Kawau pāteketeke/King Shag (*Leucocarbo caruncolatus*) Research 2018-2022

Final report on the Marine Farming Association and Seafood Innovations Limited King Shag research project

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Cover image: Adult King Shag White 56 from Tawhitinui Colony roosting on mussel buoy in Horseshoe Bay, July 2021. Photo Dave Boyle.

Preface

The legend of Te Kawau-a-Toru

The Shag kept by Toru, Kupe's daughter as a pet, was called Te Kawau-a-Toru. A King Shag, also known as a cormorant, loyal to Kupe, the first known Māori to visit Aotearoa. Te Kawau-a-Toru possessing a huge wingspan, was reputed to be "the eye of the ancestors" a special bird with insight into ancient knowledge.

Figure 1. Kawau pāteketeke/King Shag, Te Kawau-a-Toru was reputed to be "the eye of the ancestors", a bird with insight into ancient knowledge. Photo Dan Burgin.

Te Kawau-a-Toru's job was to test the currents in the waters around Aotearoa for Kupe; while testing the currents at Te Aumiti (French Pass passage) he was warned by the local shags to wait for the change of the tides, as the water would then be slack, he answered saying he had to do as his master requested. So, he swam into the currents of Te Aumiti, the current was far too strong and dragged him under. One of his wings hit a rock and broke off, and he vanished into the swift currents and perished. Te Kawau-a-Toru's wing formed the reef stretching across the channel from Rangitoto ki te Tonga (D'Urville Island) to the lighthouse marking the shipping channel.

When you stand on the road looking down into Te Aumiti at low tide you can distinctly see how the reef is shaped like a shags wing.

As told to me by Roma Elkington, Ngāti Koata Kaumātua, and Kuru Pongi Landowner.

Figure 2. The strong currents of Te Aumiti overcame Te Kawau-a-Toru, who perished whilst testing the waters for Kupe, his wing forming the reef which runs to Rangitoto ki te Tonga.

Acknowledgements

This research project was primarily funded by the Marine Farming Association and Seafood Innovations Limited. We thank the Marine Farming Association and its member organisations for their support of this research. For helping to manage this we are especially grateful to Ned Wells (General Manager), Jonathan Large (President), Debbie Stone, Amber McNamara, and Alex Henry. We are grateful to Seafood Innovations Limited funding this research via the Research Agreement with the Marine Farming Association. For helping manage this we thank Kathlyn Kerr (Project Co-Ordinator), Hayley Camp, and Anna Yallop.

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This research project was coordinated through the King Shag Working Group, and we are grateful for the input from all participant members, and the organisations they belong to. The input of members of this group helped shape and direct the research.

Kuru Pongi/Trios is privately owned Māori Freehold Land, and we are indebted to the owners for allowing access to their islands to undertake this mahi. We are especially grateful to Roma Elkington, Ngāti Koata Kaumātua, and Kuru Pongi Landowner and Alice Woodward (Kiawhakakahaere Taiao/Environmental Manager, Ngāti Koata for facilitating access. Roma also opened our eyes to Matauranga Māori in regard to this species and the wider Te Tauihu-o-te-waka/Marlborough Sounds.

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New Zealand King Salmon funded aerial surveys during the non-breeding season, initially as part of their resource consent, but then to support research on population trends, and we thank Mark Preece for managing this.

The Department of Conservation have been a central part of the King Shag Working Group and have been vital in carrying out the research. The Waitohi/Picton Office has provided boat transport and personnel to assist with trips to capture birds. We are especially grateful for the help of Dan Palmer, Phil Clerke, and other DOC staff for their involvement. In addition to on the ground support, The Department of Conservation Marine Threats Team (National Office) have supported this work by funding aerial surveys during the breeding season, and funding research on diet and breeding behavior that run concurrently with this project. This has increased the knowledge of King Shag, and we are grateful to Dr Karen Middlemiss and Graeme Taylor for managing these studies.

Finally, but not least, the Marine Farming Industry provided boat transport for all re-sighting trips and some capture trips. We are grateful to Jonathan Large and especially Aiden Ganes (Marine Farm Management Limited) for providing most of these trips; Aiden not only provide excellent boatmanship, but also great company, assistance, and food! Sanford and New Zealand King Salmon supplied additional trips, and we thank these organisations and Mark Preece, and Grant Boyd for arranging these.

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Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) Research 2018-2022

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Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) is a large (length 76cm, weight 2.5kg) black and white marine cormorant restricted to Te Tauihu-o-te-waka/Marlborough Sounds (Marchant and Higgins 1990).

King Shag are part of the blue-eyed shag *Leucocarbo* spp. group; a highly speciose group exhibiting a circumpolar Southern Ocean distribution, with 17 currently accepted species and subspecies, many endemic to single island groups (Kennedy & Spencer 2014; Rawlence *et al*. 2017). They show remarkably shallow evolutionary histories among island-endemic lineages, consistent with a recent high-latitude circumpolar radiation. This rapid sub-Antarctic expansion contrasts with significantly deeper lineages detected in more temperate regions such as South America and New Zealand that may have acted as glacial refugia (Rawlence *et al*. 2022).

Prior to Polynesian settlement of New Zealand in the late 13th Century, King Shag were widespread around the southern North Island and northern South Island but experienced range restrictions, likely after and because of Polynesian arrival (Rawlence *et al.* 2017).

Currently King Shag breed on a limited number of rocky islets and cliffs throughout Te Tauihu-o-te-waka/Marlborough Sounds (Figure 3), within small colonies of 2-80 nests (Marchant and Higgins 1990, Bell 2010, Schuckard *et al.* 2015). From 1992-2018 the total population has been estimated at 645-839 birds, and 102-187 breeding pairs (Schuckard 2006; Bell 2010, Schuckard *et al.* 2015). With the population appearing to have been stable for at least the past 50 years (Schuckard 2006).

Figure 3. King Shag breeding at Tawhitinui, Te Hoiere/Pelorus Sound, an atypical colony as it is located on the mainland, not an offshore islet.

King Shag are very timid, especially when nesting, leading some authors to suggest that studies on this species should not involve landing on breeding sites or handling birds (Nelson 1971, Marchant and Higgins 1990).

Up to 2018, studies of King Shag foraging ecology have been limited to studies on diet from regurgitated pellets (Lalas and Brown 1998), and observations of birds from boats (Schuckard 1994, Schuckard 2006, Fisher and Boren 2012); with no instrumentation of birds carried out.

Birds from the Duffers Reef colony had a mean foraging range of 8km (maximum 24km) (Schuckard 1994), and 10km (maximum 18km) from Kuru Pongi/North Trio (Schuckard 2006a). In a study of Admiralty Bay, Fisher and Boren (2012) found most King Shag foraged in the outer reaches of the Admiralty Bay.

The only published information on the diet of King Shag originates from 22 regurgitated pellets collected in 1991 and 1992 (Lalas and Brown 1998), that identified Witch (*Arnoglossw scapba*), a right eyed flatfish, accounted for 90% of the prey.

Organised via the King Shag Working Group (see below), two studies were run concurrently to this research project. As this project involved landing at colonies to capture birds, to maximise use of this access, the Department of Conservation funded studies relating to diet and breeding behaviour via trial cameras established at colonies.

The diet of King Shag was studied using over 300 regurgitated pellets collected at colonies throughout Te Tauihu-o-te-waka/Marlborough Sounds during landings (van der Reis and Jeffs 2021, Lalas and Schuckard 2021). This confirmed that King Shag are opportunistic generalist predators targeting benthic fish species. King shag diet was dominated by Witch, Crested Sole and Opalfish, although the proportion of different prey was influenced by sex, colony location and season (breeding vs non-breeding season) (van der Reis and Jeffs 2021).

Figure 4. Adult King Shag on the water in Horseshoe Bay, Te Hoiere/Pelorus Sound. Photo Dave Boyle.

Related to diet, a study investigating the indirect effects of commercial fishing on King Shag foraging was also carried out (Taylor 2020); investigating changes over time in harvest levels, fishing effort verse catch rates and spatial change in fishing effort driven by decreased catch rates between 1989-90 and 2018-19. Changes in fisheries reporting methods in 2007 complicated analysis. There was no evidence of reduced harvest or shifting of fishing effort in respond to decreased catches. However, was evidence of an increase in fishing effort as a response to lower catch, probably related to the set net fishery. Flatfish made up 15-37% of the commercial fisheries catch (Taylor 2020).

Again, during landings at colonies trail cameras were installed and serviced at four colonies; the review of this footage significantly increased the knowledge of King Shag breeding behaviour (Gummer 2021). Nesting territories were retained year-round but not strongly defended by December. Nest-building commenced in February-April, when birds started to sit on nests by day but only sat on nests at night after eggs had been laid. Nest-building extended over many months, particularly at exposed, low-lying nesting areas vulnerable to wave surges. Laying occurred in March-May over 5-10 weeks, depending on the colony. Clutch size was 2-3 eggs, with as long as 13 days between the first and last egg. Incubation was 28-32 days, with late hatching chicks often not surviving. Replacement clutches were only occasionally laid after failure at either egg or young nestling stage and were unsuccessful. Chicks remained guarded for approximately a month when they left the nest and formed creches. Chicks reached adult size by 6 weeks old and were fully feathered at 2 months. Many juveniles disappeared 4-5 months after fledging, considered to have either perished or dispersed (Gummer 2021).

With little known about the ecology of King Shag, a historical lack of understanding on how the birds interact with aquaculture has been used to oppose marine farm resource consents. With this in mind, in 2018 the Marine Farming Association (MFA) formed the King Shag Working Group which includes representatives from the aquaculture industry, the Ministry for Primary Industries, Iwi, Marlborough District Council and the Department of Conservation. The primary aim of the working group was to co-ordinate and guide science-based research on King Shag.

In 2019, MFA partnered with Seaford Innovations Limited and industry members to fund an extensive research programme on King Shag. The three-year project included chick banding and GPS tracking of adult birds to understand aspects of King Shag foraging ecology, survival, and breeding biology.

This report summarises the results of the three-year MFA Seafood Innovations Limited research. Results are separated into Chapters, each focusing on different aspects of this research.

Chapter 1. Breeding population of kawau pāteketeke/King Shag (Leucocarbo carunculatus) in the Te Tauihu-o-te-waka/Marlborough Sounds 2019-2021.

Mike Bell

Summary

The breeding population of kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) was surveyed during the 2019, 2020 and 2021 breeding season using a combination of fixed-wing aircraft, boat-based and Unmanned Aerial Vehicle (UAV) surveys. In addition, a boat-based survey of the entire outer Te Tauihu-o-te-waka/Marlborough Sounds was conducted each season to ensure all colonies were censused. With recent research highlighting several previously undescribed breeding traits of King Shag, assessment of photos following the fate of individual nests, throughout the breeding season, was undertaken to estimate the breeding population. Between 2019–2021, an estimated 287-326 nesting pairs ($\bar{x}$=303 pairs) were recorded from 9 locations throughout Te Tauihu-o-te-waka/Marlborough Sounds. On average 4% of the nesting pairs comprised non-breeding pairs on empty nests, likely young pre-breeders or older non-breeders which having lost partners are in the process of gaining new ones. These results are 9.5% higher than previously recorded using the highest single-day annual count from fixed wing aerial surveys; and represent a more accurate method of determining the population size of King Shag. Furthermore, with no ground-truthing, results of aerial surveys prior to 2019 have likely underestimated breeding population size, as colonies were likely to have been missed in certain years. These results highlight the importance of ground-truthing the breeding range/colony locations beforehand to ensure all current breeding colonies are surveyed. It is also recommended that carrying out multiple surveys each season is necessary to enable individual nest fates to be followed thereby allowing accurate census of King Shag breeding numbers. This method allows for inter-colony breeding synchronicity and extended egg laying in King Shag and is recommended for future surveys for this species as well as other *Leucocarbo* shags, but likely applies to all cormorant species.

Introduction

Regular aerial surveys of kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) have been undertaken since 2015 to estimate the breeding population during the breeding season and to determine population numbers during the non-breeding period. Aerial survey has proven to be a practical, rapid, and cost-effective method for surveying this species across its entire range in just a few hours with minimal evidence of disturbance (Schuckard *et al.* 2015, Schuckard *et al.* 2018).

Results reported to date have estimated the breeding population as the highest count of nests with eggs or chicks across all colonies on a single day, with surveys timed to be during peak-incubation each breeding season (Schuckard *et al.* 2015, Schuckard *et al.* 2018, Schuckard and Frost 2020, Bell *et al.* 2022). However, new research has recently shown that this approach does not consider several key features of King Shag breeding ecology:

- The timing of breeding can vary markedly among colonies with asynchronous breeding regularly recorded each season (this study).

- The long duration of the egg laying period; Gummer (2021) reported that egg laying extended across 5–10 weeks at individual colonies.
- Re-laying following nest failure is rare. Gummer (2021) found that replacement clutches are seldom laid and, when observed, were never successful.
- Results from this study (Chapter 4) show that King Shag exhibit high nest-site fidelity.

Based on the new information listed above, it is now considered that previously published breeding population estimates, solely reporting the highest single-day annual count, have likely underestimated the total breeding population. With a total adult population of <1000 individuals, of which only about two-thirds breed in any given year, under or over-estimation of the King Shag population will likely impact conservation management and decision making for this species.

Standardisation of research methodology is imperative for comparative studies of population data. Each season's aerial survey has followed a similar methodology, especially in ensuring flights cover all known colonies. Some colonies have been found to be abandoned and new/previously abandoned sites re-established, especially small colonies tended to be occupied sporadically for breeding. Even larger colonies can occasionally shift between sites (this study). There is often a delay in discovering that a colony has shifted, which means that previously reported population estimates may have underestimated the total breeding population.

This report presents the results of fixed-wing aircraft aerial surveys, boat-based surveys, and photographs taken from a camera-equipped UAV during the 2019, 2020 and 2021 breeding season to determine the King Shag breeding population more accurately during this time.

Methods

Survey methodology

Aerial surveys of King Shag colonies during the 2019, 2020 and 2021 breeding seasons were carried out with a Cessna 180 fixed-wing aircraft using a specialised camera mounted on the underside of the aircraft. Once triggered, it took photographs automatically, with the aircraft flying a pre-programmed GPS-controlled course. Each season, between 1–2 fixed-wing aerial surveys were undertaken. For detailed information on methods used for each of these annual aerial surveys see Schuckard and Frost 2020, Bell *et al.* 2022.

In addition, to improve on earlier aerial surveys, which had missed colonies, boat-based surveys were conducted in the outer Te Tauihu-o-te-waka/Marlborough Sounds to search for additional colony sites, thereby ensuring the aerial surveys included all established colonies. During these surveys, observations and images of all known colonies were collected from both the boat and a UAV.

Aerial photograph assessment

Images from each colony, within a season, were assessed together regardless of survey type (fixed-wing, boat-based or UAV). For images of a colony taken on the first date, each individual nest site was numbered, and its fate tracked on images taken during subsequent surveys in the same season. Thus, it could be determined if each nest was used for actual breeding, as opposed to one in which a bird was occupying an empty nest. At each colony site, on every survey occasion, individual nests were categorised into the following three categories so that breeding could be followed through the season:

1. **Empty nest** - one or two birds standing upright by an empty nest, or loosely gathered nesting material, and not incubating.
2. **Incubating/apparently incubating** - one or two adults sitting horizontally on a nest (thought to be either incubating eggs or brooding small chicks). Following individual nests through time it was possible to confirm that apparently incubating birds were breeding as opposed to occupying empty nests.
3. **Chick** - nests with one or more chicks clearly visible with one adult, two adults, or a chick alone.

This method of following the fate of individual nests across multiple surveys throughout the season meant that the breeding status of each nest could be determined accurately. All nests categorised as apparently incubating were later either confirmed to be incubating or were later seen with chicks. As such, applying a correction factor to account for empty nests categorised as apparently occupied nests as in other *Leucocarbo* studies was not warranted (Parker and Rexer-Huber 2022).

If a new nest appeared after the initial image (*i.e.,* in the second or third image in a series), previous images were re-assessed to determine bird activity at this location. These were categorised as follows:

1. **Nothing** – there was no bird present at the nest site, nor any nest material.
2. **Bird on territory** – one or two birds standing upright at the nest site with no visible nesting material. We presumed that these birds were occupying the nesting site but had not yet started nest building.

As King Shags appear to have high site-fidelity and re-laying is rare (Gummer 2021), we assumed that any failed pairs were unlikely to have moved to a new site. Consequently, each actively occupied nest site was considered to represent a nesting pair (but see below regarding determining breeding status of pairs). Further, following individual nest fates to determine breeding status enabled issues around the extended egg laying period of King Shag (Gummer 2021), correcting for occupied but empty nests and inter-colony synchronicity, to be resolved (Figure 1.1).

Following individual nests throughout the season, the breeding status of each nesting pair within the colony could be determined. With each nesting pair categorised as follows:

1. **Breeding pair** - nest where breeding was confirmed throughout the series of images during the season (with an egg or chick confirmed in at least one image in the series to confirm the actual breeding did occur).
2. **Non-breeding pair (empty nest)** – one or two birds standing upright on/or by an empty nest, or loosely gathered nesting material, which throughout the season is not utilised for laying. Considered to be younger pre-breeding pairs or older birds following mate loss in the process of gaining a new partner.

Figure 1.1. Aerial census methodology needs to account for nest status, are apparently incubating birds actually on eggs, or sitting on empty nests? Further, the extended laying period in King Shag as shown here - with birds yet to lay, incubating, and with large downy chicks – needs to be factored in. King Shag nesting on Hunia Rock, Port Gore, 17 June 2022.

Results and discussion

Between 1–2 fixed-wing aircraft aerial surveys were undertaken each season, supplemented by 2–3 boat and/or UAV-based surveys. In 2019, there was an equal number of fixed-wing aerial surveys (n = 2), boat-based surveys (n = 2) and UAV surveys (n = 2). From 2020, no boat-based surveys were undertaken, as all surveys from a boat from this time utilised a UAV (Table 1.1).

Table 1.1. Number of surveys of King Shag colonies for which images were assessed for breeding for population estimates, 2015-2021.

Season	Fixed-wing	Boat based	UAV
2019	2	2	2
2020	2		3
2021	1		3

From 2019 to 2021, by following the fate of individual nests (Figure 1.2), a revised estimate of 287–326 nesting pairs of King Shag were recorded at 12 locations throughout the Te Tauihu-o-te-waka/Marlborough Sounds (Table 1.2, Figure 1.3). These results average 9.5% higher than those reported in previous studies (253-299 breeding pairs) using the highest single-day annual count from fixed-wing aerial surveys (Schuckard and Frost 2020, Bell *et al.* 2022).

