was no discernible impact on the shags, particularly during the off-season when many birds were normally absent from the colony in the middle part of the day. The closest small boat would have been anchored an estimated 10-20m from the rocks (e.g., roughly four boat lengths away at a guess), and still birds did not seem to react at the time the images were taken.

Bad weather events

No storm or other bad weather events were seen to affect nesting behaviour at Tawhitinui over two seasons when cameras were operating. The site was only recorded as unoccupied on one evening after dark (12 October 2018) where it is possible birds were delayed returning to the colony and not necessarily caught out by bad weather; this coincided around the time of the last juveniles fledging. Nor were any notable bad weather events reported for Kuru Pongi during the time of camera operation.

In contrast, many bad weather events affected movements of birds at White Rocks (Table 11). On several dates in late 2018 the following was observed: the site was empty at nightfall and daybreak; or, only a small proportion of birds overnighted; or, only adults but not juveniles returned at night (once); or all birds vacated the site overnight and did not return until the following afternoon.

On a few dates in May and July 2019, nests were attended by single adults only late at night with partners (and non-breeding floaters) still absent at daybreak or back by morning. Partners were thought to be sheltering elsewhere overnight—either out of camera view, or even away from the colony—and returning in the morning. In July and August, downy chicks were often seen in a creche at one end of the White Rocks nesting area just after daybreak in bad weather events. It should be noted that occasionally, adults unexplainably failed to return to roost on a night when there did not appear to be really bad weather, e.g., night of 10 August when only a creche of what look like 14 juveniles were roosting at the far end of the site by early morning and adults arrived back by 0800h.

At Duffers Reef colony, there was a notable difference in the birds' response to bad weather depending on what part of the site they occupied.

Duffers Reef Cam 1 seemed to view a very exposed site. Between 12 March and 10 May 2019, adults were only seen roosting right up in front of the camera in bad weather (wet and presumably windy). Significantly bad weather was recorded several times in March-May and August (Table 11) resulting in loss of nests, young chicks, and even adults vacating the site for a night and day (Fig 5).

In complete contrast, the nesting area in Duffers Reef Cam 3 appeared to be quite sheltered as birds did not move away from nests in response to any bad weather, nest material never seemed to be blown away, and birds were rarely forced to roost away from the site on bad weather nights.

There were not any notably bad, prolonged weather events at Duffers Reef (Cam2); just occasional days and/or nights with wet and windy weather (e.g., 29 April, 18 August 2019).

Seals and other wildlife

On 26 October 2019 at 1225h, a fur seal (*Arctocephalus forsteri*) temporarily entered Duffers Reef Cam1 view causing all birds to vacate the nesting area briefly. On 29 October, all birds in view were seen to be 'fleeing' at 0657h and the camera was noted to have been knocked by 0929h.

A fur seal entered White Rocks Cam2 view on 15 November 2018 (1530-1600h) and left 3-4 hrs later. Shags remained at the colony; adults from affected nest sites were displaced all afternoon (Fig 9).

A sheep (*Ovis aries*) was seen once at the edge of the nesting site (1645h) at Tawhitinui on 3 September 2019; there were no shags in sight for at least an hour and this was not normally a time the birds would all be away. The birds had returned by 1745h.

Table 11: Impact of bad weather recorded at Duffers Reef and White Rocks king shag colonies between September 2018 and September 2019.