Figure 1.2. Comparison of UAV images from a section of the Kuru Pongi/North Trio King Shag colony in 2021 showing how individual nests can be followed to confirm nest status through time. Left image, 1 October, most birds apparently incubating. Right image, 21 Nov, with nests in the same area mostly with chicks.

Counts from 2019–2021 include the entire King Shag population as in addition to the fixed-wing aerial surveys each season, a boat-based survey was conducted in the outer Te Tauihu-o-te-waka/Marlborough Sounds each breeding season to check for any additional colonies. Before this, because only known colonies were flown over, it is likely that new colonies were missed in the population surveys during certain years (especially 2017 and 2018).

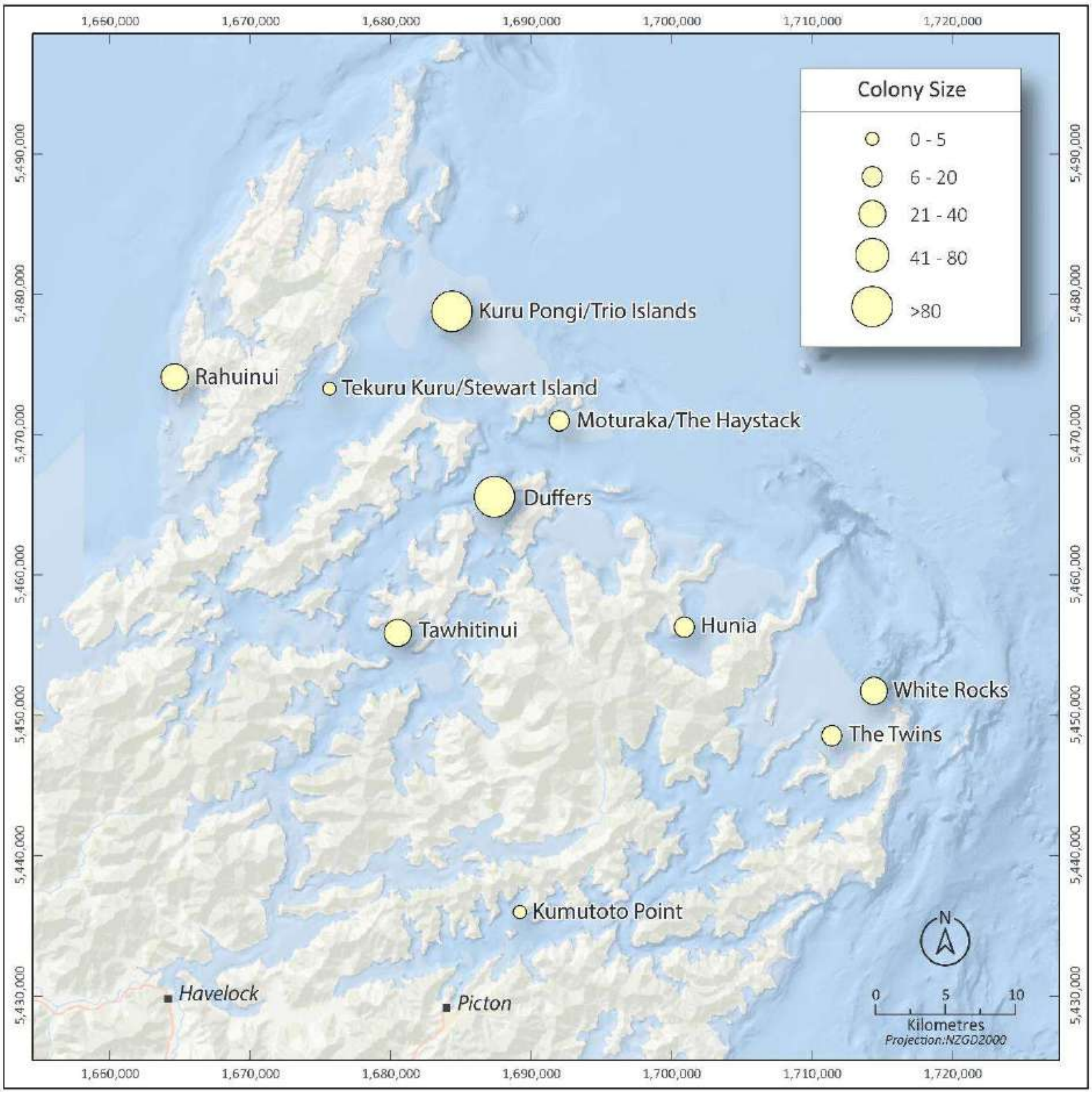
On average, 4% of nests remain empty throughout the season (range 1-7.3%, Table 1.2), these were probably ones occupied by non-breeding pairs (younger birds yet to start breeding, or older birds courting new mates after loss of partners). Most of these occurred on the edges of colonies, an observation supported by Gummer's (2022) finding that a small proportion of nests, especially on the periphery of the colonies, were never laid in, and they were considered to be occupied by less-experienced birds, probably pre-breeders. From 2019–2021, an average of 4% of nests remained empty throughout the season, suggesting that around 4% of King Shag nesting pairs at each colony involve pre-breeding birds.

Table 1.2. Number of breeding pairs, non-breeding pairs (empty nests) and total number of nesting pairs at King Shag colonies in the Te Tauihu-o-te-waka/Marlborough Sounds between 2019-2021.

	2019			2020			2021		
Colony	Breeding pairs	Non-breeding pairs (empty nests)	**Total – nesting pairs**	Breeding pairs	Non-breeding pair (empty nests)	**Total – nesting pairs**	Breeding pairs	Non-breeding pairs (empty nests)	**Total – nesting pairs**
Kumutoto Point			**NS-**			**NS-**		2	**2**
The Twins	17	4	**21**	17	1	**18**	4	1	**5**
White Rocks	30	0	**30**	30	0	**30**	28	4	**32**
Sentinel Rock	0	0	**0**	0	0	**0**	0	0	**0**
Tawhitinui	26	1	**27**	24	1	**25**	27	2	**29**
Duffers	89	2	**91**	86	1	**87**	77	3	**80**
Moturaka/ The Haystack	16	1	**17**	22	0	**22**	19	1	**20**
Hunia	18	1	**19**	18	0	**18**	19	0	**19**
Tekuru Kuru/ Stewart Island	0	0	**0**	0	0	**0**	0	0	**0**
Kuru Pongi/North Trio	48	1	**49**	45	0	**45**	70	7	**77**
Kuru Pongi/South Trio	38	1	**39**	32	0	**32**	0	0	**0**
Rahuinui	32	1	**33**	18	0	**18**	22	1	**23**
Total	**314**	**12**	**326**	**292**	**3**	**295**	**266**	**21**	**287**

Note: NS- not surveyed in that season unlikely to occur - roost not known to exist at the time of the survey, and it is unlikely that it was present at the time of survey.

Figure 1.3. Location and relative size of King Shag colonies recorded in the Te Tauihu-o-te-waka/Marlborough Sounds 2019-2021.



Conclusion

During the 2019, 2020 and 2021 breeding season a total of 287-326 nesting pairs of King Shag (mean = 303 pairs) were recorded. Furthermore, boat surveys of the entire outer Te Tauihu-o-te-waka/Marlborough Sounds ensured ground truthing that all known colonies were included in the surveys. Utilising multiple surveys and following the fate of individual nests estimates the breeding population at 9.5% higher than previously recorded using the highest single-day annual count from fixed wing aerial surveys (Schuckard and Frost 2020, Bell *et al.* 2022).

Around 4% of King Shag nesting pairs at each colony, on average, were assessed to be pre-breeding or non-breeding birds. Pre-breeders comprise mostly 3–5-year-old birds that haven't yet started breeding. Non-breeders are assumed to be older birds that have lost partners and are in the process of gaining new ones. If this assumption is correct, then 4% is a relatively minute buffer of non-breeding birds against any stochastic losses that the breeders in this small population might experience (e.g., climate induced extreme weather events).

However, this may be balanced by a larger pool of immature birds. A comparison of counts during the preceding non-breeding season (reflecting the total population), to the breeding census results presented in the current study, found that 72% of birds were involved in breeding (Chapter 2). This will be the proportion of birds <3 years old, which do not yet show any pre-breeding behaviour and therefore, no nest occupancy. So, despite a small pool of pre- or non-breeding birds, with around 30% of the King Shag population consisting of immature individuals, there is a relatively large pool of birds to prevent stochastic losses.

Population estimates will be most accurate when as many breeders as possible are attending nests and is typically at peak lay (Parker and Rexer-Huber 2022). However, for *Leucocarbo* shags which can have extended egg laying and asynchronous inter-colony breeding, conducting surveys at peak lay across the entire breeding population is challenging due to the resources required. In this study, using multiple survey methods and following individual nest fate to accurately census annual breeding populations provided a more accurate method and therefore, results are considered more reliable as being reflective of the true population size.

Ground-truthing the outer Te Tauihu-o-te-waka/Marlborough Sounds ensured all breeding colonies were surveyed. Methods for earlier censuses did not include ground truthing and it is likely that some colonies were missed in during some seasons - especially 2017 and 2018.

For example, in 2017, Kuru Pongi/North Trio was abandoned by King Shag as a breeding site. It is probable that the birds shifted to Kuru Pongi/South Trio, although this site was not surveyed that year as it was not known to be used for breeding at that time. About a third of the birds returned to Kuru Pongi/North Trio in 2018, but again Kuru Pongi/South Trio was not surveyed. After the 2018 breeding season a local Ngāti Koata fisherman reported that King Shag had bred on Kuru Pongi/South Trio that year (R. Elkington *pers comm*); and a photo confirms birds present on Kuru Pongi/South Trio in 2017 but was unable to be used to count birds due to distance from the colony when the image was taken (Rob Duff *pers comm*). This strongly suggests that population counts at the Kuru Pongi/Trios group under-estimated the breeding population there in 2017 and 2018.

Likewise, in 2015, 27 pairs were present on Sentinel Rock, but these declined sharply in 2016 to nine pairs and further to six pairs in 2017, after which the site was abandoned. In 2018, after the breeding season, King Shag were discovered to have bred on Moturaka/The Haystack (T. Bliss *pers comm*). In 2019, when Moturaka/The Haystack was surveyed for the first time, 17 pairs were present. The numbers have stayed relatively stable since then, with 22 and 20 pairs recorded in 2020 and 2021, respectively. Given this sites proximity to Sentinel Rock, it is likely that birds colonising Moturaka/The Haystack had emigrated from that location. The timing of this shift coincided with an upsurge in recreational fishing activity around Sentinel Rock (Aiden Gane *pers comm*, personal observation). On any given day many boats can be seen around the island. The topography of the seafloor at this site means that targeting kingfish here requires fishing close to shore. This may have increased the level of disturbance to the King Shag nesting there, causing them to abandon Sentinel Rock the site in favour of Moturaka/The Haystack. Because the latter was not identified as a nesting site in 2016, 2017 and 2018, the number of birds breeding in this region were probably underestimated.

These results highlight the importance of carrying out multiple surveys in a season to cover the full span of the egg-laying period and using ground-truth checks to ensure all active breeding colonies are surveyed. Accordingly, future breeding censuses of the King Shag population should involve ≥3 surveys during the egg laying period, with some assurance that all colony sites will be included. The resulting counts from the aerial imagery, taken either from aircraft or UAV, should be analysed in ways that allow the fate of individual nests to be followed, thereby more clearly determining the breeding status of their occupants. This recommendation is highly relevant also for other *Leucocarbo* shags, but likely applies to all cormorant species.

Chapter 2. Population size and trends of kawau pāteketeke/King Shag (*Leucocarbo carunculatus*).

Mike Bell

Summary

To estimate the total population of kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) an aerial survey of all known roosts was carried out on a single morning in late January 2018-2022. An average of 763 King Shag were counted at 10-13 sites each non-breeding season. However, as roost sites can shift without warning some sites were missed in surveys, correcting for these the population is estimated at 784 birds. Despite differences in survey methodology over time, the current population is slightly higher than estimated in 2002; a trend also seen in breeding numbers. On average 70% of the population breeds in any one year, with 30% being younger birds yet to start breeding. This proportion of immature birds provides some buffer to stochastic events which may cause increased adult mortality and help mitigate a breeding population decline. Small fluctuations in annual counts may be related to productivity, with counts in years following low productivity being lower than in years with improved productivity. Despite these caveats, aerial survey during the non-breeding season is recommended as the best way to determine total population size and trends. Improvements in image quality in the future may enable counts to separate birds by age (first year versus adults), which will further refine this method.

Introduction

Following New Zealand King Salmon receiving resource consent to establish new salmon farms in the Waitata Reach and Richmond Bay in April 2014, a consent condition required that the company develop and implement a King Shag Management Plan. This was to ensure that the establishment and operation of the new salmon farms did not result in a reduction in the King Shag population in the Te Tauihu-o-te-waka/Marlborough Sounds, especially at Duffers Reef (Schuckard 2015). As recommended by Schuckard (2015), the management plan was reviewed after 3 years and a new one adopted in 2019 (Bell 2019).

The first King Shag Management Plan required the population to be censused by aerial survey at least once every three years (Schuckard 2015). If either the overall population, or the Duffers Reef roost site, were found to have declined by >3% per annum over this interval, then aerial surveys must be undertaken annually. A base-line aerial survey carried out in February 2015 recorded 834 King Shag at nine sites throughout the Te Tauihu-o-te-waka/Marlborough Sounds (Schuckard 2015), with a repeat survey in February 2018 suggesting a decline (Schuckard 2018), annual surveys were initiated (Bell *et al.* 2019).

Given the fluctuations in King Shag numbers recorded during these non-breeding season aerial surveys, and further to support research by the Marine Farming Association and Seafood Innovations Limited co-ordinated by the King Shag Working Group, New Zealand King Salmon adopted annual aerial surveys as routine in their revised King Shag Management Plan (Bell 2019). This report presents the results of aerial surveys of King Shag roosts during the non-breeding season 2018-2022 to estimate the population size and determine population trends.

Methods

This aerial survey aimed to census the entire King Shag population during the non-breeding season, a time when King Shag roost both at breeding colonies and at other known sites within the Te Tauihu-o-te-waka/Marlborough Sounds. For consistency throughout this report, we refer to all these sites as King Shag roosts.

Aerial survey

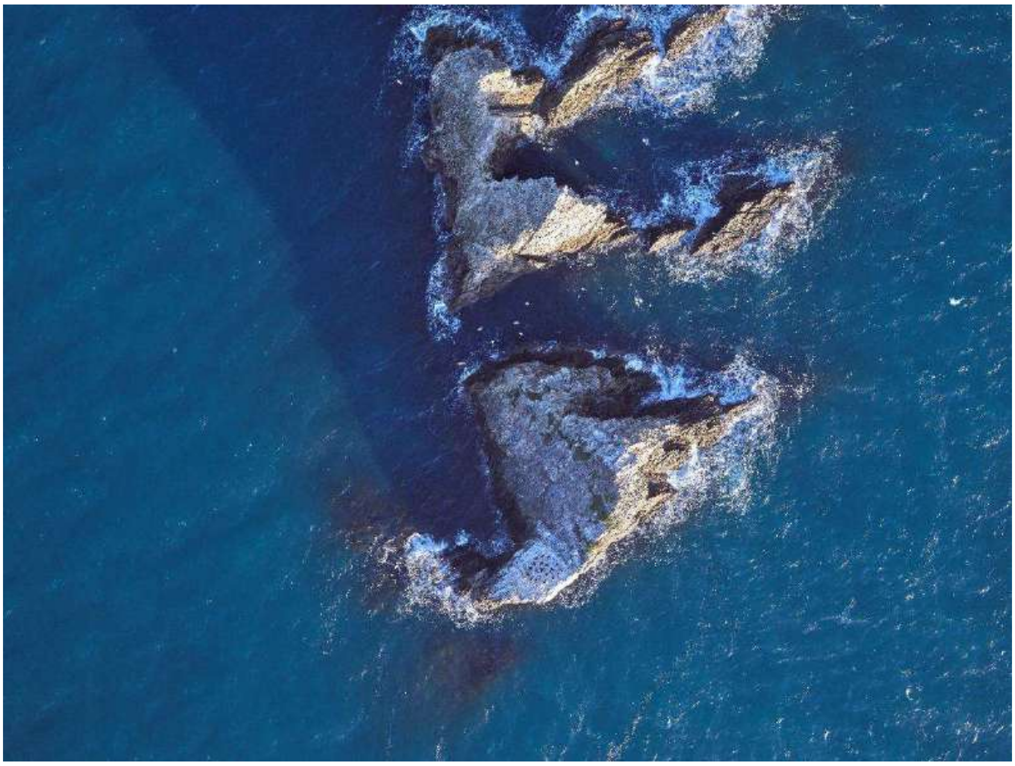
Aerial surveys of King Shag roost sites during the non-breeding season have been carried out since 2015, utilising a fixed wing aircraft (either a Cessna 102 or Cessna 180) with a camera mounted on the underside of the aircraft. When triggered, the camera took photographs automatically, with the aircraft flying a pre-determined GPS-controlled course. Each season, between 2–3 passes over each roost sight were undertaken to capture images for assessment.

Given that Schuckard *et al.* (2015) found that <3% of birds had left one hour after sunrise, and around 10% by 2 hours, surveys were conducted as early as possible each day. Aircraft height was between 201-450m above sea-level and speed less than 90 knots (166km/h). Because up to three passes of each roost site might be needed to fully cover the site, the aircraft had to turn to line up the next run no closer than 0.4 NM (740m) from the roost to prevent disturbance. For detailed information on methods used for each of these annual aerial surveys see Schuckard *et al.* 2015, Schuckard 2018, Bell *et al.* 2019, Bell *et al.* 2020.

Aerial photograph assessment

Three independent assessors counted the number of shags present at each roost site from the set of images taken each season (Figure 2.1). The mean was calculated for each roost site and the sum of these means across all roost sites used to estimate the total population of King Shag in the Te Tauihu-o-te-waka/Marlborough Sounds each non-breeding season.

Figure 2.1. White Rocks colony captured from fixed wing aircraft during aerial survey, high quality images allow the colony area to be zoomed in on, and individual birds counted.



Analysis

To investigate the relationship between breeding numbers and the non-breeding population, revised breeding population counts were used (Chapter 1) to compare to counts from the preceding non-breeding season to determine the proportion birds breeding each season. To account for movement of birds between roost sites during the non-breeding season (Chapter 7) counts from all colonies and non-breeding roosts in Queen Charlotte Sounded were combined, Kuru Pongi/North and South Trio were combined with Tekuru Kuru/Stewart Island, and Rahuinui and Squadron Rocks combined.

Then to investigate the relationship between productivity and non-breeding population estimates, productivity data from the 2019-2021 season was used (Chapter 3) to compare to counts from the following non-breeding season.

Results

An average of 763 King Shag were counted at 10-13 sites each non-breeding season 2018-2022 (Table 2.1). However, it is highly probable that in 2018 and 2019 birds had shifted to new roost sites which were unknown at the time of the aerial survey and therefore were not surveyed, for example the abandonment of Sentinel Rock was mirrored by birds occupying Moturaka/The Haystack and will be birds shifting to this new site (Figure 2.2). Correcting for these missed colonies by using a median figure from counts prior to and after missing counts (taking into consideration movement from roost sites), increases the estimated average non-breeding population to 792 birds (Table 2.1).

Figure 2.2. The Moturaka/The Haystack King Shag colony, comprising of birds shifting from the former Sentinel Rock colony.

Table 2.1. Numbers of King Shag counted at roosting sites during the non-breeding season and estimate population correcting for roost sites missed during aerial surveys; 2015-2022 (data from Schuckard 2018, Bell et al. 2019, Bell et al. 2020. and this study).

	Actual count results					Corrected count results				
Colony	**2018**	**2019**	**2020**	**2021**	**2022**	**2018**	**2019**	**2020**	**2021**	**2022**
Kumutoto Point	NS-	NS-	NS-	NS-	12	NS-	NS-	NS-	NS-	12
Rauakaka	5	0	2	0	0	5	0	2	0	0
Oruawairua/ Blumine	4	37	55	29	32	4	37	55	29	32
Bottle Rock Point	NS-	NS+	8	2	6	NS-	6*	8	2	6
The Twins	51	54	43	66	0	51	54	43	66	0
White Rocks	69	69	46	37	46	69	69	46	37	46
Hunia	31	45	44	46	37	31	45	44	46	37
Tawhitinui	65	79	78	98	76	65	79	78	98	76
Duffers Reef	212	214	207	198	159	212	214	207	198	159
Moturaka/ The Haystack	NS+	47	16	35	55	55*	47	16	35	55
Sentinel Rock	0	0	0	0	0	0	0	0	0	0
Tekuru Kuru/ Stewart Island	16	0	9	16	30	16	0	9	16	30
Kuru Pongi/ North Trios	129	76	119	106	196	129	76	119	106	196
Kuru Pongi/ South Trios	NS+	96	85	80	0	45*	96	85	80	0
Rahuinui	51	70	103	97	98	51	70	103	97	98
Squadron Rocks	0	2	0	11	10	0	2	0	11	10
Total	633	789	815	822	757	733*	795*	815	821	757

Note: NS- = not surveyed in that season unlikely to occur - roost not known to exist at the time of the survey, and it is unlikely that it was present at the time of survey.
NS+ = not surveyed in that season likely to occur - roost not known to exist at the time of the survey, but it is probable that it was present at the time of survey and was missed.
*= estimated count for colony missed during aerial survey

For the three seasons with complete data (2019-2021), the proportion of birds nesting in the breeding season in relation to the total population count prior (preceding non-breeding census) averaged 80.8% (range=40.7-275%) across all colonies/colony groups (Table 2.2). There was considerable variation between colony/colony groups, both between and within seasons (Table 2.2). Pooling results from all colonies in a season, annually 71.9% of birds partook in breeding each season (range 65-80%).

Table 2.2. The proportion of King Shag breeding each season within colonies or colony groups 2019-2022.

Season	Breeding Site	Prior non-breeding population (birds)	Breeding population (pairs)	Portion breeding birds (%)
2019	Queen Charlotte (White Rocks/The Twins)	160	47	59
	Tawhitinui	79	26	66
	Duffers Reef	214	89	83
	Moturaka/ The Haystack	47	16	68
	Hunia	45	18	80
	Kuru Pongi/Trios (N and S Trio/Tekuru kuru/Stewart I.)	174	86	99
	Rahuinui (and Squadron Rocks)	72	32	89
2020	Queen Charlotte (White Rocks/The Twins)	154	47	61
	Tawhitinui	78	24	62
	Duffers Reef	207	86	83
	Moturaka/ The Haystack	16	22	275
	Hunia	44	18	82
	Kuru Pongi/Trios (N and S Trio/Tekuru kuru/Stewart I.)	213	77	72
	Rahuinui	103	18	35
2021	Queen Charlotte (White Rocks/The Twins)	135	32	47
	Tawhitinui	98	27	55
	Duffers Reef	198	77	78
	Moturaka/ The Haystack	35	19	109
	Hunia	46	19	83
	Kuru Pongi/Trios (N and S Trio/Tekuru kuru/Stewart I.)	202	70	69
	Rahuinui	108	22	41

Productivity appeared to influence the non-breeding season population count. The non-breeding census result in years following low productivity was lower than in years with higher productivity (Table 2.3). However, sample sizes are too small to test this assessment for significance.

Table 2.3. Relationship between productivity the preceding season and the non-breeding season count for King shag 2019-2021 breeding seasons.

	2019	2020	2021	2022
Productivity (preceding season)	0.36	0.64	0.64	0.36
Non-breeding count	789	815	822	757

Discussion

Over the past five years (2018-2022) the population of King Shag during the non-breeding season is estimated to average 784 individuals. This is lower than that recorded in 2015 (Schuckard *et al.* 2015), but higher than the average recorded 1992-2002 Schuckard (2006) and estimated in 2006 Bell (2010) (Figure 2.4).

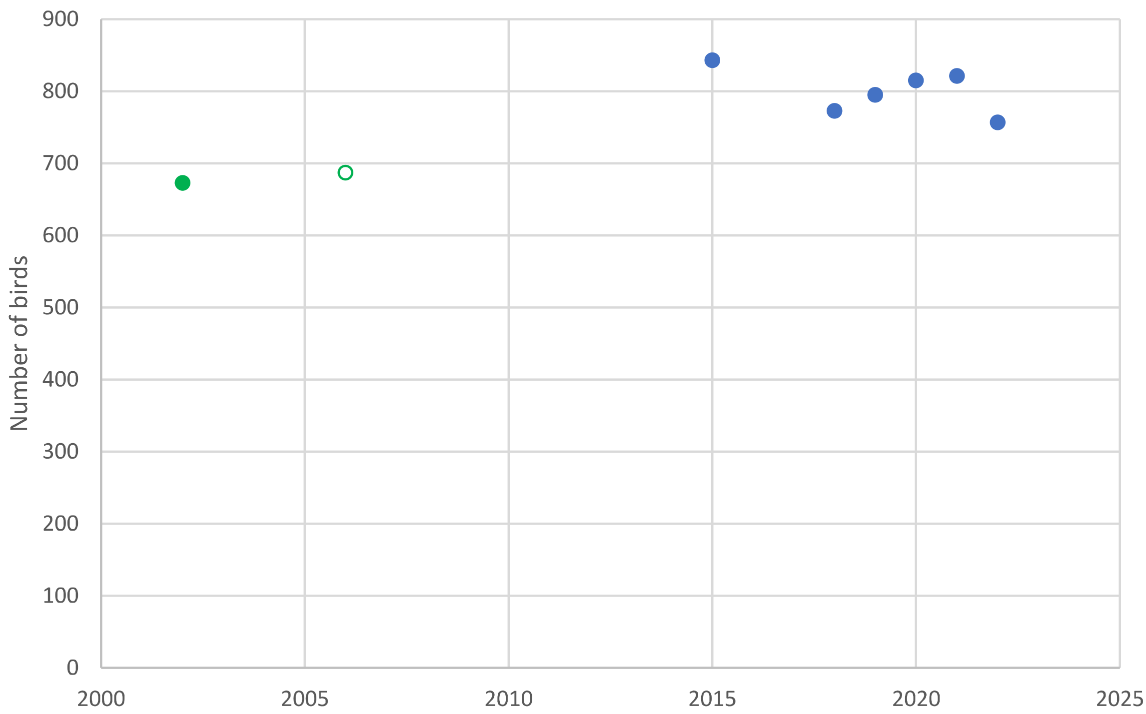
Comparison of King Shag population estimates over time are problematic, which then means determining population trends is equally challenging. Census methodology has changed over time. Counts from 1992-2002 were pre-dawn boat-based and covered all known colonies over several weeks, with an average of all years providing an estimate of 645 birds (Schuckard 2006). The 2006 count was based on estimate of numbers using a correction factor accounting for birds absent from the colony foraging (again over several weeks) (Bell 2010). From 2015, aerial surveys covering all colonies in a single morning have been employed. Furthermore, historical counts (counts <1991) usually have no record of the time of the count, and therefore do not consider birds absent from colonies foraging (Schuckard 2006).

Understanding this, Schuckard (2006) assessed historical counts for birds absent from colonies foraging and determined a stable population from the 1950's to 2002. Following a higher count in 2015, Schuckard *et al.* (2015) concluded that their results were likely due to better methodology (single day aerial surveys compared to boat-based surveys conducted over several weeks), although they couldn't rule out a genuine population increase.

King Shag were considered exceptionally rare in the early 1900's, with estimates of a total population of 100-200 birds (Falla 1933, Oliver 1955, Nelson 1971). Despite King Shag gaining legal protection in 1927 (Falla 1933) to arrest a feather trade (Nelson 1971), they were still being shot well into the 1940's in the misguided belief that they impacted fish stocks (Falla 1948, Nelson 1971). Although these early counts are likely an under-estimate (Schuckard 2006), there is little doubt that King Shag was rare, with a small population at the start of the 20th century.

Recent data indicates that the King Shag population is slightly higher than the early 2000's. The 2002 figure of 645 birds included all known colonies at the time (Schuckard 2006) but may have missed colonies. Given that when Bell (2010) surveyed the entire coast of Te Tauihu-o-te-waka/Marlborough Sounds in 2006 and reported breeding in Port Gore, this does suggest that the 2002 count may be an underestimate. However, at the time Port Gore was estimated at 28 birds, adding that to the 2002 count, estimates for the entire population at 673 individuals are 15% lower than the current population (Figure 2.4).

Figure 2.3. Population estimates for King Shag from Te Tauihu-o-te-waka/Marlborough Sounds 2002-2022. Data sources: 2002 (green filled circle) dawn boat-based counts from Schuckard 2006, with the addition of potential missed birds from Port Gore in Bell 2010. 2006 (green open circle) estimates from boat-based counts adjusting for birds absent from colony foraging. 2015-2022 (blue filled circles) early morning single day aerial surveys (Schuckard et al. 2015, and this study).



During the same period, the breeding population has also increased. From 1992-2002 between 102-126 King Shag nests were counted (Schuckard 2006). Again, correcting for the potentially missed colony in Port Gore (8 nests; Bell 2010), the breeding population is estimated at 110-134 breeding pairs. From 2019-2021 the breeding population is estimated to be 303 pairs (Chapter 1).

Drivers of population increase are interesting, but Duffer's Reef is a good example, increasing from 30-37 nests (1992-2002) to 80-91 (2019-2021). In 1992-2002 annual productivity was 20-30 chicks (Schuckard 2006), equating to productivity of 0.66-81 chicks/pair. Between 2018-2021 productivity was considerably lower (0.28 chicks/pair; Chapter 3). Crawford et al. (2009) found productivity of 0.66 chicks/pair leads to significant increases in Crozet Shag population. The drop in productivity at Duffer's Reef between these two time periods with an increasing breeding population, suggests density dependent effects are operating. Currently, breeding space on Duffers Reef is limited, and the islet certainly appears to be at capacity.

In any year, on average 30% of the population is not breeding, presumably pre-breeders yet to come to maturity and older birds who have lost partners. Immature birds can make up a significant proportion of a seabird population, up to 40% in some species (Weimerskirch 2002). Cormorants exhibit a relatively conservative (k-based) reproductive strategy, in general adapted to low population turn over and are less able to recover quickly from sudden increases in mortality (Johnsgard 1993). Our results show that King Shag have a relatively high pool of non-breeding birds, which may lessen the effects of stochastic shocks causing increased adult mortality and mitigate the risk of breeding population decline.

It appears that productivity the proceeding winter influences the non-breeding season count. Productivity at colonies essentially determines the number of juvenile birds present and will be a cause of interannual variation in counts. However, as counts are carried out in late January during the period of peak juvenile mortality and dispersal (Chapter 5), these factors will also influence results. Unfortunately, images from these aerial surveys are too low resolution to be able to accurately identify juvenile versus adult birds, so we could not test this by just counting adult birds at colonies. Despite these fluctuations, non-breeding season aerial surveys are a good way to determine population trends, and improvements in image quality should help resolve issues of productivity and juvenile survival impacting each season's results.

Chapter 3. Aspects of breeding ecology and breeding success in kawau pāteketeke/King Shag (*Leucocarbo carunculatus*).

Mike Bell, Patrick Crowe, Dan Burgin, and Samantha Ray

Summary

Aspects of the breeding ecology of Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) were studied at colonies in the Te Tauihu-o-te-waka/Marlborough Sounds from 2018 to 2022. Annual average productivity was 0.57 chicks/pair (Range 0.36-0.64 chicks/pair), with considerable variation between colonies and years. Exposed colonies in the outer Te Tauihu-o-te-waka/Marlborough Sounds had significantly lower productivity than more sheltered colonies in the inner Te Tauihu-o-te-waka/Marlborough Sounds. Although sample size is low, King Shag appear to have high nest site and mate fidelity, a trait which will assist experienced breeders to hold the best nest sites in colonies. Predictions for increased severity, frequency, and duration of adverse weather events due to anthropogenic climate change is emerging as a key threat to King Shag.

Introduction

Prior to this research project little was known about the breeding ecology of Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) with no systematic studies having been undertaken (Marchant and Higgins 1990, Taylor 2000).

Initiation of the Marine Farming Association and Seafood Innovations Limited King Shag research project, which involved regular visits to colonies provided the opportunity to collect information on several aspects of breeding ecology and attempt to measure breeding success across all colonies.

Running in tandem to this project, trail cameras were set up during landings at colonies to investigate breeding biology. Reviewing this footage significantly increased our knowledge of King Shag breeding ecology, providing the first detailed information on egg laying, incubation period, and chick rearing (Gummer 2021).

This report presents details of the breeding ecology of King Shag from regular observations at breeding colonies, and estimates productivity for most colonies for the past four years.

Methods

Regular trips to re-sight banded birds were undertaken at the Tawhitinui and Duffers Reef colonies, and all other colonies were visited throughout the breeding season to follow breeding progress. During these trips, the behaviour of individually banded birds as well as/or the entire colony were recorded to gain insights into aspects of the breeding ecology and breeding success of King Shag.

Productivity

Productivity is defined here as the number of chicks fledged per pair at King Shag colonies. Productivity was determined by using the number of breeding pairs recorded at colonies during aerial surveys (Chapter 1) and counts of fledging birds at the colony sites immediately after the breeding season, with the timing of counts variable to allow for colonies breeding asynchronously.

Colonies were visited following fledging each breeding season, and the number of first-year birds present at the colony were recorded. Fledgling counts were carried out either directly at the time of the visit using binoculars from a boat offshore >100m away, to not disturb the colony, or subsequently using images captured on a digital SLR camera or Unmanned Aerial Vehicle (UAV) (Figure 3.1).

Figure 3.1. Digital SLR photo from White Rocks taken on 9am 5 August 2021 used to confirm productivity at this colony. Breeding was low at many colonies in 2021 due to a severe weather event in July.

To reduce error associated with juvenile mortality and dispersal, only counts carried out at colonies within three months of the known post-fledging date (accounting for variability in the timing of breeding at individual colonies) were included in this analysis. This study (Chapter 5) and Gummer (2021) recorded low mortality of chicks in their first four months post-fledging, followed by higher mortality and dispersal from 5 months old.

To reduce the error associated with birds being away from colonies whilst foraging, only colony counts undertaken in the early morning and late evening were included (i.e., <2 hours after sunrise or <2 hours before dusk). Schuckard *et al.* (2015) found that <3% of birds had left one hour after sunrise, and around 10% by 2 hours after sunrise. Gummer (2021) found recently fledged birds departed the colony slightly later than adults, with all fledglings still present approximately 2 hours after sunrise, but with all young departed by 3.5 hours after sunrise. Gummer (2021) also found juveniles returned to the colony earlier, with the first birds back by noon, and all birds having returned by 1330h.

Although it is possible that a small number of fledglings may have been missed in counts (either chicks perished or dispersed from colonies prior to counts or were absent from colonies due to being away) foraging, methodology discussed above mitigated this and as such, no correction factor has been applied to fledgling counts, and the productivity figures presented here should be treated as a minimum value. To investigate differences in productivity due to weather exposure within the Te Tauihu-o-te-waka/Marlborough Sounds, we split 8 of the 9 colonies into “Inner and Outer Sounds”. With “Inner Sounds” colonies being Tawhitinui and The Twins and “Outer Sounds” colonies being White Rocks, Hunia, Moturaka/The Haystack, Duffers Reef, and Kuru Pongi/North and South Trios. Rahuinui was excluded from this analysis as it is in Tasman Bay (for colony locations see Chapter 1) and is affected by different weather patterns than colonies within Te Tauihu-o-te-waka/Marlborough Sounds.

Breeding ecology

Aspects of breeding ecology, such as the timing of breeding, nest site fidelity, and mate fidelity were investigated by recording the behaviour of both individually banded birds and/or behaviour of the entire colony. Due to the more regular re-sighting effort at the Duffers Reef and Tawhitinui colonies, key aspects of breeding ecology that follow individual birds are inherently focused on these colonies.

Results

Productivity

In 2018 productivity was only determined for 4 of the 7 breeding colonies; for 2019, 2020 and 2021 productivity were determined for all colonies (8 or 9 colonies each season). Productivity at individual colonies averaged 0.49 chicks/pair (range 0-0.97 chicks/pair), with considerable variation both between colonies and years (Table 3.1). Overall, in the three seasons when productivity was measured at all colonies (2019-2021), average productivity was 0.57 chicks/pair (0.33-0.64 chicks/pair). Colonies classified as "Inner Sounds" had significantly higher productivity (mean=0.69 chicks/pair, SD=0.23) than "Outer Sounds" colonies (0.5 chicks/pair, SD=0.27), Student's two sample t-test, $t(16)=1.92$, $P=0.036$.