Note: No images at D_C1 between 24 May and 23 July 2019

Colony_Camera	Date of bad weather	Impacts at colony
D_C1	27/03/2019	Wave spray over birds, some nests completely washed away
D_C1	1/04/2019	Adults roosting by camera at 0525h. All nest sites vacated until 0847h; all but one nest washed away
D_C1	29/04/2019	Adults not at nest sites during night or morning and many nests washed away
D_C1	10/05/2019	Nests likely washed away but all out of camera view (camera drop)
D_C1	20/08/2019	Nests washed away and young chicks disappeared
W_C2	4/09/2018	No shags roosting overnight (site empty at 2230h and still at 0530h)
W_C2	5/09/2018	Less than 25 shags roosted overnight in camera view
W_C2	17/09/2018	No shags roosting overnight (site empty at 2230h and still at 0530h)
W_C2	12/10/2018	Rough seas and no birds noted at 1900h. Site empty at 2230h, most birds back by 0530h.
W_C2	8/11/2018	Likely no shags roosting overnight. Site empty at 2230h, adults but not juveniles back by 0530h
W_C2	4/12/2018	No shags roosting overnight (site empty 2230h and 0530h), Birds did not return until 1300h the next day.
W_C2	30/05/2019	No partners had returned to roost by 2000h, only 3 or 4 bird has returned by 0500h, and the bulk of partners were back by 0800h.
W_C2	13/06/2019	Rain from dawn into early morning (camera shake, and wet site and rough seas noted in daylight) around time when downy chicks present in nests. Impact unknown.
W_C2	23/06/2019	Wet and windy from 1530-2000h. Adult at Nest 1 off nest and no longer incubating. Nest was gone (washed away) by 1630h. No pair roosting there by 1830h. Adults had been sitting tight day and night since 9/05; unclear if nest contained non-viable eggs or small nestlings.
W_C2	3/07/2019	Nests attended by single adults only; all partners (and any non-breeding floaters) failed to return to camera view by 2230h and were still absent at 0500h the next morning. Downy chicks were in creche at far end of nesting area by 0630h. All partners and non-breeding floaters were back by 0830h.
W_C2	13/07/2019	Many king shags unusually sheltered on slope in front of camera after daybreak. Around 80 shags were counted in one image taken at 0830h on 14 July. (On a usual day, around 65 shags were in view: pairs, floating non-breeders, and large juveniles.) Extra birds were probably from nests out of camera view.
W_C2	15-16/07/2019	Only single adults in attendance at nests before daybreak, indicating partners were sheltering elsewhere. Partners started returning after 0830h.
W_C2	12/08/2019	Most adults had just got back to colony by 1700h, but the majority disappeared again with onset of bad weather, leaving behind a group of a dozen or so juveniles. Adults returned sometime 2230-0500h.
W_C2	17/08/2019	Mainly juveniles abandoned at site overnight. Adults started arriving back at colony after 0730h.
W_C2	23/09/2019	Roughly half the birds normally in view made it back to the site (camera fogged). The rest returned in morning at 0630-0700h.

Potential avian/mammalian predators

A Southern black-backed gull (*Larus dominicanus*) adult was seen with a medium-sized, downy king shag chick corpse on 19 July 2019 over a 6-hr period at White Rocks. It is not known if this chick was taken alive by the gull, or already deceased and scavenged by the gull; possibly the chick had already perished in bad weather. The same or another black-backed gull was back feeding on the carcass all the next morning (Fig 8). This time, most of the adult shags had left the colony, and the chicks were in a creche together at the far end of the nesting area. It is not known if the gull was the cause of the shag behaviour, or if there was another disturbance at the site and the gull was being opportunistic during the disruption. Later, a juvenile black-backed gull was feeding on the carcass, which was gone the following day.

Only two images were noted as featuring a black-backed gull out of all images viewed from July to November 2019 at Duffers Reef (Cam3), with no sinister activity observed. There were no significant notes recorded about gulls at Tawhitinui.

Red-billed gulls (*Larus novaehollandiae*) were spotted in images throughout most months at all colony sites, but not in numbers that were in any way alarming. The only obvious predation event was at Kuru Pongi (Cam1) when an abandoned (unattended) king shag egg (laid/dumped the previous night on bare rock in front of the camera) was broken by a red-billed gull. There were no

other images to suggest that red-billed gulls were a threat to king shags. Most commonly, they were seen wandering between nests, presumably foraging, and picking through nests when they were unoccupied by shags (Fig 8).

At Duffers Reef Cam 1, red-billed gulls featured in relatively few images in March to early May 2019 (nest-building period) but were frequently seen in many images from July onwards. A few images suggested that red-billed gulls either harassed the shags to regurgitate or, more likely, the shags were regurgitating pellets of mucous and indigestible material (a known behaviour in shags), and the gulls were opportunistically feeding on this regurgitant. Red-billed gulls were seen in the near vicinity of a nest that failed at egg and hatchling stage here, but no actual predation was observed.

On 17 October, when two eggs in a late second clutch were due to hatch, a disturbance caused the clutch to be left unattended for 1.5 hours, after which the nest was ruffled and returning birds exhibited behaviour associated with breeding failure. It is strongly suspected these eggs were predated opportunistically, most likely by a gull species.

A Western weka (*Gallirallus australis australis*) was seen in the Tawhitinui nesting area (Cam1) on 27 March; 7, 21 and 27 April; and 5 and 6 May, and several times during an unexplained disturbance on 9 October 2019 (see below).

A common brush-tailed possum (*Trichosurus vulpecula*) was captured on camera on 4 nights in March-August 2019 at Tawhitinui Cam2 but was only seen in the vegetation in front of the camera. No possums were recorded entering Cam 1 or 3 views of the nesting area during operating hours. No rat or mustelid species were seen in any images at this site, which is linked to the mainland.

No significant disturbances (other than weather and seal) were observed at White Rocks; birds at the nesting area were hardly ever seen in alert posture in 2018 or 2019.

Unexplained disturbances

Disturbances and disruptions at Duffers Reef and Tawhitinui, for which causes could not be identified, are summarised in Table 12. Only one mild response to disturbance was noted at Kuru Pongi (Cam2) on 25 April 2019: birds did not fly off but were notably focused/alert. Adults moved away from their nests by an estimated 1-2m at 1058h, returning within half an hour. They were then standing alert at 1456h, returning to business as usual within half an hour.

Note that the winter aerial king shag census was undertaken on 14 June 2019 (G. Taylor, DOC, pers.comm., 2021) and no disturbances were noted on this date.

Incidental sightings of other species

Spotted shags (*Stictocarbo punctatus*) roosted in the foreground at Tawhitinui (Cam2) from early November 2018 onwards, with two regularly visible at night, and occasionally three birds in view. A group of around 10 spotted shags were also seen briefly on the far side of the White Rocks nesting area in early September 2018.

A fluttering shearwater (*Puffinus gavia*) was observed at Moturaka/The Haystack.

Red-billed gulls and white-fronted terns (*Sterna striata*) were seen to roost in bigger numbers at White Rocks than at other sites.

Table 12: Impact of unexplained disturbances recorded at Duffers Reef and Tawhitinui king shag colonies between October 2018 and November 2019.

Colony_Camera	Date of disturbance	Impacts at nesting area in view
T_C1	12/10/2018	All birds failed to return to colony before dark but arrived during night or just before dawn. Unclear if disturbance at colony, or if birds caught out by nightfall and choosing to roost elsewhere.
D_C1	23/03/2019	All adults in alerted posture in one image (daytime).
D_C1	4/04/2019	Most adults moved away from nests in circumstances not attributed to bad weather.
D_C3	4/04/2019	All birds vacated site 0843-0914h. Note: Birds at D_C1 were unaffected.
D_C1	12/04/2019	All adults in alerted posture in one image (daytime).
D_C1	16/04/2019	Most adults moved away from nests in circumstances not attributed to bad weather.
D_C3	17/04/2019	All birds vacated the site between 1349-1419h.
D_C1	17/04/2019	Most adults moved away from nests in circumstances not attributed to bad weather at 1402h.
D_C1	19/04/2019	All adults in alerted posture in one image (daytime).
D_C1	25/04/2019	All or nearly all adults moved away from nests in circumstances not attributed to bad weather.
D_C1	4/05/2019	All adults in alerted posture in one image (daytime).
D_C3	3/06/2019	Minor aerial disturbance caused most birds to adopt alert posture (and look up) and a bird on a nest to get off, leaving two eggs exposed. This was likely to be another bird coming into land as the adult was soon back on the nest, and two other shags appeared to be scrapping very nearby.
T_C1	17/08/2019	Significant disturbance: all birds alert at 1100h and adults disappeared by 1130h leaving chicks at site. A further sequence of events (undefined) caused all nests to be vacated, and chicks to move out of sight by 1200h. Chicks returned 1215-1315h, forming a creche, but no adults had returned by dark (a first-year bird was alone at Nest G). Camera was fogged indicating cold and/or wet weather. By morning, all birds were back and roosting up slope among the higher nest sites.
D_C3	31/08/2019	At 1242h, the site was vacated (no adults or young in view) but was occupied again half an hour later. Not all chicks were fully feathered, so it is not likely they had fledged, but more likely they moved out of camera view due to a disturbance.
T_C1	1/10/2019	No birds at all present at 1115h due to disturbance. There was an unidentifiable, blurry object right in front of the camera. Birds began to return by 1145h, seemingly unaffected, although the object remained in view until later that afternoon, still unidentified.
T_C1	9/10/2019	All nest sites occupied by 1845h, then suddenly the whole nest site area was empty by 1900h. Only two birds were present at 0530h the next morning, but more began to return after this. It is not clear where the birds roosted or why they roosted elsewhere.
D_C1	17/10/2019	Significant disturbance with birds alerted at 0912h, and vacating nest area by 1155h. A few birds only had returned by 1256h resulting in loss of two exposed late season eggs (probably to gulls). Note: There was no disturbance noted in D_C3 at this time.
T_C1	22/11/2019*	All birds alerted at 0815h; no birds at all at site 0815-1030h. Birds were very slowly returning over the afternoon with 12 birds in view by 1515h. Most birds were back by 1800h.

*There were a few occasions at Tawhitinui Cam1 where it was hard to distinguish between a potential morning disturbance or a possible mass exodus of birds to sea to feed. There was also the possibility on some days that birds were still at the colony but had moved completely out of view temporarily to a potentially more sheltered location.

Discussion

Ten field (trail) cameras captured nearly 132,000 usable still images at four different king shag colony locations, providing a broad range of viewing opportunities to monitor the species' breeding cycle for the first time in 2018 and 2019. Data from just under 4,000 quality images was recorded and collectively used to gain an insight into daily colony activity from early nest-building in the late (austral) summer and autumn, through the entire winter breeding season. The decline in juvenile numbers through spring and summer was followed, and king shag movements at the colony sites through the off-season recorded.