Significant adverse weather events appear to have the most impact on productivity. Lowest productivity was recorded in 2018 (0.33 chicks/pair) and 2021 (0.35 chicks/pair), when storms caused widespread nest loss at several colonies including White Rocks and Duffers Reef colonies, leading to low productivity at these sites. The significant storm event in July 2021 (Radio New Zealand 2021) caused the complete failure of breeding at Duffer's Reef, and lower productivity at all other colonies on eggs or chicks at the time (Figure 3.2). The only colonies to have productivity >0.5 in 2021 were the early breeding Tawhitinui (where chicks had already fledged), and late breeding Kuru Pongi/North Trio (where birds had yet to start breeding).

Figure 3.2. A beautiful Te Tauihu-o-te-waka/Marlborough Sounds day belies the true impacts of weather on King Shag productivity. This image taken a month after the July 2021 storm caused complete failure of the Duffers Reef colony, with no chicks produced.

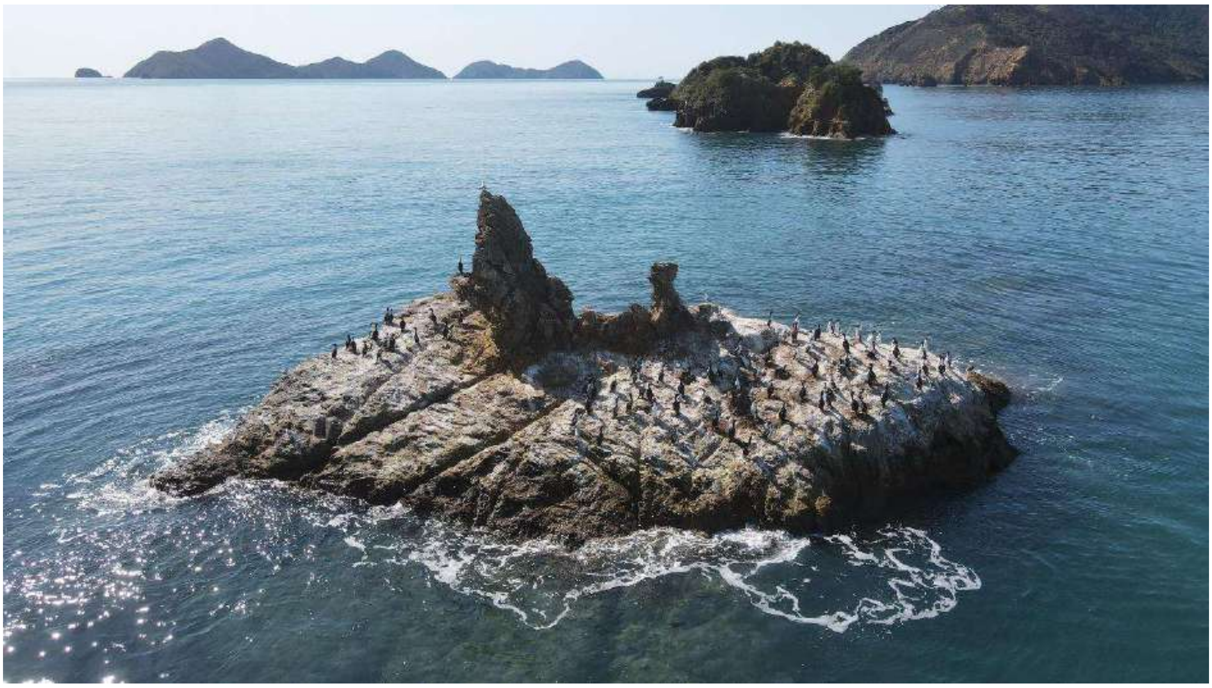


Table 3.1. Number of breeding pairs, chicks fledged and productivity at King Shag colonies where productivity was measured in the Te Tauihu-o-te-waka/Marlborough Sounds 2018-2021 (note 2018 breeding pairs numbers presented in this table are only colonies where productivity was measured, not all breeding colonies present that season).

	2018			2019			2020			2021		
Colony	**Breeding pairs**	**Chicks fledged**	**Productivity**	**Breeding pairs**	**Chicks fledged**	**Productivity**	**Breeding pairs**	**Chicks fledged**	**Productivity**	**Breeding pairs**	**Chicks fledged**	**Productivity**
The Twins	24	13	0.54	17	15	0.88	17	14	0.82	4	1	0.25
White Rocks	31	8	0.26	30	11	0.37	30	12	0.40	28	7	0.25
Hunia				18	10	0.56	18	6	0.33	19	3	0.16
Tawhitinui	17	14	0.82	26	22	0.85	24	20	0.83	27	14	0.52
Duffers Reef	78	15	0.19	89	45	0.51	86	36	0.42	77	0	0.00
Moturaka/ The Haystack				16	11	0.69	22	14	0.64	19	9	0.47
Kuru Pongi/North Trio				48	40	0.83	45	37	0.82	70	59	0.84
Kuru Pongi/South Trio				38	27	0.71	32	31	0.97			
Rahuinui				32	21	0.66	18	16	0.89	22	3	0.14
Annual total	**150**	**50**	**0.33**	**314**	**202**	**0.64**	**292**	**186**	**0.64**	**266**	**96**	**0.36**

Nest site fidelity

A total of 13 adult King Shag were first captured and banded during the breeding season whilst on nests with small young. Of these, 12 birds have data spanning ≥3 breeding seasons where nest locations were recorded (Table 3.2). Re-sightings of these banded birds revealed that birds were site faithful, nesting in the same location in consecutive years. One adult male, White 18, the first adult King Shag ever captured, has since been recorded using the same nest on the upper edge of the Tawhitinui colony every season since 2018, until he lost his partner in 2022.

Four additional birds have also been recorded breeding in the same location within the colony area in four consecutive seasons and four birds for three consecutive seasons. Two birds have been recorded breeding in the same location within the colony area in two of three seasons, with a season where the exact breeding location was not confirmed in the intervening year, however it is likely that they nested in the same location that season.

When old nests were completely washed away during the non-breeding season, the birds were found to re-build the nest at the same location within the colony in following seasons.

Table 3.2. Confirmation of individual King Shag breeding at the same nest site within a colony area each season (White birds Tawhitinui, Red birds Duffers Reef).

Bird	2018	2019	2020	2021	2022
White 18	*	*	*	*	
White 17		*	*	*	
White 20		*	*	*	
White 21		*	*	*	*
White 27		*	*	*	*
White 41			*	*	*
Red 01		*	*	*	*
Red 02		*	*	*	*
Red 27			*	*	
Red 29			*		*
Red 30			*	*	*
Red 31			*		*

Mate fidelity

There are only two pairs of birds which both partners in the pair have been banded, with one mate caught in 2019, and the partner in 2020. One of these pairs is resident at the Tawhitinui colony, the other at Duffers Reef colony. The Tawhitinui colony pair were confirmed breeding together in the 2020, 2021 and 2022 seasons. The Duffers Reef colony pair were confirmed breeding together in 2020 and 2022 but were not confirmed in 2021, as this nest site failed early in that breeding season, with the pair seen roosting together afterwards. It's assumed that these birds were breeding together that season, but unfortunately, we cannot confirm this.

Behaviour post breeding also suggests high partner fidelity. Pairs were found to roost together at nest sites after breeding, right through to the next season when nest building started again in March. Gummer (2021) recorded that nest sites were retained year-round, although less so from December-March in the middle of the non-breeding season.

Nest site occupancy

Adults continued to occupy nest sites post breeding and usually right through until the following breeding season. However, there were some exceptions to this observation. It was found that if a breeding pair were successful, juvenile birds would initially roost with adults at their natal nest sites (Figure 3.3), but as they aged, juveniles were observed at the edges of their colony. When pairs began nest building (from March), at least one bird of the pair would remain at the nest site to defend it during the day. Gummer (2021) confirmed a similar pattern of nest attendance; with birds occupying nest sites both day and night when nest building commenced, to defend the site. If given the opportunity, especially in the early nest building phase, King Shag would steal nesting material from conspecifics to add to their own nest.

Although it was not possible to investigate nests during re-sighting trips, based on our observations of bird behaviour it appeared that egg laying occurred over an extended period. This was confirmed by Gummer (2021) who recorded eggs laid at colonies extended over a 5–10-week period.

Figure 3.3. Four months post fledging a first-year fledgling is fed by its parent at its natal nest site. Other adult birds roost on old nest, with their dependent chicks roosting alongside them (Photo Kailash Willis)

Discussion

Although sample sizes are currently small, King Shag appear to have high nest site fidelity, and from our current observations we assume high mate fidelity as well. Site fidelity is considered advantageous for monogamous seabirds, as it provides dominance in territorial contests, benefits mate retention, and increases breeding success (Bried and Jouventin 2001). Whilst mate fidelity has also been shown to increase breeding success and reduce the cost of reproduction which ultimately enhances individual fitness and hence survival (Bried and Jouventin 2001). Forming dense colonies, mostly in exposed locations, King Shag would benefit from high nest site and mate fidelity by retaining prime nest locations in colonies across seasons. Defence of these sites outside the breeding season provides evidence of high nest site fidelity.

Although King Shag productivity appears relatively low (0.57 chicks/pair), it may be high enough to sustain the population. For the closely related Crozet Shag (*Leucocarbo melanogenis*) productivity of 0.30 chicks/pair was considered the driver of a 70% population decline; however, productivity of only 0.66 chicks/pair led to a population increase from 220 pairs to 500 (Crawford *et al.* 2009).

From our monitoring it appears the main cause of King Shag breeding failure is adverse weather events. With severe weather events often causing extremely low productivity, especially in more exposed colonies, as was found during 2021 where a large storm event resulted in zero productivity at Duffers Reef. Gummer (2021) found replacement clutches were seldom laid, and were always unsuccessful, suggesting that storm events at any stage during the breeding season would have significant negative effects on productivity.

Considering the modelled increase in frequency and magnitude of large storm events due to anthropogenic climate change (Frame *et al.* 2020), we predict that climate change will have a significant impact on King Shag productivity. Climate change is emerging as one of the key influences to shape the future of natural systems across the globe (Cramer, *et al.* 2014), and is noted as a significant threat to seabirds (Dias *et al.* 2019; Orgeret *et al.* 2021). Reduced productivity of King Shag could then lead to population declines.

Chapter 4. Development of sexual dimorphism in kawau pāteketeke/New Zealand King Shag (*Leucocarbo carunculatus*) chicks and intercolonial variation in chick condition.

Mike Bell, Simon Lamb, Patrick Crowe, Dan Burgin, and Samantha Ray

Summary

Cormorants and shags are sexually dimorphic with males larger than females, with these traits developing during chick growth. We studied sex-specific growth and chick condition of kawau pāteketeke/New Zealand King Shag (*Leucocarbo carunculatus*) chicks by analysing body mass and wing length from single colony visits during mid chick rearing at four colonies in the Te Tauihu-o-te-waka/Te Tauihu-o-te-waka/Marlborough Sounds. We found that sexual dimorphism in body mass in King Shag develops during chick growth, with change in body mass occurring prior to 17 days old. We detected an intercolonial difference in chick condition (chick mass), the follow-on effect of this on juvenile survival are discussed.

Introduction

Cormorants are sexually dimorphic in body size with males larger than females (Nelson 2005). Across cormorants, differences in body size start developing during early chick rearing with sex-specific chick growth likely having a differential effect on chick survival and fledgling condition, especially regarding brood sex composition (Velando *et al*. 2000, Svageli and Quintana 2017). In procellariform seabirds juvenile survival is positively correlated to mass at fledging (Visser 2002), however, there is no parental care post-fledging in procellariforms. Whereas Pelecaniformes seabirds lay 2-4 egg clutches with asynchronous hatching and have a period of parental care post-fledging (Nelson 2005). So, although fledging mass does impact juvenile survival, a range of other factors such as chick growth rate, fledgling age, and sex all also likely influence survival (Maness and Anderson 2013).

Figure 4.1. Adult King Shag feeding a young chick at the Tawhitinui colony. Photo Kailash Willis.

Little data exists for kawau pāteketeke/New Zealand King Shag (*Leucocarbo carunculatus*) on body size and mass of both adults and chicks (Marchant and Higgins 1990). In this report we detail the development of sexual size dimorphism in King Shag chicks, and intercolonial differences in chick condition from measurements collected during landings at four colonies in the Te Tauihu-o-te-waka/Te Tauihu-o-te-waka/Marlborough Sounds to band chicks.

Methods

Morphometric measurements

To balance the need for morphometric data with potential researcher effects of landing at breeding colonies, only two measurements were taken from chicks: wing length and body mass. Wing length (maximum chord, length of flattened and straightened wing) measurements were taken using a wing rule (ruler with a stop at zero) measuring to the nearest 1mm. Body mass was recorded using either a 2500g or 5000g spring balance, recorded to the nearest 20g (2500g scales) or 50g (5000g scales). Chicks (n=150) were only measured once. With the timing of breeding variable between colonies, chick measurements occurred at differing times between late June and August, with landings aimed for mid chick rearing to maximise the number of chicks available to be caught and minimise the risk of older chicks taking to the water to escape researchers. Chicks old enough were also banded with a metal and an alpha numeric engraved ring (Figure 4.2.), and sex was determined by DNA testing of feather samples collected from birds during handling (see Chapter 7 for more details).

Statistical analysis

We investigated the growth trajectory of sexual dimorphism in King Shags by examining how body mass changes with wing length (as a proxy for age). Chicks that we were unable to DNA sex (i.e., chicks that were newly hatched and naked in the nest thus feathers were unable to be collected, n = 38), were not included in the analysis (birds analysed n = 112). We ran a linear model with mass (g) as the response variable. As explanatory variables we included wing length (mm, centred on zero) as a quadratic term, sex (categorical: male and female) and an interaction term between wing length and sex to test for the change in sexual dimorphism 'over time'. We also included colony of origin (categorical: Duffers Reef, Kuru Pongi/North Trio Island, The Twins, and Tawhitinui) to account for colony differences. We assessed model validation using the 'DHARMa' package (Hartig 2020). Lower and upper 95% confidence intervals were calculated using the 'confit' function. We examined post-hoc comparisons using the contrasts function from the emmeans package (Lenth 2022) using a 'Tukey' adjustment for multiple comparisons (these are presented in text). For reference, 95% CI that do not pass zero are considered statistically significant. The predicted marginal effects were calculated and plotted using the 'ggpredict' function in the 'ggeffects' package (Lüdecke 2018). All statistical analyses were done in R (R Core Team 2022).

Figure 4.2. King Shag chick being banded, Tawhitinui colony, July 2018.

Results

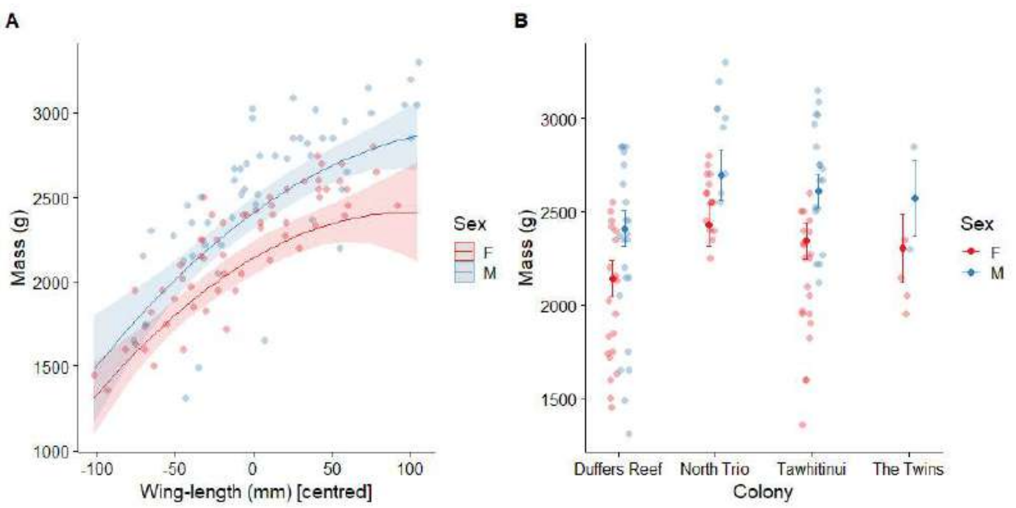
Males tended to be heavier than females, with males having an average body mass of 2543 g (± 451 SD, range 1310 – 3300 g) compared to the female mass average of 2192 g (± 361 SD, range 1360 – 2800 g). However, we failed to detect when the change in body mass between males and females occur (i.e., lack of significant interactive effect between sex and wing-length^2; Figure 4.3; Table 4.1), with the model indicating sexual dimorphism in body mass likely occurs before wing-lengths of around 100-128 mm (minimum female and male wing-length data collected, respectively).

Overall, birds from Tawhitinui and the Kuru Pongi/North Trio colonies were significantly heavier compared to birds from Duffers Reef, whereas no significant difference between birds from Duffers Reef and The Twins was detected (Figure 4.3; Table 4.1). No other significant differences in body mass were detected between the other colonies (Kuru Pongi/North Trio vs Tawhitinui est. 85.4 [-84.8, 255.5 95%CI]; Kuru Pongi/North Trio vs The Twins est. 125.8 [-151.0, 402.5 95% CI]; Tawhitinui vs The Twins est. 40.4 [-219.6, 300.3 95% CI]).

Table 4.1. Results of model investigating sexual dimorphism in body condition over time (using wing length as a proxy for age). Reported are the parameter estimates, standard errors (SE), lower and upper 95% confidence intervals (CI). Sex (female) was the reference group for Sex (male) and Colony (Duffers Reef) was the reference group for all colonies of origins. Note, wing length was coded as a quadratic term denoted by wing-length^2.

Variable	Estimate	SE	95% CI	T-value	P-value
Intercept	2142.14	50.73	2041.53, 2242.74	42.229	<0.001
Wing-length	5.39	0.67	4.06, 6.72	8.039	<0.001
Wing-length^2	-0.03	0.012	-0.051, -0.002	-2.172	0.032
Sex(male)	267.87	58.84	151.18, 384.56	4.553	<0.001
Colony(Kuru Pongi/North Trio)	286.99	63.68	160.70, 413.27	4.507	<0.001
Colony(Tawhitinui)	201.62	49.86	102.74, 300.50	4.044	<0.001
Colony(The Twins)	161.24	98.53	-34.17, 356.64	1.636	0.105
Wing-length:Sex(Male)	1.34	0.98	-0.61, 3.29	1.366	0.175
Wing-length^2:Sex(male)	0.004	0.02	-0.03, 0.04	0.220	0.826

Figure 4.3. The relationship between the mean predictions (± 95% CI) of mass (g) with (A) wing length as a function of sex and (B) between colonies of origin (Duffers Reef, Kuru Pongi/North Trio, Tawhitinui and The Twins). Raw data (points) are overlayed on top of predictions.



Discussion

We used wing length as a proxy for age, a method commonly used in studies of procellariform seabirds to estimate chick age (Yoda *et al.* 2016). In cormorant species divergence of wing length arising due to sexual dimorphism occurs later in chick development compared to other morphometric measurements (Velando *et al*. 2000, Svageli and Quintana 2017). As such, we believe wing length is a good proxy for age in both sexes of cormorants.

Our inability to detect an interactive effect in body mass between male and female chicks (i.e., developmental transition of sexual dimorphism) suggests sexual dimorphism in mass in King Shag occurs before chicks reach a wing length of *c.* 120mm (estimated to be 17 days). This is in line with Svageli and Quintana (2017) who found male Imperial Shag chicks became heavier than females from 15 days, whilst wing length does not become longer until 40 days; and Velando *et al.* (2000) where male European Shag weight separation occurred at 15 days, wing length at 40 days.

Chicks in this study were only measured once to determine sexual dimorphism and chick condition. Benson *et al.* (2002) showed assessing seabird condition from a single colony visit using only wing length and mass are adequate to evaluate chick development; ideally measuring chicks late in their linear growth phase, but prior to pre-fledging weight regression. With our measurements taken during the mid-chick rearing period, to minimise the risk of large chicks escaping to sea, we feel confident we can use our data to assess King Shag chick condition.

We discovered an intercolonial difference in chick condition, with birds from Duffer's Reef lighter on average than birds from Kuru Pongi/North Trio and Tawhitinui. This result is then mirrored in lower juvenile survival reported from Duffers Reef (Chapter 5). Why Duffer's Reef produces lower quality chicks is unclear, the colony is very low lying with all nests <5m above sea-level (Schuckard et al. 2015) and exposed (especially to the north-east). Two other similarly low-lying exposed colonies (Hunia and White Rocks) were not included in this study and have both had low productivity at times (Chapter 3). Colony exposure is potentially an important factor effecting chick condition and survival. Additional potential factors affecting body mass may include intercolonial differences in prey-availability and/or differences in prey quality. Further research is warranted to better understand the intercolonial differences we have observed in this study.

Chapter 5. Early-life traits in kawau pāteketeke/King Shag (*Leucocarbo carunculatus*).

Mike Bell, Patrick Crowe, Dan Burgin, Simon Lamb, and Samantha Ray

Summary

A total of 112 kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) chicks have been banded at colonies during the 2018, 2019 and 2020 breeding seasons. Juvenile survival was low with only 29% of birds ever resighted at least once, one-year post-banding, with no difference between survival of male and female chicks. Intercolonial differences in chick survival were observed, with birds from Kuru Pongi/North Trio and Duffer's Reef having lower survival than Tawhitinui. Pooling band re-sighting data from all years, the average period of parental care was 21 weeks/or 4.9 months (range 5 - 121 weeks, 1.2 - 28.3 months), with no difference between length of parental care for male verse female offspring. Chicks which survived ≥1-year post-fledging had a significantly longer period of parental care than chicks which died within a year post-fledging. Juvenile mortality was highest in January and February when chicks were 5-7 months old. Juvenile King Shags dispersed from colonies between 4-12 months old ($\bar{x}$=6 months), with a mean distance seen from natal colonies of 21km (range 4.5-90km). Males were recorded significantly further from their natal colonies than females, although both sexes had a dispersal phase. The timing of juvenile mortality and start of juvenile dispersal coincides with the end of parental care and is the key factor influencing these early-life traits in King Shag.

Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) is a large (length 76cm, weight 2.5kg), black and white marine cormorant restricted to the Marlborough Sounds and is considered sedentary (Marchant and Higgins 1990). Prior to this research project, little was known about survival and behaviour of juvenile King Shags (Marchant and Higgins 1990; Taylor 2000). Butler (2003) considered the possible effects of mussel farming to be of increasing concern, although most potential impacts had little supporting evidence, with this report highlighting the lack of data relating to age of first breeding, along with juvenile survival and recruitment.

The use of population models as predictive tools to determine potential impacts on seabirds in relation to changes in environmental factors (i.e., climate change) and anthropogenic impacts (i.e., fisheries impacts and oil spill effects) has become increasingly common in conservation management of seabird species (Votier *et al.* 2008; Fay *et al.* 2015; Koehn *et al.* 2021). However, early-life demographic traits are poorly known for many species and are not well represented in such models (Fay *et al.* 2015).

To move towards being able to develop a robust predictive population model for King Shag, it is vital to understand early-life traits such as the period of parental care, juvenile survival, and timing of mortality, along with the rate and duration of juvenile dispersal. This report presents the results of re-sighting of King Shags banded as chicks, to determine these early-life traits.

Methods

Banding

As King Shag are highly susceptible to disturbance, and previous recommendations for studies had encouraged no landing or handling of birds (Marchant and Higgins 1990), a pilot study aimed at capturing and banding birds was first trialled in mid-late chick rearing in July 2018 at Tawhitinui. In this first attempt, 11 chicks and a single adult bird were captured and banded. Although the landing caused significant disturbance at the colony, with all adults departing and larger nestlings moving from nests, there were no long-term effects detected. Once we had left the colony, both adults and banded older chicks returned relatively quickly to nests (<2 hours). Both 24 hours and 7 days after capture and banding, all banded young and the single adult were recorded alive, and all nests with smaller young were still active; indicating that there were no long-term effects on the colony from the disturbance.

Following this initial success, banding was extended to other colonies throughout the Marlborough Sounds. The key drivers of banding were to band chicks to develop a known-age, marked population to investigate juvenile survival and age of first breeding, to capture adults for GPS tracking and to determine annual adult survival.

Banding was initially carried out in the middle of the day during the mid-chick-rearing period. Landing near the colony from a boat, one person would slowly work their way into the colony attempting to capture adult birds guarding chicks at nests using a crook (Figure 5.1). Between 1-4 adults could be captured using this method before the disturbance caused all adults to depart the colony. Following the departure of adult birds, all chicks large enough to be banded where caught and held in bird bags for processing outside of the main colony area. Smaller naked chicks were covered with soft material to protect them both from exposure, and from potential predation from gulls.

Figure 5.1. After slowly creeping to the each of the colony, a researcher uses a crook to capture an adult King Shag on a nest brooding young chicks (Photo Dan Burgin).

Birds were banded with a metal band, and an alpha numeric engraved ring to assist individual identification at a distance (Figure 5.2). All individuals were weighed and had wing length recorded while adults, first- and second-year birds were checked for moult. Following the discovery of a juvenile bird with feather dystrophy in 2013 (Melville and Schuckard 2021) all birds caught were checked for this, and any other possible health issues by visual inspection. All birds were aged on plumage characteristics, and had a feather collected to enable DNA sexing. Adult birds were fitted with a GPS device (see Chapter 7).

Figure 5.2. Engraved colour bands have enabled individual identification of King Shag and enable this research. Left- Estimated two-week-old chick alongside its nest immediately after banding (Photo Dan Burgin). Right- A two-year old bird banded as a chick roosting on a mussel buoy in Port Ligar (Photo Dave Boyle).

To target more adults and increase sample sizes of GPS tracked birds, landings were undertaken one hour prior to dawn to capture birds in the dark during the non-breeding season. The colony was approached using a red light and birds were captured with a crook. On moonless nights, King Shags were reluctant to leave the colony and a significantly higher number of birds could be captured, including first-year, second-year and adult birds. All birds were held in bird bags and were taken onboard a boat for processing (or on one occasion processed on shore, near the colony). Birds were released soon after dawn.

Re-sighting visits

Regular trips to re-sight banded birds were undertaken at Tawhitinui and Duffers Reef immediately after banding trips. Re-sighting trips were carried out in the late afternoon and evening as birds returned to the colony. At Tawhitinui, observers remained on the boat anchored offshore while at Duffers Reef observers landed on the small reef just offshore which was exposed at low tide (hence all resights here were done to coincide with a low tide in the early evening). Digital cameras with large zoom lens were used to help identify birds.

During re-sighting trips, the behaviour of banded birds was recorded including the breeding activity of adults, onset of pre-breeding behaviour of juveniles, and whether juveniles were being fed by their parent(s).

Fixed camera re-sighting data

In addition to boat-based observations, fixed cameras were set up at several colonies from August 2018 timed to take a photo every 30 minutes during daylight. Gummer (2021) reported on banded birds recorded at Tawhitinui from August 2018 to October 2019, and at Duffers Reef from December 2018 to November 2019. Additional re-sightings from footage collected until November 2020 were provided by Dr Karen Middlemiss, Department of Conservation. Although this footage seldom recorded parents feeding chicks, the number of re-sightings of individual birds did provide a more precise timing of when juvenile birds were last observed at a colony

Determining the length of parental care

The length of parental care was determined from the estimated fledging date of chicks based on wing length and weight at the time of banding, to the last day that chicks were recorded being fed by parents. As re-sighting trips were 3-7 weeks apart, it is likely that this method will slightly underestimate the actual parental care period and results reported here should be treated as a minimum. Although chicks were also banded at Kuru Pongi/North Trio and The Twins, for this analysis we only use data from Tawhitinui and Duffers Reef as these are the only two sites with regular re-sighting effort, making it possible to accurately determine how long chicks were fed by their parents post-fledging.

Juvenile survival statistical analysis

All statistical analyses to determine juvenile survival were done in R (R Core Team 2022). As a proxy for juvenile survival, we modelled the probability that a chick, once banded in the nest is resighted after fledging at least once from the following year onwards (i.e., sighted at least once in the 365 days post-banding). We ran a generalised linear model, with a binomial error function (logit-link) with the response variable as either re-observed (1) or not re-observed (0). We included the explanatory variables; sex (categorical, two levels, male and female); and breeding colony of origin (categorical, four levels, Duffer's reef, North Trio Island, The Twins, and Tawhitinui). We assessed model validation using the 'DHARMa' package (Hartig 2020). Lower and upper 95% confidence intervals (CI) were calculated using the 'confit' function. Post-hoc comparisons between colonies of origin were examined using the 'glht' function from the 'multcomp' package with a 'Tukey' adjustment (these are presented in text). Note, only lower and upper 95% CI are presented for post-hoc comparisons. For reference, 95% CI that do not pass zero are considered statistically significant. The predicted marginal effects were calculated and plotted using the 'ggpredict' function in the 'ggeffects' package (Lüdecke 2018).

Timing of juvenile mortality

The timing of juvenile mortality was taken as the last time a chick was seen at a colony. Care was taken to ensure that only chicks which had truly perished were included in this analysis. Some juvenile birds were re-sighted 4-12 months after they were thought to have disappeared from a colony; therefore, absence from a colony does not always mean birds have perished as these birds were re-sighted later and had survived, they were excluded from this analysis. Only chicks banded at Tawhitinui, and Duffers Reef colonies were used in this analysis as these two colonies were where resighting effort was high enough to accurately determine when chicks perished.

Juvenile dispersal

In addition to re-sighting trips targeting the colonies themselves, band re-sightings were also recorded away from colonies. All re-sightings of banded King Shags away from colonies were recorded on a GPS to accurately record their location. All roosting shags seen were checked for bands, as King Shags mainly roost on mussel farms and prominent headlands, bands are often clearly visible. Digital cameras were used to zoom in on birds, to assist the reading of bands to confirm identification without causing disturbance. With the provenance of banded chicks known, the distance of movements from colonies could be measured. We measured this as the minimum distance following water, as King Shag seldom crossed land.

Results

Researcher effects

During daylight landings, a small number of older chicks jumped and swam away from the colony. One of these was captured on the shore and returned to the colony, others were unable to be captured. These older chicks were able to find their way back to the colony and counts of the colony 24 hours after landings recorded all large chicks back at colonies. Using fixed camera footage from Tawhitinui and Duffers Reef, Gummer (2021) reports a small number of nests where young chicks died after banding trips. These were younger chicks, and it is suspected they had been displaced from nests and were unable to return. The rate of mortality from researcher disturbance was significantly lower than natural mortality rates recorded but does indicate that landings at colonies during the breeding season can cause low levels of chick mortality.

Birds banded

A total of 198 King Shag have been banded from four colonies comprised of 112 chicks, 12 first-year birds, 7 two-year old birds, and 67 adult birds (Table 5.1). No birds caught displayed any feather abnormalities or other health issues.

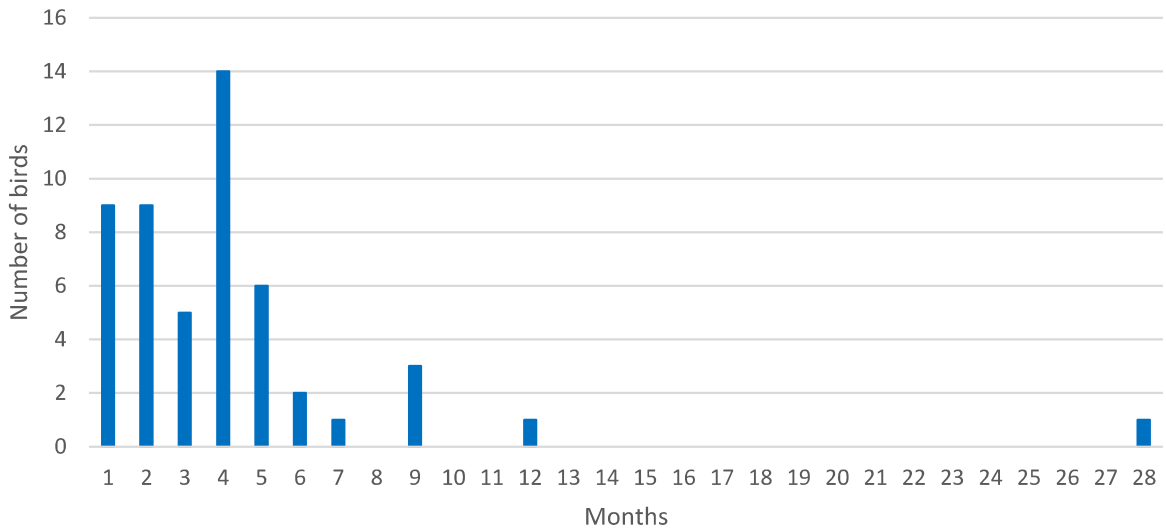
Table 5.1. The number, age and location of King Shag banded from 2018-2022

Location	Age	2018	2019	2020	2021	2022	Total
Tawhitinui	Adult	1	4	1	6		12
	1Y				6		6
	Chick	11	13	15			39
Duffers Reef	Adult		2	15			17
	1Y			4			4
	Chick		23	20			43
North Trio	Adult					21	21
	2Y					5	5
	1Y					2	2
	Chick			24			24
The Twins	Adult			1	16		17
	2Y				2		2
	1Y						0
	Chick			6			6
Total		12	42	86	30	28	198

Length of parental care

Pooling data from re-sighting visits across all years, 51 of the 82 (62%) chicks banded at Tawhitinui or Duffers Reef were recorded as being fed by their parents on at least one occasion. On average the last time chicks were fed by their parents was 21 weeks/4.9 months (range 5-121 weeks, 1.2-28.3 months) (Figure 5.3).

Figure 5.3. Length of parental care (months) of King Shag fledglings at Duffers Reef and Tawhitinui.



There was no significant difference in the length of parental care period of male chicks ($\bar{x}$=20.9 weeks; SD=22.8) and female chicks ($\bar{x}$=18.8; SD 11.9), Student's two sample t-test; t_{34} =-0.397, p=0.694.

Chicks which survived ≥1 year post fledging had a significantly longer parental care period ($\bar{x}$=24.7 weeks; SD=23.6) than chicks which disappeared <1 year old ($\bar{x}$=15.2 weeks; SD=7.1), Student's two sample t-test; t_{28} = 1.926, p=0.032.

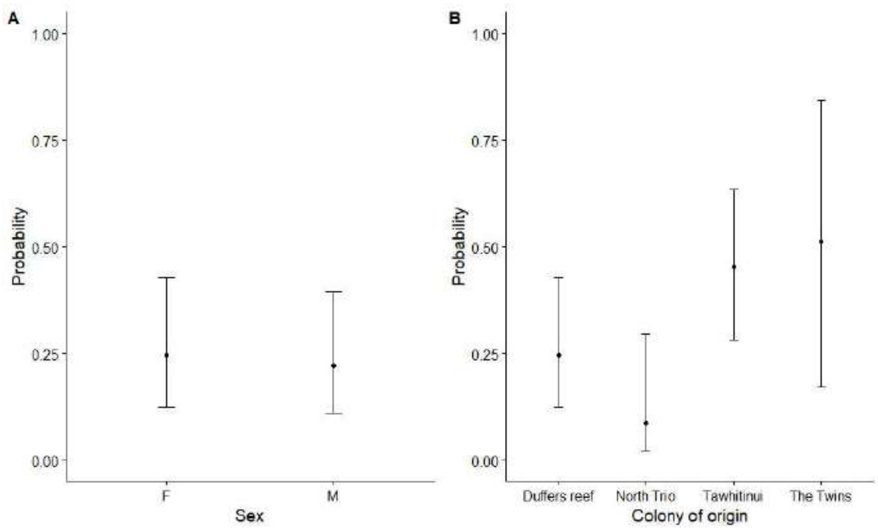
Juvenile survival

As a proxy for survival into at least the following year, the probability of resighting a King Shag chick once banded was low with only 29% (*n* = 32) of birds ever re-sighted at least once, one-year post-banding. Males and females were equal in their low probability of being resighted (Figure 5.4; Table 5.2). Chicks from different colonies showed some differences, with chicks from Tawhitinui having a significantly higher probability of being re-sighted compared to birds from North Trio (est. 2.15, [0.10, 4.21 95% CI]) and marginally higher probability (though not statistically significant) than birds from Duffers Reef (Figure 5.2B; Table 5.2). No other statistically significant differences between colonies were found in re-sighting probability (The Twins vs Tawhitinui est. 0.24 [-2.00, 2.48 95%CI]; The Twins vs Kuru Pongi/North Trio est. 2.40, [-0.40, 5.19 85%CI]).