Not every bird nor every nest at each colony was included in each trail camera view, so the proportion of a colony represented in each view was considered a sample of birds/nests. However, camera views thought to have captured a large proportion of all nests at a colony included some at Tawhitinui and those at White Rocks.

The White Rocks trail camera covered 28 nests (in both 2018 and 2019), which included 26, or a possible maximum of 27 breeding pairs in 2019. In comparison, Schuckard et al. (unpubl. data) counted 27 nests in photographs taken during the aerial census on 22 June 2018, and 28 nests on 14 June 2019, suggesting these were of breeding status. The latter figure closely matches the figure given in this study for 2019.

Tawhitinui (Cam1) included 20 of the 23 nests reported by Bell (2019) in 2018. However, far fewer nests were covered here in 2019, with 15 nests labelled out of a possible total of 28 nests counted from aerial photographs taken on 14 June 2019 (Schuckard et al., unpubl. data).

Two completely different camera views at Duffers Reef (Cam 1&3) together provided information on around 20 nests in 2019, and the single Cam2 covered 15 nests in 2019, but this was a much smaller sample of this colony relative to the mean of 74 breeding pairs observed at Duffers Reef from aerial surveys by Schuckard et al. (2018) in 2017 and 82 breeding pairs counted in 2019 (unpubl. data).

Only nine nests at Kuru Pongi were following for part of the 2019 season, less than a quarter of the 46 nests of breeding status counted from the air on 14 June 2019 (Schuckard et al., unpubl. data).

Details on nest-building, egg-laying, incubation, hatching, and chick development were captured well in the more close-up images at Kuru Pongi (Cam1&2), Duffers Reef (Cam1&3) and Tawhitinui (Cam1), with images from the latter two sites importantly producing most of the sightings of readable leg bands that had been fitted to birds in 2018 and 2019. Nests at Kuru Pongi provided the most accurate observations of clutch and brood size because the camera angle allowed the best viewing of nest contents. While chick ages were known at Kuru Pongi, viewing was difficult closer to fledging time and ceased soon after due to obstruction by growing vegetation in spring. Tawhitinui (Cam1) and Duffers Reef (Cam2&3) offered good viewing of downy, mobile chicks through to fledglings/juveniles, but exact ages were unknown because there was a break in camera operation mid-winter at both sites and lack of continuity between views during the incubation and downy chick-rearing phase.

The wide-angle views at White Rocks were ideal to monitor the movements, breeding effort and productivity of the whole colony as well as nest site occupation throughout the year. White Rocks Cam2 was not sharply in focus, many nests were far from the camera, and dark-coloured nestlings were hard to see in dark nests and in parents' shadows, so the detail of clutch and initial brood size was lost. Images from Cam 1 seemed to be of excellent quality—sharp, bright, good views into many nests—but unfortunately there was a camera malfunction in April 2019, so none of the breeding season was captured on this unit. Wide angle views at White Rocks, as well as Tawhitinui (Cam2), had a better view of potential disturbances to the colonies (e.g., boat appearances); however, more high-impact disturbances seemed to occur at the other colonies with close-up views (and limited views of the sea) where cause could not be ascertained.

Cameras that provided images with the most robust data on parental roles, particularly relating to gender during incubation, were those that looked down onto colonies from above, allowing sexes to be distinguished by an upper back plumage feature that was only visible when birds were sitting on nests. Both Duffers Reef (Cam3) and White Rocks (Cam1&2) facilitated this, and Tawhitinui Cam3 had great potential to collect similar data but was only running for less than 1 week in December 2018 and around 2 weeks in March 2019. All these cameras enabled viewing of nest contents.

In summary, no single camera provided excellent viewing throughout the entire year of all aspects of the breeding cycle, but each provided key images contributing towards understanding king shag breeding biology.

An increased image frequency obviously has a greater chance of capturing key events and behaviours but needs to be balanced with the restraints on viewing time for analysis. Cameras on time-lapse settings taking images at set intervals, e.g., every 15-30 mins, seemed to provide enough opportunity to see most aspects of the breeding cycles. Images taken any less frequently than 30 mins would almost certainly have missed key events and behaviours, compromised the ability to count eggs or nestlings—parents were so rarely seen standing on nests during this stage in the cycle—, and limited band-reading opportunities. Excellent detail was captured in files with multiple images taken per minute—while not necessarily intentional (nor efficient to analyse), this proved invaluable in ascertaining that some behaviours virtually unseen on single frames at greater intervals were indeed occurring. For example, one behaviour so rarely seen on 30 min time lapse frames was of parents feeding chicks, and yet this was proven to be an extremely common event seen on files containing multiple frames per minute, even many months after juveniles had fledged.

Viewing through the entire night was possible at Duffers Reef (Cam3) and this was invaluable in confirming that adults do not sit down at all at night unless they have eggs or small chicks in the nest, as well as identifying the timing of parental shift changes during the night.

Observations of the white plumage patterns on the upper backs of incubating king shags—mainly in two camera views—meant that sexes could be distinguished. Males tended to have more prominent white markings, taking the form of a saddle, or two large almost-merging white spots, or medium-sized (occasionally small) separated spots on the upper back. In contrast, their female partners in nearly all cases had much smaller distinctly separate spots which ranged from small-medium in size, with some so small they were hard to discern giving the impression of a completely black back. Further investigation is warranted to identify if this is a conclusive method for sexing adults that can be used at all colonies, for all pairings. There was just one pairing in all the images/files viewed to date (banded adult White18 and mate at Tawhitinui Cam3) where the upper back markings did not fit the general observed pattern for the sexes. The presumed male, based on relative body size and daytime movements, had distinct medium-sized spots while his mate had a small-medium patch of slightly merged spots. White18 was confirmed as a male by feather sampling (Bell, 2020).

In three nesting pairs where markings were less distinguishable between the two partners, it cannot be presumed these pairings contained males as only eggs were seen (no chicks). Although their feeding behaviour (pattern of departure to sea) resembled that of mixed sex pairings, it is possible these were female-female pairings, a situation that is known to occur in seabirds if there are surplus females at a colony, and that any possible hatches might have occurred if one of the females had copulated with a neighbouring male (G. Taylor, DOC, pers.comm., 2021).

White Rocks colony males and females had white upper back markings that were smaller than those on birds at Duffers Reef. While there were some 'saddled' males at White Rocks, there was a greater proportion of saddles in males viewed at Duffers Reef (Cam3). Again, further investigations would be required to determine the extent of intra- and inter-colony variations in these markings, which may reflect genetic variation between sites. This may possibly be achieved from aerial photography surveys used for census counts around May-July time.

It is possible that the white upper wing (alar) patches are slightly more extensive on male king shags (and related to the size of the upper back patches), but this needs further investigation as it could be a useful gender identification tool when birds are standing, and when looking across or up at nests.

Surprisingly, a few females at Duffers Reef were noted to have slightly larger caruncles than their male partners. This needs to be verified; caruncles would need to be observed throughout the

season on both male and female to identify the exact time in the season that it becomes larger/brighter as this may differ between sexes.

Off-season viewing through summer 2018/19 found that nest sites were retained year-round but were not strongly defended by the end of the year (2018), at a time when juveniles were also disappearing. Distinct nest sites were occupied sporadically by pairs at the start of the year (2019), and there was a variation between colonies in the timing that pairs commenced shifts to facilitate 24-hr presence at the nest site to defend it, most likely to anchor nest material—and even guard it from potential thieves(!)—once nest-building commenced February-April. Presumed less established pairings, often on the periphery of the nesting area and in front of cameras, started nest-building at later dates and often took longer to coordinate nest attendance; consequently, their nests were more prone to disappearing, and they appeared less experienced, building numerous nests from scratch. These were the pairings seen more often engaging in courtship behaviours, some of which had not previously been described for the species in Marchant & Higgins (1990), such as mutual 'sky-pointing', 'biting', and 'neck-crossing'. Non-breeding pairs did not remain constantly at the site day and night, and therefore a nest was not always present. Nest-building was a behaviour that could be seen for many months, from late January at Tawhitinui right through to October at Duffers Reef, the latter being very late second breeding attempts.

The exposure of different colony nesting areas to the elements was easiest to see during nest-building. Some nests used in 2018, at colonies in more sheltered and/or elevated locations seemed to remain to the 2019 season in the form of muddy mounds (accumulated guano and vegetation), and birds did not seem to have great difficulty in building large nests, e.g., Duffers Reef Cam3, Kuru Pongi and Tawhitinui. In contrast, White Rocks was assessed as being an exposed site—to wind and rain—by the lack of nest mounds from one season to the next, despite being reasonably elevated. And the lower nesting area on Duffers Reef (Cam1) appeared to be one of the closest to sea-level with nests regularly washed away by waves, and birds covered with sea spray, all caught on camera in rough weather.

In the off-season, birds rarely sat down on land. Pairs only started to sit at nest sites, at first by day, when they commenced nest-building. As soon as birds began to sit, nests were established and more likely to withstand the elements. Pairs, however, would always stand on or next to their nests at night when roosting until the first egg arrived (usually at night), after which they sat day and night.

Clutches, most commonly two or three eggs, were laid over a 5-7-week period, and in 2019 laying started in mid-March (Tawhitinui) through to early May (Kuru Pongi), with the greatest first clutch lay date range seen at Tawhitinui (10 weeks). Earliest eggs were laid in nests higher up slopes at Tawhitinui and Duffers Reef, and some of the latest clutches were laid in peripheral nests near to cameras. Three-egg clutches were observed to take from 6 to 13 days to complete for different females, most likely linked to age and/or experience.