Table 5.2. Results of model investigating the probability of re-sighting a banded chick from the following season onwards (as a proxy for juvenile survival). Reported are the estimates, standard errors (SE), lower and upper 95% confidence intervals (CI). Sex (female) was the reference group for Sex (male) and Colony (Duffers Reef) was the reference group for all colony of origins.

Variable	Estimate	SE	95% CI	Z-value	P-value
Intercept	-1.12	0.42	-2.00, -0.33	-2.66	0.008
Sex(male)	-0.14	0.45	-1.02, 0.73	-0.32	0.752
Colony(Kuru Pongi/ North Trio)	-1.22	0.82	-3.16, 0.23	-1.48	0.138
Colony(Tawhitinui)	0.93	0.48	-0.01, 1.91	1.92	0.055
Colony(The Twins)	1.17	0.90	-0.65, 3.00	1.31	0.192

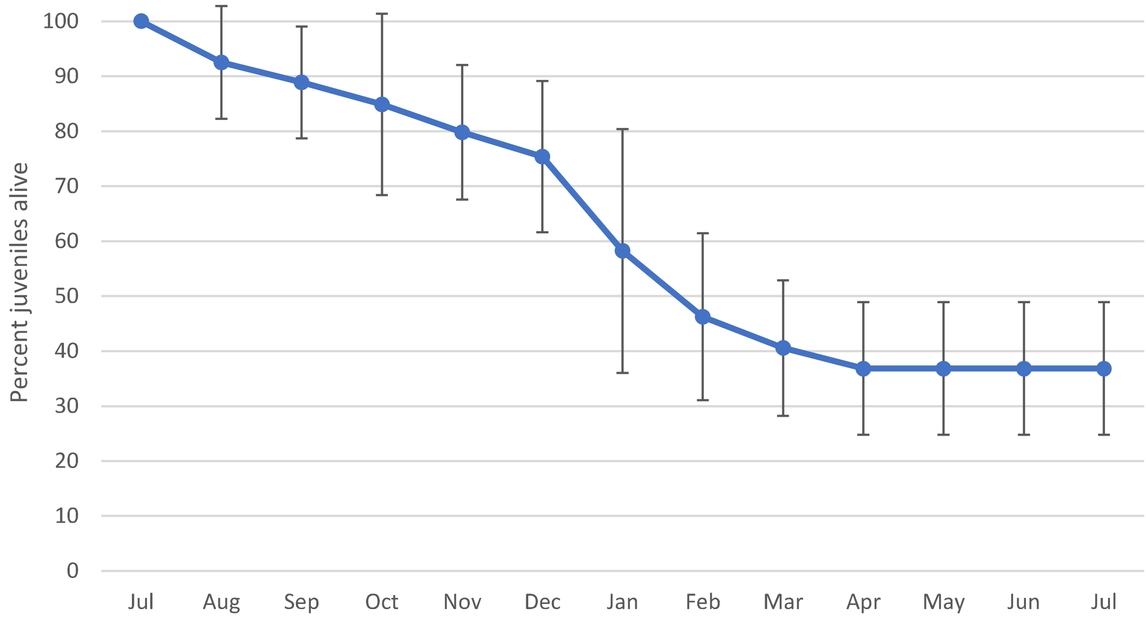
Figure 5.4. The relationship between the mean predicted probability (± 95% CI) of re-sighting a chick one year after being banded (as a proxy for juvenile survival) between (A) each sex (female and male) and between (B) colonies of origin (Duffers Reef, Kuru Pongi/North Trio, Tawhitinui and The Twins).



Timing of juvenile mortality

Pooling data from Tawhitinui for the 2018, 2019, and 2020 breeding season, and Duffers Reef from the 2019 and 2020 season, a total of 82 chicks were banded. In each of these seasons, fledging occurred in late July/early August for both colonies. Re-sighting data shows that there was a gradual rate of juvenile mortality post-fledging for the first five months until December; by which time 25% of juvenile birds had died (Figure 55.). This was then followed by a significant period of mortality (a further 29%) in the two months from January to February when chicks were 6-7 months old, before stabilising after March when chicks were 8 months old.

Figure 5.5. Proportion of juvenile King Shag still alive each month from Tawhitinui and Duffers Reef 2018-2020 cohorts when fledgling was late July/early August: annual mean with 95% confidence interval shown.



Juvenile dispersal

Since banding started in July 2018, to June 2022, there has been a total of 40 re-sightings of 25 birds banded as chicks or first-year birds away from their natal colony (Figure 5.6). The mean distance from natal colony of these sightings was 21km (Range 4.5-90km), with 80% of sightings being ≤20km (Figure 5.7). Male King Shag were recorded significantly further from natal colonies ($\bar{x}$ =27.4km, SD=25.5) than females ($\bar{x}$ =14.3km, SD=16.8); Student's two sample t-test; $t_{36} = -1.95$, $p = 0.029$.

To date, it is difficult to be certain that juveniles have shifted from their natal colony to breed elsewhere, as breeding is yet to be confirmed. However, two Tawhitinui chicks (one male and one female), and one Duffer's Reef chick have shifted to Tōtaranui/Queen Charlotte Sound, and a Duffer's Reef chick (female) has been seen on The Haystack on an empty nest in June 2022, so may go on to breed there.

Figure 5.6. Location of re-sightings of King Shag banded as chicks or first-year birds from natal colonies.

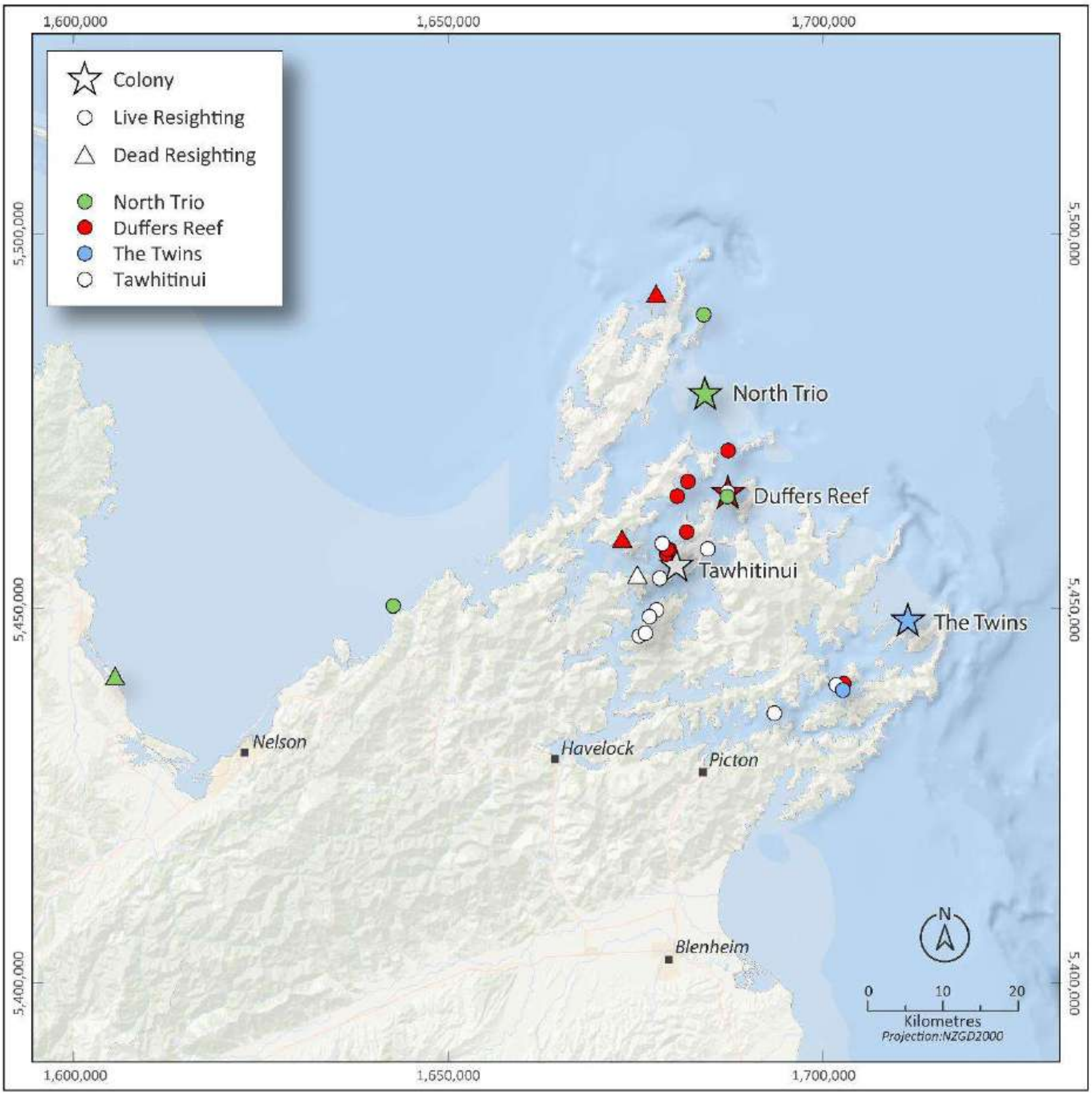
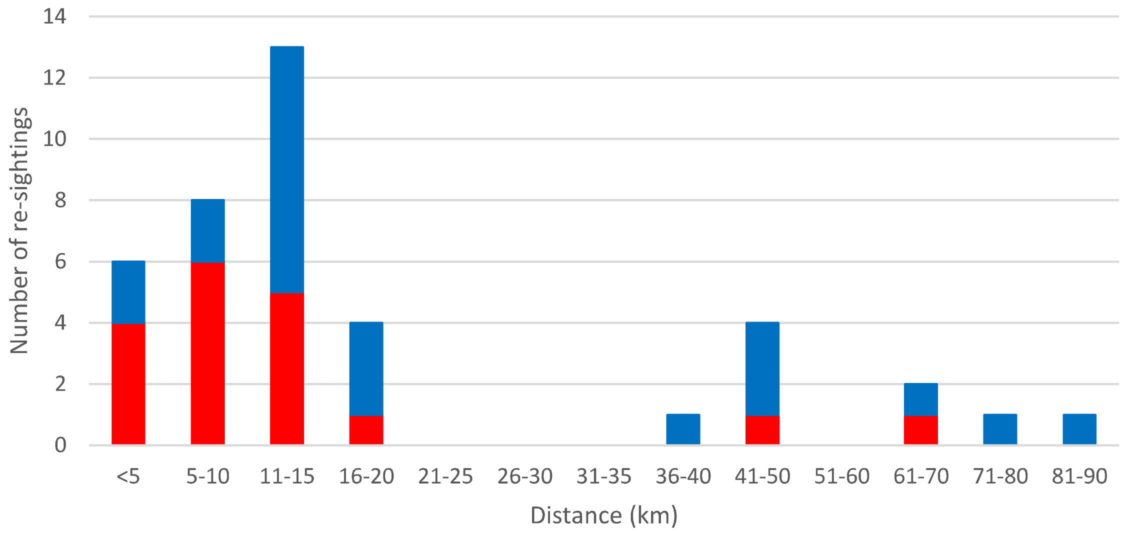


Figure 5.7. Distance of re-sightings of King Shag banded as chicks or first-year birds from their natal colony. Blue bars = male, red bars = female.



A total of 26 of the 82 (32%) chicks banded at Tawhitinui and Duffers Reef were re-sighted up until late in their second year of life. Of these, 18 (69%) have gone for a period of ≥4 months with no re-sighting; although this may be an under-estimate as some of the 2020 cohort of chicks may still be re-sighted in the future. On average, these juvenile birds are going "missing" when they are 6 months old (range 4-14 months) and are not seen for an average of 8 months (range 4-12 months). There is no significant difference in the duration of no observations of males ($\bar{x}$=8.5 months, SD=2.1) than females ($\bar{x}$=7.4, SD=4.2). Student's two sample t-test; t_{10} = 0.69, p=0.5.

Of the 18 birds that went "missing", 11 returned to their natal colony, four have shifted to new sites (the two Tawhitinui and one Duffers Reef birds shifting to Tōtaranui/Queen Charlotte, and the second Duffer's Reef Bird moving to The Haystack), and three have only been recorded roosting on mussel farms when out foraging.

Discussion

This is the first-time juvenile survival has been estimated for a blue-eyed shag species in New Zealand; and there is limited data for blue-eyed shags globally. We recorded similar first-year survival rates as South Georgia Shag (0.36) (Cobley 1992) and Imperial Shag (0.33) (Quintana *et al.* 2022). King Shag juvenile survival recorded here is within range for other cormorant species such as 0.37 for Double-crested cormorant (Ayers et al. 2019) and 0.50 for Great Cormorant (Hénaux *et al.* 2007).

Lower juvenile survival found in colonies in the outer Marlborough Sounds suggests birds fledging from more sheltered colonies within the Sounds, have higher survival because of this improved shelter. Daunt *et al*. (2007) found fledgling European Shag mortality was linked to developing foraging proficiency. The inner Marlborough Sounds with less exposure potentially provides better foraging for juvenile King Shag as they hone their foraging skills, and this ultimately leads to higher survival rates.

The timing of when fledglings become independent is an important part of understanding their life history, especially in long-lived seabirds. The timing of juvenile mortality coincides with the end of parental care and is also the period when juveniles begin to disperse from colonies. Further, juvenile survival is linked to parental care, with chicks which survived ≥1 year post fledging having a longer period of parental care than chicks which died. Guo *et al.* (2010) considered when fledgling Red-footed Booby spent >4 nights away from the colony to be when chicks were independent which was 16 weeks after fledging. This suggests that for King Shag the end of parental care is when chicks are truly independent and is the start of a dispersal period.

It is during this dispersal period that birds wander further afield and have been recorded outside of the Marlborough Sounds, with most extra-limital sightings of King Shag being juvenile birds (Bell *et al.* 2022 this study). Our results highlight that juvenile King Shag do have a dispersal period, and that they have a greater dispersal ability than previous thought (Marchant and Higgins 1990).

Chapter 6. Extra-limit records of kawau pāteketeke/King Shag (*Leucocarbo carunculatus*).

Mike Bell

Summary

Since 2002 there have been a small number of Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) sightings outside of the normal range within Te Tauihu-o-te-waka/Marlborough Sounds. The distance from the nearest King Shag colony to each of the sightings averaged 102km (range 60-180km). With most sightings being first-year birds, this suggests King Shag have a higher dispersal ability that previously recognised, and this aligns with studies of banded chicks within Te Tauihu-o-te-waka/Marlborough Sounds showing a dispersal period for juveniles at the end of parental care.

Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) are restricted to Te Tauihu-o-te-waka/Marlborough Sounds and are considered to be sedentary, with no movements recorded away from Te Tauihu-o-te-waka/Marlborough Sounds (Marchant and Higgins 1990).

The relatively recent development of online databases to record biological sightings by members of the public has resulted in a rapid accumulation of data on species distributions and abundance across the globe. The value of this "citizen science" data is now being recognised and is being used to help inform wildlife managers and government policy (Ruiz-Guitierrez et al 2021).

Since the mid 2000's the Ornithological Society of New Zealand have sponsored the development of an online database to record bird observations in this country; eBird (www.ebird.org). Powered by the Cornell Lab of Ornithology eBird records an observer's bird sightings into to structured checklists which can then be used by scientists for research, conservation, and education. Significantly, the open access and searchability of eBird means data on individual species can be readily accessed.

This report presents records of King Shag outside of their normal distribution and discusses the implication of these records regarding the species ecology.

Methods

The online bird recording database eBird (www.ebird.org/nz) was searched for King Shag records to identify extra-limital records. The Ornithological Society of New Zealand Records Appraisal Committee online records database (www.rare.birds.org.nz) was searched for additional records, or for further information on records in eBird. In addition, the Ornithological Society of New Zealand publications - both the scientific journal *Notornis*, along with the Societies more informal magazine *Birds New Zealand* – were searched for King shag reports.

Knowing that some observations may have been made by birders who are not members of the Ornithological Society, a wider internet search for additional sightings was undertaken using the search Google search engine. Typing in the key words King + Shag + NZ, results were manually checked for sightings outside of Marlborough. If a possible sighting was picked up, the location was added and the search repeated (i.e., King Shag + Kaikoura) to try and detect more records or further information. Sightings found this way were only included if they contained a photo to confirm identification, or a contact person listed.

Results

A total of 5 sightings, or groups of sightings, of King Shag outside of the Te Tauihu-o-te-waka/Marlborough Sounds were found (Figure 6.1). Four of these sightings were of individual birds, but one group of sightings in Abel Tasman National Park may have included up to 5 individuals. Detail of each sighting is provided below:

Worser Bay, Wellington Harbour, 14 July 2002.

Report of a *Leucocarbo* shag in Wellington Harbour was accepted by the Ornithological Society of New Zealand Records Appraisal Committee and was considered most likely to be a King Shag (Medway 2002).

Barney's Rock, Kaikoura, 6 November 2011.

A report of a juvenile present on Barney's Rock was considered most likely a King Shag by the Ornithological Society of New Zealand Records Appraisal Committee, but at the time they felt the information provided was insufficient to rule out Otago Shag (Miskelly et al. 2019). Re-evaluating the Unusual Bird Report and additional images provided by the observer that this bird appears to be a first year King Shag. The same bird had been seen by other observers at least a week previously to this sighting.

Motuareronui/Adele and Tonga Island, Abel Tasman National Park, Tasman Bay, January 2015-November 2016.

The first report was of a single bird from Motuareronui/Adele Island on 1 January 2015 (Miskelly et al. 2017). Following this until October 2016 there was a further six sightings of individual birds, which were suggested to include up to 5 individual birds. Most records were of birds roosting on Adele Island, but also a record of an adult from nearby Tonga Island (Robertson 2017). With A further report of a first year bird in Nov 2016 appeared on Abel Tasman Eco Tours Facebook page (https://m.facebook.com/AbelTasmanEcoTours/photos/a.567909103261977/1334456626607217/?type=3&_rdr).