Eggs were likely to be incubated straight after they were laid—an incubation period of 28-32 days (excluding day of hatch) was established for king shag eggs—with parents sitting tight day and night from the date the first egg in a clutch was seen. Consequently, most nests would have had staggered hatches, and this was suspected as being the primary cause for loss of young nestlings when adults were still incubating eggs and brooding chicks at the same time. Few failures could be reported as definitively occurring at the egg stage as it was just too hard to discern nest contents around this time. But in general, the bulk of breeding failures (around one-third of 34 nests monitored in 2019) were thought to have occurred before, during or very shortly after hatch. All failed breeding pairs, at

all colonies were still noted to be regularly occupying their nesting sites right through to the end of the breeding season, with one divorce and re-pairing noticed.

King shag pairs laid replacement (second) clutches but only after failure at either egg or young nestling stage and no later. Replacement clutches are known to be laid in another marine, pink-footed shag if the first clutch fails, the Macquarie Island shag (Michaux, 2013). Some pairs continued sitting on nests between clutches, so it was hard to define lay dates of second clutches. But at one nest, it was seen that the pair laid their second clutch around 1 month after the loss of the first brood. Second clutches at White Rocks were laid around a similar time, or not much later, to the last breeding pairs laying first clutches at Kuru Pongi (late May and June). At the low-lying nesting area at Duffers Reef, most vulnerable to weather disruptions, second breeding attempts caused some king shag pairs to be sitting on nests as late as October. No second attempts were successful in 2019.

For pairs that went on to successfully raise first-clutch chicks, it was suspected that many second (and even third) nestlings hatched but perished early on during brooding—not seen in images—as most successful pairs at Duffers Reef (Cam3) and Tawhitinui reared single chicks, and all broods were single chicks at White Rocks in 2019. Two-chick broods were common at Kuru Pongi. There was only evidence at one Tawhitinui nest that a three-chick brood had survived beyond small nestling stage; however, the smallest chick perished when the others had reached downy, mobile stage.

King shag chicks were visible at nests, while adults were sitting, from approx. 1 week of age. They were at least 2 weeks old before they were no longer brooded by day, and most were unguarded for the first time at roughly 1 month old. Most chicks left the nest for the first time within 4 days from first being unguarded, around the time creche behaviour was obvious at all four colonies (although to a lesser extent at Tawhitinui), and increased chick mobility was apparent from around 5 weeks. White Rocks seemed quite exposed, so here creche behaviour may have been a good way to keep warm, especially when all adults vacated the colony. At Duffers Reef it seemed likely to be a social behaviour as temperatures were not as cold and the colony site (Cam3) seemed not as exposed.

Failures at downy, mobile chick stage were far fewer than those at early nestling stage and were mainly attributed to bad weather and/or chicks going missing—i.e., wandering away from nests and potentially suffering some form of misadventure or predation—particularly following human disturbance. The event of accessing the colony to capture and band chicks is likely to have caused the premature displacement and loss of three mobile chicks at Tawhitinui. One of these chicks would have been 3 weeks of age, or younger, and therefore was unlikely to have been left unguarded before this event, or to have roamed away from the nest prior to this disturbance. Chick loss caused by this intervention seems almost unavoidable given the staggered season and overall is probably acceptable for the significant gain in knowledge made by banding whole chick cohorts.

The strong creche behaviour shown by king shag young made it hard to keep track of individuals without bands as many roamed sporadically during the day, often not returning to the natal nest until nightfall, if at all (overnighting in other nests). Growth and development could not be related to precise age in the banded chicks at Tawhitinui and Duffers Reef as ages were unknown. Strong creche behaviour from an early age can also mask pairs' brood sizes if not observing on a continual basis.

At all sites, chicks reached the size of their parents at around 5-6 weeks and were fully feathered and ready to fledge by around 2 months of age. Fledging occurred in winter and spring, between late July (e.g., White Rocks, 2019) and early October (e.g., Tawhitinui, 2018). Fledglings may have been accompanied to sea for the first time by a parent although it could never be confirmed. But in

general, juveniles appeared to depart in loose groups with other juveniles and return together by early afternoon, before the adults. The most common time for a colony to be vacated was around late morning and/or early afternoon during September and October. During bad weather events at White Rocks, juveniles were observed moving quite independently from adults from September.

Juveniles wandered much further away from natal nests after they had fledged, e.g., from September onwards at Duffers Reef, with movement away from natal nest sites peaking here in November—banded juveniles entering different camera views for the first time.

After the 2018 breeding season, a proportion of juveniles were known to disappear by the end of the year, with juvenile sightings decreasing through October-December as they reached 4.5-5 months of age. Most juveniles still visited natal sites, mainly only at night and sometimes sporadically, until they permanently disappeared. This disappearance of young was assumed to be dispersal, but Bell (2020) indicates that this gradual decline in numbers reflected in sighting patterns of banded young at Duffers Reef and Tawhitinui in 2019, was attributed to mortality. Banding studies should reveal in future whether some surviving juveniles permanently leave the natal colony at this time.

Productivity could only be calculated for White Rocks (2019) and was 42% of young fledging from 26 nests with breeding attempts, or 41% of 27 attempts accounting for an additional breeding pair potentially situated just out of trail camera view but within view on images taken during an aerial survey made on 14 June by Schuckard et al. (unpubl. data). If the birds that disappeared prior to December were likely to have perished rather than dispersed, then productivity was as low as 11% (three juveniles from 26 or 27 nests).

This study was able to confirm that adult females tended to leave the colony at first light to feed at sea in the morning, returning in the middle of the day, and males then departed to sea returning late afternoon to dusk, as suggested by Schuckard (2013). Males were seen at one colony to take over at the nest generally sometime between 0200-0400h during the night, ready for the first day-time shift. Variations on this theme occurred at different stages in the breeding cycle whereby one or both birds in a pair would fit in additional feeding excursions during the early chick rearing phase. Gender was harder to follow (using the upper back markings) once birds ceased sitting on nests; alar markings could prove useful to distinguish gender through later chick rearing, and when juveniles are harassing parents for food prior to independence.

Males may generally spend less time sitting at the nest outside the period of incubation/brooding than females (e.g., prior to egg-laying, and following breeding failure), but this needs further study.

A proportion of 2018 juveniles remained at all colony sites into 2019 and through to various months before, during and even after the 2019 breeding season. They were often observed allopreening, presumably with parents, but also with immature birds suspected as being siblings or other same-age birds they 'creched' with as chicks/juveniles.

At least two first-year birds (one each at Tawhitinui and Duffers Reef) were known to stay at natal nest sites to late November 2019, when cameras stopped operating. They were predicted to have completed the transition into full adult plumage by 18 months of age. Interestingly, the bird still with its parents at Tawhitinui did not appear to be one of the latest reared chicks in 2018. From mid-July, the pair was assumed to be non-breeding based on their behaviour and the presence of their 2018 offspring; however, Bell (2019) notes that this pair were failed breeders in June 2019. The feeding of this bird by parents was never captured on images; however, Bell (2019) directly observed it being fed by a parent every month January-June 2019.

Forty-two banded birds (36 juveniles and six adults) were re-sighted in images at Duffers Reef and Tawhitinui, providing an important addition to the re-sighting data collected via boat observations (M. Bell., pers. comm., Sept 2020), thus providing a picture of dispersal and attrition in king shag juvenile cohorts. Observations of a radio-tagged adult female did not reveal any obvious negative impacts caused by carrying the device before it fell off around 20 days after attachment.

A level of bad weather can be tolerated at most sites by king shags. Heavy winds and rain overnight often resulted in many birds leaving their nests, if there were no eggs/chicks present, to roost relatively tightly together; sometimes this was close to the camera where perhaps it was more sheltered. Birds resiliently started rebuilding immediately after a nest was lost. During the incubation and rearing phase, it was more likely that one adult remained at the nest while the partner roosted somewhere more sheltered out of camera view. And juveniles would group up and shelter together in a creche through the night, even if parents were caught out by conditions and failed to return until the following day. However, bad weather had a significant negative impact on the king shag breeding cycle at the low-lying nesting area on Duffers Reef (Cam1) where nesting attempts were thwarted and delayed by multiple wave washout events, pushing repeat nesting attempts late into the season. It is easy to see that rough, high seas could impact in the same way at the more exposed colonies such as White Rocks in any season, even if not seen during this analysis.

There were no incidents seen in images during the 2019 breeding season when all nests with eggs and/or nestlings were abandoned due to a boat disturbance at any colony. The longest times birds were kept away from the site by the presence of a boat was 1-2 hours before breeding had started at White Rocks. A similar event during incubation and young nestling stage could have fatal consequences on breeding efforts and so boat disturbance remains a high risk to breeding king shags from March (first clutches) to at least August (most replacement clutches).

Only two incidents of fur seals entering colony nesting areas were captured on camera (at White Rocks and the low-lying area on Duffers Reef), and a third suspected. These were all outside the king shag breeding season. One animal displaced birds from their sites for up to 4 hrs; an appearance like this during the early breeding season would inevitably destroy several breeding attempts. Sheep also have the similar potential to disrupt events at Tawhitinui if occurring at a critical time in the season. Possums were not seen among nests through the breeding season at Tawhitinui, but cameras were not set to take images all night. King shags sit tightly through the night during egg and small nestling stage, so possums are unlikely to have an opportunity to predate eggs and young. Predators such as rats and mustelids were not noted in any images at this mainland site.