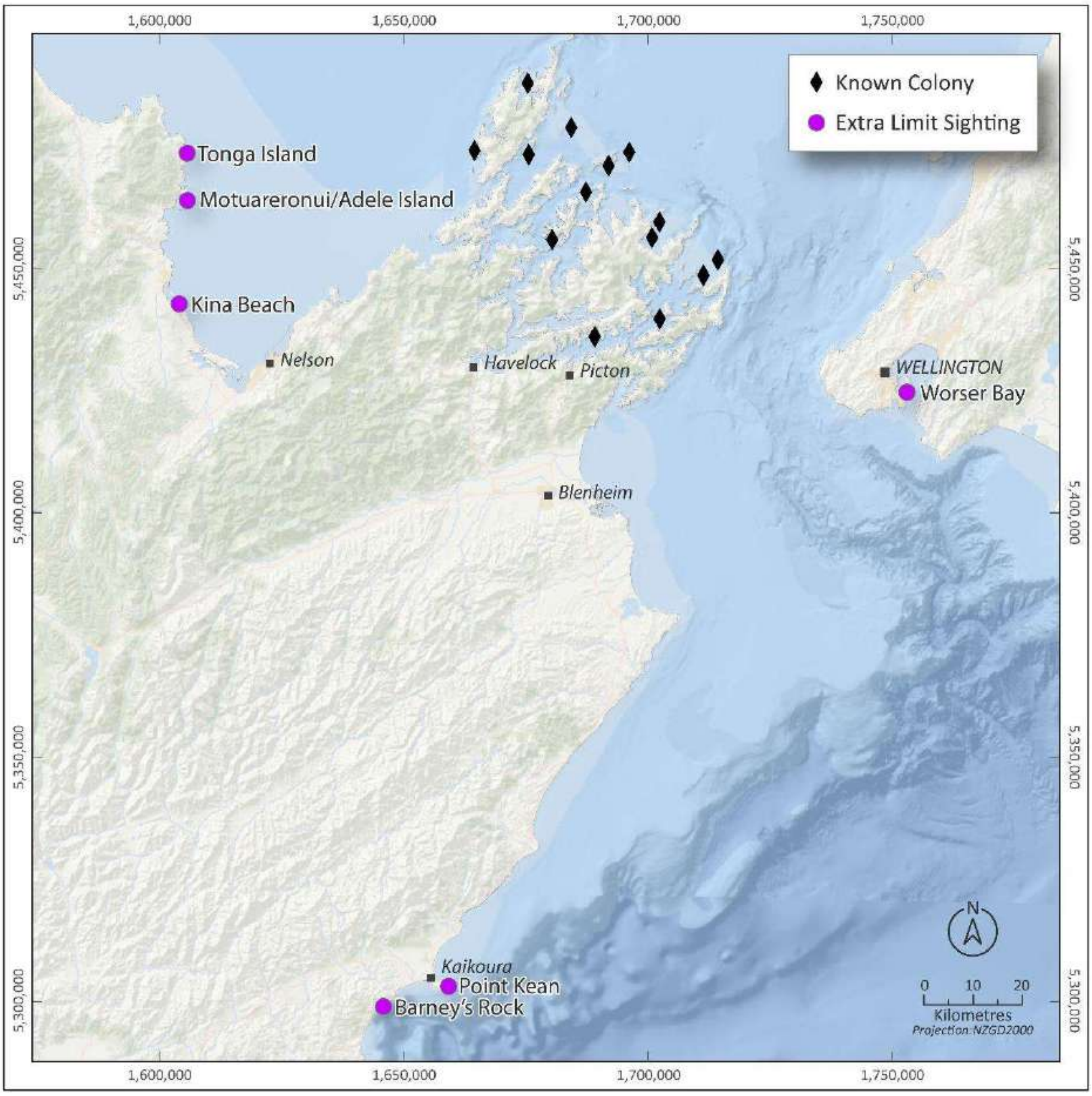
Point Kean, Kaikoura Peninsula, 30 May 2020.

Photographs of a first year King Shag taken at Kaikoura Peninsula on 30 May 2020 were passed on to the Ornithological Society of New Zealand Marlborough Branch (P. Crowe *pres. comm.).* The photos confirm that this bird was a first year King Shag.

Kina Bay, Motueka, 23 March 2022.

A dead banded first year bird was found by a member of the public on Kina Beach and reported to the Department of Conservation Banding Office. This bird had been banded at the Kuru Pongi/North Trios colony three weeks earlier on 4 March 2022.

Figure 6.1. Sightings of King Shag from outside Te Tauihu-o-te-waka/Marlborough Sounds



Discussion

Four of the five sightings were of individual birds, all of which were first-year birds. The records from Abel Tasman National Park are interesting and occurred over nearly a two-year period. Records include both first year and second year birds, with a single adult bird also being seen. However, no further details were available on the timing of these individual sightings; and it is possible given the two-year timeframe, that these sightings follow the development of several first-year birds through to adult type plumage across this period.

The distance from the nearest King Shag colony to each of the sightings averaged 102km (range 60-180km) (Figure 6.1, Table 6.1). With most of the sightings being first-year birds, suggests that King Shag possibly have a higher dispersal ability that previously recognised (Marchant and Higgins 1990). Studies of banded chicks within Te Tauihu-o-te-waka/Marlborough Sounds confirmed a dispersal period of juveniles following the end of parental care (Chapter 5).

Table 6.1. Distance to nearest colony for each extra-limital King Shag sighting

Location	Distance (km)
Worser Bay, Wellington Harbour	60
Motuareronui/Adele Island, Abel Tasman National Park	60
Tonga Island, Abel Tasman National Park	60
Kina Bay, Motueka	90
Point Kean, Kaikoura Peninsula	165
Barney's Rock, Kaikoura	180

This behaviour may mean that it is possible for King Shag to colonise new areas outside of their current restricted range. Obviously, establishment of any new colony would rely on enough birds dispersing to a site and surviving through to adulthood.

Chapter 7. Foraging ecology of kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) using GPS and time-depth recorders.

Mike Bell, Simon Lamb, Patrick Crowe, Dan Burgin, and Samantha Ray

Introduction

Aotearoa New Zealand is a global cormorant biodiversity hotspot, with 13 breeding species (Kennedy and Spencer 2014, Rawlence et al. 2017), of which 9 are endemic. Despite this high biodiversity, very little research or conservation action focuses on our cormorant species, with cormorants being the least studied of Aotearoa New Zealand's seabirds (Taylor 2000).

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) is a large (length 76cm, weight 2.5kg) black and white marine cormorant restricted to Te Tauihu-o-te-waka/Marlborough Sounds (Marchant and Higgins 1990). The fossil record suggests that King Shag were more widespread at the time of Polynesian arrival, distributed at least as far north as the southern Wellington coastline; however, by the time of European arrival, the range and population had contracted substantially and was considered rare by early naturalists of the 1800's (Rawlence et al. 2017; Nelson 1971). It is the most northern extant member of the blue-eyed shag *Leucocarbo* spp. group within Aotearoa New Zealand (Rawlence *et al.* 2017); which are sexually dimorphic and show sex-based differences in foraging traits (see review in Camprasse *et al.* 2017a). However, to date, none of Aotearoa New Zealand's blue-eyed shag species (comprised of seven extant species, all endemic) has been investigated using instrumentation.

King Shags face a myriad of threats, including climate change, disturbance, and fisheries/aquaculture (Taylor 2000). Recently, mussel farming had been considered likely to be impacting King Shag, despite limited research (Butler 2003, Fisher and Boren 2012). The ability to determine the risk of potential threats to King Shag has been limited by a lack of understanding of the species foraging ecology. To date, the studies of King Shag foraging ecology has mostly been limited to studies on diet, or observations from boats. For instance, van der Reis and Jeffs (2020), found that the King Shag diet is predominantly composed of flatfish, such as left eyed flounder (Bothidae), witch (*Arnoglossus scapha*) and crested flounders (*Lophonectes gallus*) among other benthic dwelling fish, indicating that King Shag are predominantly foraging along the seafloor. Schuckard (2006) found that King Shag from the Trio and Stewart Island colonies travelled an average of 10 km from the colony to foraging sites and foraged almost exclusively in water <50m. However, an in-depth and holistic understanding of how King Shag use and operate within the water column is still lacking and can only be captured by using high-resolution tracking devices.

In this study integrated GPS Time Depth Recorders were deployed to explore the foraging ecology of King Shag from four colonies in Te Tauihu-o-te-waka/Marlborough Sounds. This report aims to describe the foraging ecology of King Shag and compare this to other blue-eyed shag species.

Methods

Logger deployment

Adult King Shag were captured to attach GPS loggers to investigate foraging behaviour. Initial capture attempts were carried out in the middle of the day during the mid-chick-rearing period.

Landing near the colony from a boat, one person would slowly work their way into the colony attempting to capture adult birds guarding chicks at nests using a custom-made crook (Figure 7.1). Between 1-4 adults could be captured using this method before the disturbance caused all adults to depart the colony.

To increase sample sizes of GPS tracked birds, timings of landings shifted to night captures during the non-breeding season. One hour prior to dawn the colony was approached using a red light and birds were captured with a crook. On moonless nights, King Shag were reluctant to leave the colony and a significantly higher number of adult birds could be captured. Birds were held in individual cloth bags and were taken onboard a boat for processing (or on one occasion processed on shore, near the colony); allowing non-captured birds to settle at the colony. Once processed, birds were released to sea after dawn.

Birds were banded with a metal and alpha numeric engraved ring to assist individual identification at a distance. All individuals were weighed, had wing length recorded and were checked for moult. A GPS logger (Technosmart, Rome Italy) was attached to the dorsal feathers using Tessa Tape and super glue, anterior to the central back of the animal (Figure 7.1).

GPS loggers were programmed to record a location fix every minute, but also included a pressure switch that triggered when a bird surfaced to get a fix immediately after each dive. As King Shag return to colonies/roost sites overnight, to reduce battery consumption, loggers were programmed to record data from 1 hour before dawn, to 1 hour after dusk (i.e., during daylight).

Figure 7.1. King Shag White 56 with attached GPS device, not the tape is starting to give way and the device starting to fall off the bird.

The loggers used had integrated time depth recorders. In 2019, tags recorded depth every minute; however, technological improvements in 2020-2022 resulted in tags recording pressure every second and enabled full dive profiles to be recorded. In addition, loggers recorded wet/dry status, temperature, and speed.

The GPS loggers communicated with a base station positioned near the colonies. The Base stations stored data from tags, which was recovered by connecting a laptop to the base station and downloading data. Tags could store data until they were in contact with a base station, meaning any birds away from a colony for a period, would retain data until the bird returned to the colony and came within range of a base station. Birds were not re-captured to recover GPS loggers, with the tape failing and devices falling off birds in 5-18 days.

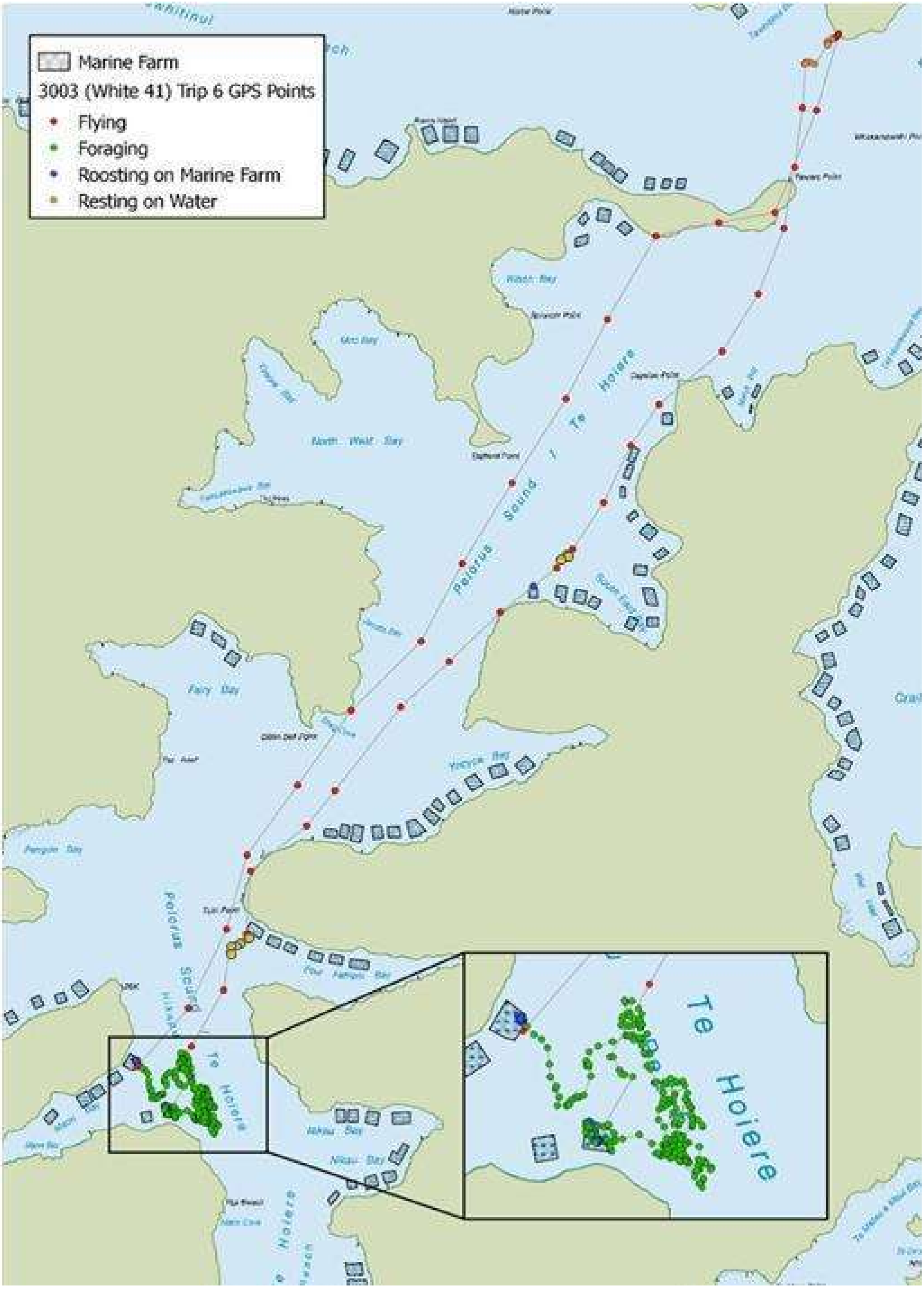
Classification of behaviour

Each GPS fix was attributed to one of four behaviours (Figure 7.2). Each birds daily GPS track was visually inspected, and behaviour determined for each GPS fix by assessing movement from previous and following fixes, unit speed, temperature, wet/dry status, and times of diving. Behaviour classes included:

1. Roosting – GPS fixes showed no movement in a single direction, with fixes clustered around a single point (recognising and allowing for individual drift in GPS fixes); there was nil or a gradual change in temperature (as birds exited the water temperature increased, then stablished to ambient temperature) with a dry status. Location of birds at colonies, known roost sites or on mussel floats helped determine if birds were roosting.
2. Flying – GPS fixes recording speed ≥20km/hour, with >50m between fixes, and usually with a low turn angle between fixes, and a steady temperature. King Shags usually had relatively short flights, with birds moving between the colony and foraging sites, and/or colonies and roosting sites.
3. Swimming – GPS fixes with speeds <20km/hour, and <50m between fixes, with or without high turn angles, and usually with a rapid drop in temperature (as birds entered the water for the first time, temperature rapidly drop from ambient to water temperature).
4. Foraging – GPS fixes immediately prior to and between dives. Fixes were usually <20km/hour, often with sharp and irregular turns, and fluctuating temperatures due to changing water temperature during dives. King Shag usually undertook extended foraging bouts with birds resting on the surface for approximately the same period as the preceding dive. When birds took an extended break during foraging bouts without going to roost, these were classified as swimming, not foraging. With only the GPS fix immediately after the dive then classified as foraging.

Although we did record birds undertaking “commute dives”, where birds dived ≤8m for ≤45s and GPS tracks indicating straight movement to or from colonies, we assigned these as swimming.

Figure 7.2. Individual foraging trip of King Shag White 41 (female) from Tawhtihui. She departs the colony and flies directly to Maori Bay, where after a short period roosting on a mussel farm she starts foraging, doing two foraging bouts seperated by a short break roosting on a second mussel farm. After foraging she travels home, interspecing flying with swimming (and another short stop on a mussel farm in South East Bay).



Determining foraging area and foraging distance

To determine foraging area, kernel density estimates were calculated using the kernel density tool in Arcmap using default parameters. Using ArcGIS tool "Extract values to points" we extracted the points from the kernel density output and determined 95% of observations using values of extracted points from attribute tables. Using the ArcGIS "Reclassify" tool, reclassify kernel density raster to represent 95% of points and converted rasters to polygons, calculate the area of each polygon using calculate geometry tool.

To determine the distance birds foraged from colonies, we used the ArcGIS tool "Near" to measure the distance between each foraging location and the colony of origin to the nearest 0.1km.

Preparation of time depth recorder data and calibration

We extracted and pre-processed time depth recorder (TDR) data in R (R Core Team 2022) using the R package diveMove (Lunque 2007). We applied the filter method for Zero Offset Correction (ZOC) to correct for possible drift following the recommendations outlined in Luque and Fried (2011) and tutorials available in Isaksson *et al.* (2021). Because there was little noise, narrow windows and quantiles were appropriate. A first median filter of 2 (2 s based on a 1 s sampling interval), a second filter quantile of 0.05 on a window size of 180 (6 min) and bound depths between 0-0.5 were selected and applied to all birds. Smoothing parameters were visually inspected before proceeding with dive calibration. Dives were calibrated using a threshold of 8 m, to remove any non-foraging related behaviour e.g., washing, travel (e.g., king shags can exhibit a porpoising-like behaviour whilst commuting between sites, descending to as deep as 5-6 m before quickly resurfacing).

Due to either occasional low battery or device performance deficiency, data was sporadically not recorded during some portions of the TDR deployment, usually this occurred at night when birds were not foraging. We identified gaps in recording using the GapFinder function from the TrackReconstruction R package (Battaile, 2014). We visually inspected and removed all affected dives that were partially recorded (e.g., the dive descent was recorded but the ascent was not). Further, as king shags are strictly diurnal, we removed all dives that occurred outside of daylight hours (assuming that these dives were instances of escape behaviour caused by disturbance of a vessel transiting close to the roost site). However, there were occasions when a king shag exhibited foraging behaviour through the dusk period – these dives were retained.

Likely in response to being handled, king shags can exhibit atypical (i.e., extensive) roosting behaviour away from the colony after they are released, spending up to two days in the same locality, after which they begin to resume normal routine behaviour, such as foraging (Bell M., *personal observation*). To account for this, we therefore visually examined each individual's GPS track and corresponding dive-profiles was examined until routine behaviour was thought to have resumed (i.e., began foraging). Dives prior to the resumption of 'typical' foraging behaviour were therefore excluded.