In all viewing analyses, it was concluded that gulls do not present a primary threat to breeding king shags. There was no single incident where the death of a chick could be directly attributed to predation by black-backed or red-billed gulls—scavenging was suspected—, and any eggs known or suspected as being predated by either species were done so opportunistically, when eggs were left exposed in nests, due to another disturbance, or were already lying on bare rock outside nests. Red-billed gulls were regularly present at colony sites foraging opportunistically in and around nests, and could even play a beneficial role in removing parasites from nests (G.Taylor, DOC, pers.comm., 2021). A limited number of images suggest these gulls utilise regurgitated shag pellets as a food source. Only a few images revealed shags regurgitating, and no pellets were ever identified or noted in images—either difficult to see, or not present if picked apart immediately by gulls—; this is another behaviour thought to occur on a regular basis in king shags (R. Schuckard, pers. comm., 2021) yet was rarely captured on images in this study. The weka was not identified at all as an avian species of threat to king shag productivity in this analysis.

The more productive nesting areas in camera view appeared to be Kuru Pongi and the sheltered Tawhitinui (both estimated as >10m above sea-level) and higher area on Duffers Reef (Cam3), with most of the two-chick broods successfully reared at Kuru Pongi (at least to near fledging stage) where there were relatively fewer disturbances noted; Duffers Reef and Tawhitinui received the greatest number of unexplained disturbances or disruptions. White Rocks generally received less overall disturbance than other sites—birds rarely seen alerted over seasons—but appeared more exposed to the elements and may be why creche behaviour is prevalent here and all pairs reared only single chicks in 2019. The most vulnerable nesting area subjected to most disruption—rough seas, seal intrusion, and unexplained disturbances causing temporary exodus from the camera view or alerted/alarmed postures—was the low-lying (<5m above sea-level) area Duffers (Cam1), with no breeding output at nests in camera view in 2019.

Use of static field cameras to study king shags has proved invaluable in gathering data and observations that were previously unknown. While birds occupying sites nearest to cameras seemed quite restless at night before the breeding season, choosing to roost away from the cameras and returning before daybreak, they seemed to adapt to the cameras as the breeding season progressed. Overall, cameras probably affected king shag behaviour to a small degree (at night only), but their presence did not directly cause any nest failures. Birds nesting near to cameras at all sites were deduced to be less established pairs anyway (from day-time behaviour) on the edge of the main nesting area. The benefit of using cameras is likely to outweigh any negative effects on roosting behaviour at night.

This study had also provided significant information that can be related to breeding surveys of king shags which are conducted annually through photographing colonies from the air and independently assessing these aerial photographs to identify active nests of breeding status. Schuckard et al. (2018) was concerned that birds seen sitting on nests in winter (e.g., June) aerial surveys were presumed to be 'effective breeders', yet their breeding status was not really known. Image analysis in this study provides useful information on this. Known breeding birds were seen sitting on nests by day, especially in the afternoon, even when eggs were not present and sometimes for many weeks before eggs were laid. While some pairs would sit sporadically following breeding failure (again, often more so in the afternoon), other pairs, particularly at good nest sites with no disruption, would sit tightly until a replacement clutch was laid or until they eventually abandoned. Overall, sitting on a nest was seen as quite a strong indication of breeding (incubating or brooding), or the intention to breed (first or replacement clutch). Therefore, observations made in this study corroborate the assumption that king shags sitting in a horizontal position on the nest are breeders or pre-breeders and therefore should be included in the annual census results.

Schuckard et al. (2018) also questioned the status of an empty nest bowl with a bird(s) next to it, in winter aerial photographs. Knowledge from this study shows that such a nest seen in the middle of the day (at the time when censuses were conducted) could be interpreted as any of the following, if it is seen in the context of the colony location and the overall timing of breeding there: 1) a non-breeding pair, particularly if at the edge of nesting area; 2) breeders about to lay that are sitting tightly on the nest in the day before eggs are laid but that just happen to be off the nest at the time of the census photograph to change over, display, copulate or nest-build; 3) early failed breeders, particularly those re-nesting in a bad site prone to disruption (e.g., regularly washed out) whose behaviour can be more sporadic with longer gaps between replacement clutches due to the nest re-build process; or 4) breeders rearing mobile chicks—a pair's nest may be empty if their chicks are creching in an adjacent nest.

Non-breeding pair nest attendance was not followed in detail across the season in this study as it was not specifically included in the brief, but non-breeders were seen at times sitting by day. In most views, non-breeders made up a tiny proportion of nests, e.g., one in 27 White Rocks nests in 2019.

In conclusion to these queries by Schuckard, nest counts from winter aerial photographs of colonies are likely to misinterpret the status of some nests belonging to both breeders and non-breeders. A nest belonging to a breeding pair might be temporarily empty for any of the reasons given above. And non-breeders could easily be counted as breeders if sitting on nests when the season is well underway. These misinterpretations are likely to balance out, so having a few not determined correctly is probably not significant when comparing annual surveys.

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