In addition to the usual diving behaviour metrics obtained from the diveMove package (e.g., dive duration, maximum depth) for each individual we calculated the time spent underwater (as the sum duration of all dives conducted per day) relative to day length (hereafter, proportion underwater). Day length was calculated as the difference in time between sunrise and sunset using the getSunlightTimes function from the R package suncalc (Thieurmel & Elmarhraoui 2019). Because of the aforementioned gaps in recording, we retained only records of individuals where data recording encompassed at least 75% of the day length in an effort to minimise data loss and maximise data quality and precision.

Results

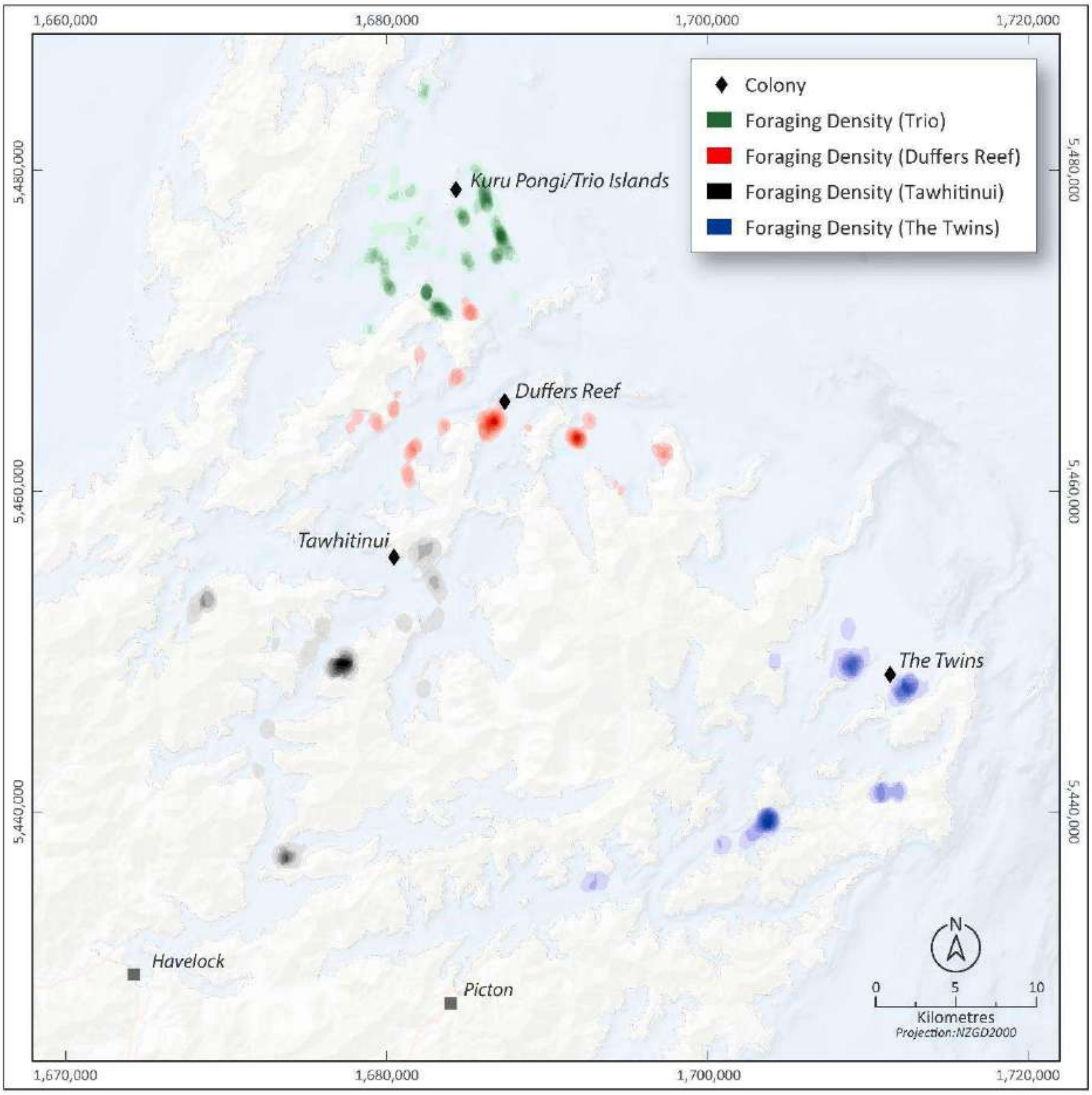
A total of 51 adult King Shag were captured and had GPS loggers attached from 4 colonies; of these data was recovered from 43 birds (Table 7.1). Male King Shag were significantly heavier ($\bar{x}$=3.2kg, SD=0.16kg) than females ($\bar{x}$=2.6kg, SD=0.14kg), Student's two sample t-test; t_{57} =-15.5358, p<0.001), equating to a 21% difference in mass. Male King Shag wing length was significantly longer ($\bar{x}$=316mm, SD=6,4mm) than females ($\bar{x}$=300mm, SD=4.3mm), Student's two sample t-test; t_{24} =-8.5902, p<0.001), a 6% size difference.

Table 7.1. Number, date, and location of King Shag fitted with GPS loggers in the Te Tauihu-o-te-waka/Marlborough Sounds; with number of birds where data was recovered in parentheses.

	Jul-19	Jul-20	Dec-20	Jul-21	Oct-21	Mar-22	Total
Tawhitinui	4 (4)	2 (2)		6 (5)			12 (11)
Duffers Reef	2 (2)	5 (4)	9 (7)				16 (13)
The Twins		1 (1)			8 (5)		9 (6)
Kuru Pongi/ Trios						14 (13)	14 (13)
Total							51 (43)

The mean foraging area of King Shag was 5.09 Km² (SD=3.91, range=0.19-13.69 Km²). There was no difference between the foraging area of males ($\bar{x}$=5.73, SD=4.13) compared to females ($\bar{x}$=4.49, SD=3.69); Student's two sample t-test; t_{38}=1.014, p=0.317 (Figure 7.3). There was no overlap in the foraging range of birds from different colonies, and individual birds showed relatively high foraging site fidelity, returning to the same areas to forage. The heat map of foraging points largely shows areas of individual fidelity to a foraging area. Birds from Tawhitinui, Duffers Reef and The Twins all tended to forage inwards, although three individuals from Duffer's used outer portions of the Te Hoiere/Pelorus Sound (Guards Bay, Annie Bay and Paparoa). Birds from the Kuru Pongi/North Trio however spread out in all directions, foraging on flat seafloor plains typical of this part of Te Tauihu-o-te-waka/Marlborough Sounds.

Figure 7.3. Heat map of GPS points classified as foraging of King Shag tracked from four colonies in Te Tauihu-o-te-waka/Marlborough Sounds, showing 95% kernel distributions for each colony.



Male King Shag (x̄=8.4km, SD=5. 6) foraged a similar distance from the colony as females (x̄=5.7km, SD=3.9); although there were differences in relation to colonies tracked (Figure 7.4). Males from Tawhitinui, The Twins and Duffers Reef foraged further from colonies than females; with birds from Kuru Pongi/North Trio foraging a similar distance.

Figure 7.4. Violin plots depicting the distance from colony of foraging GPS fixes (km) for Males and females at each of the different colony locations. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles.

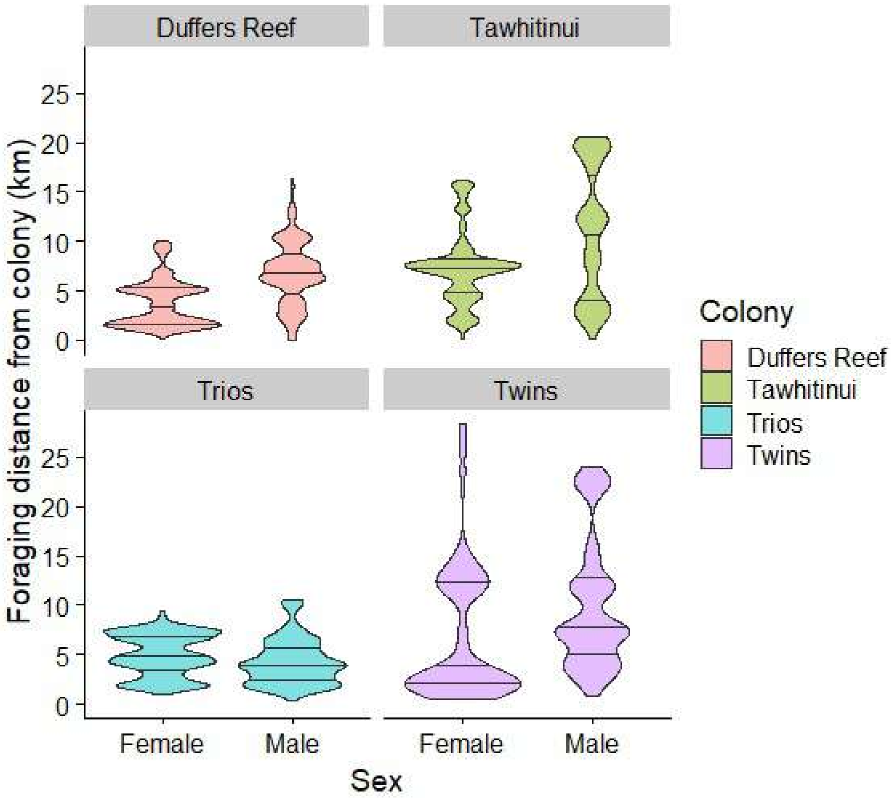
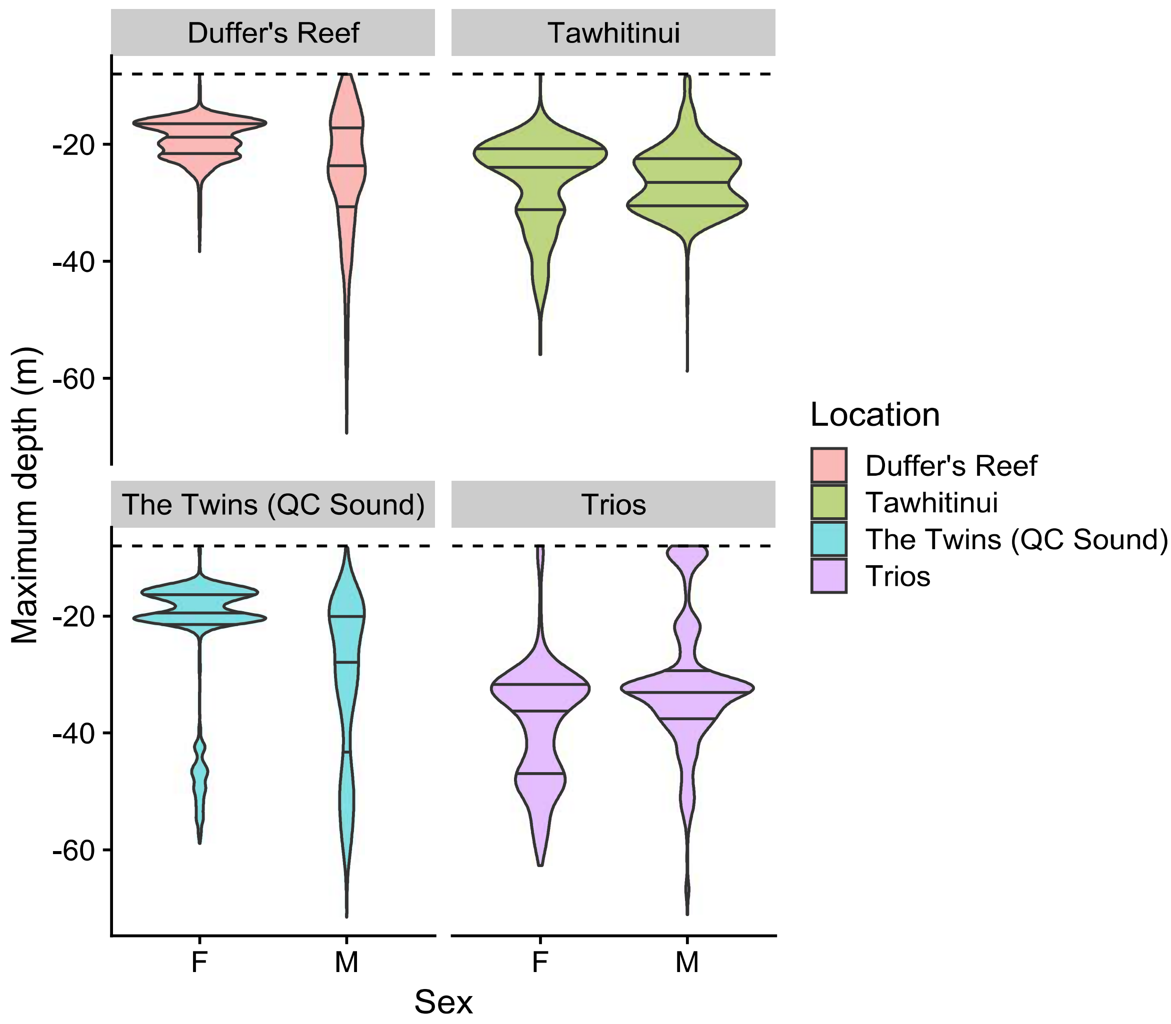


Figure 7.5. A King Shag starting a foraging dive in Horseshoe Bay, July 2021. Photo Dave Boyle.

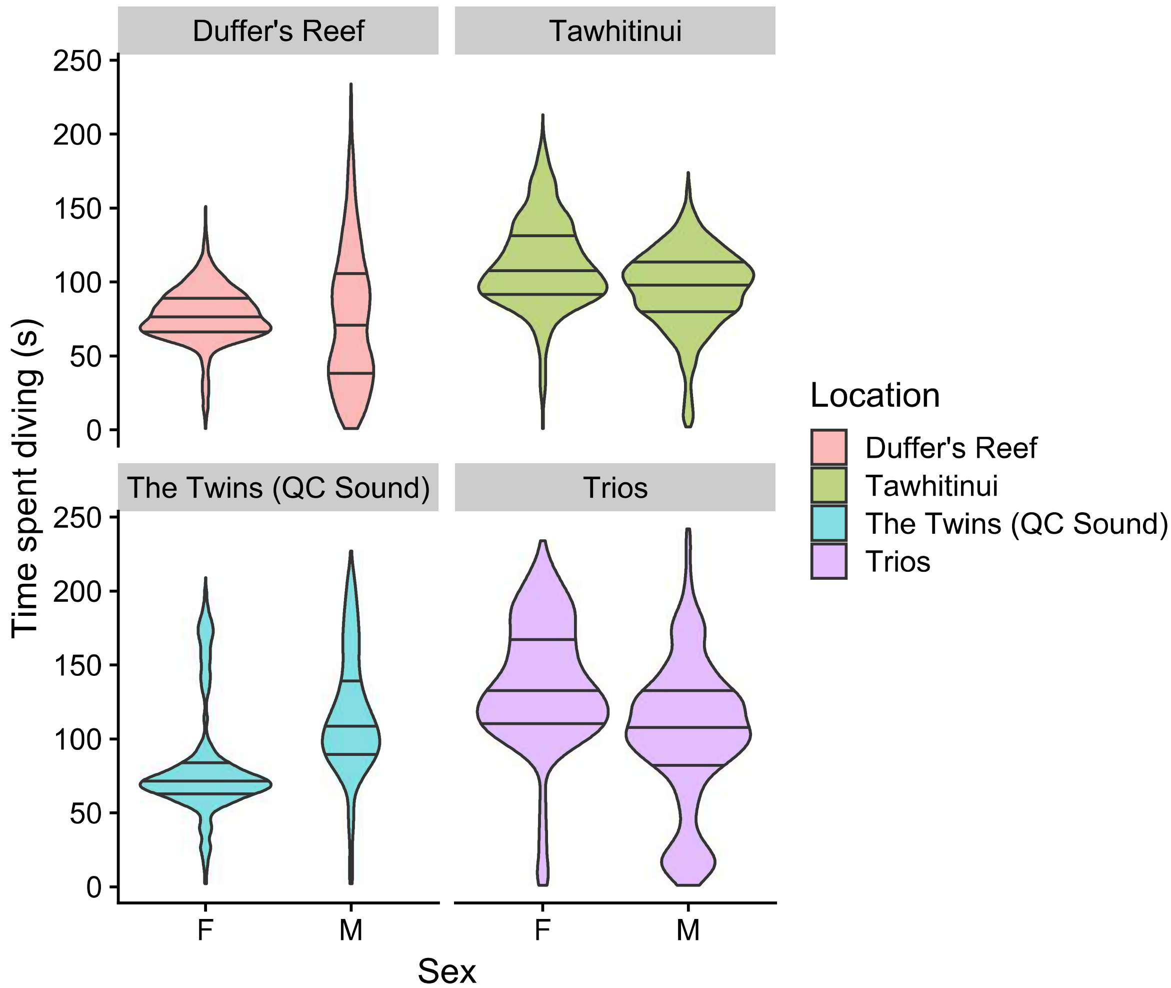
During a dive (Figure 7.5), King Shags descended to an average max depth of 25.7 m ± 10.2 SD range (8.01–71.5 m), with dives lasting on average 92.8 s ± 39.9 SD range (1 – 242 s). Females tended to perform slightly shallower dives (average max depth 24.5 m ± 10.3 SD range (8–62.6 m)) compared to males (average max depth 27.1 m ± 10.0 SD range (8–71.5)), however the maximum depth reached during a dive by males and females appeared to be largely dependent on the colony location (Figure 7.6). Indeed, females located at Tawhitinui (female average 26.3 m ± 7.5 SD), dived on average to the same max depths as males (male average 26.15 m ± 5.6 SD) and females at Kuru Pongi/Trios dived deeper on average than males (female average 38.5m ± 10.1, male average 31.8 m ± 11.3 SD). Males tended to dive deeper on average at Duffers Reef (male average 24.8 ± 10.5 SD, female average 19.2 m ± 3.4 SD) and at The Twins (male average 31.5 ± 14.0, female average 23.3 ± 11.7 SD).

Figure 7.6. Violin plots depicting the distribution in the maximum depth (m) during a dive, for males and females at each of the different colony locations. The horizontal dashed line indicates the 8 m threshold. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles.



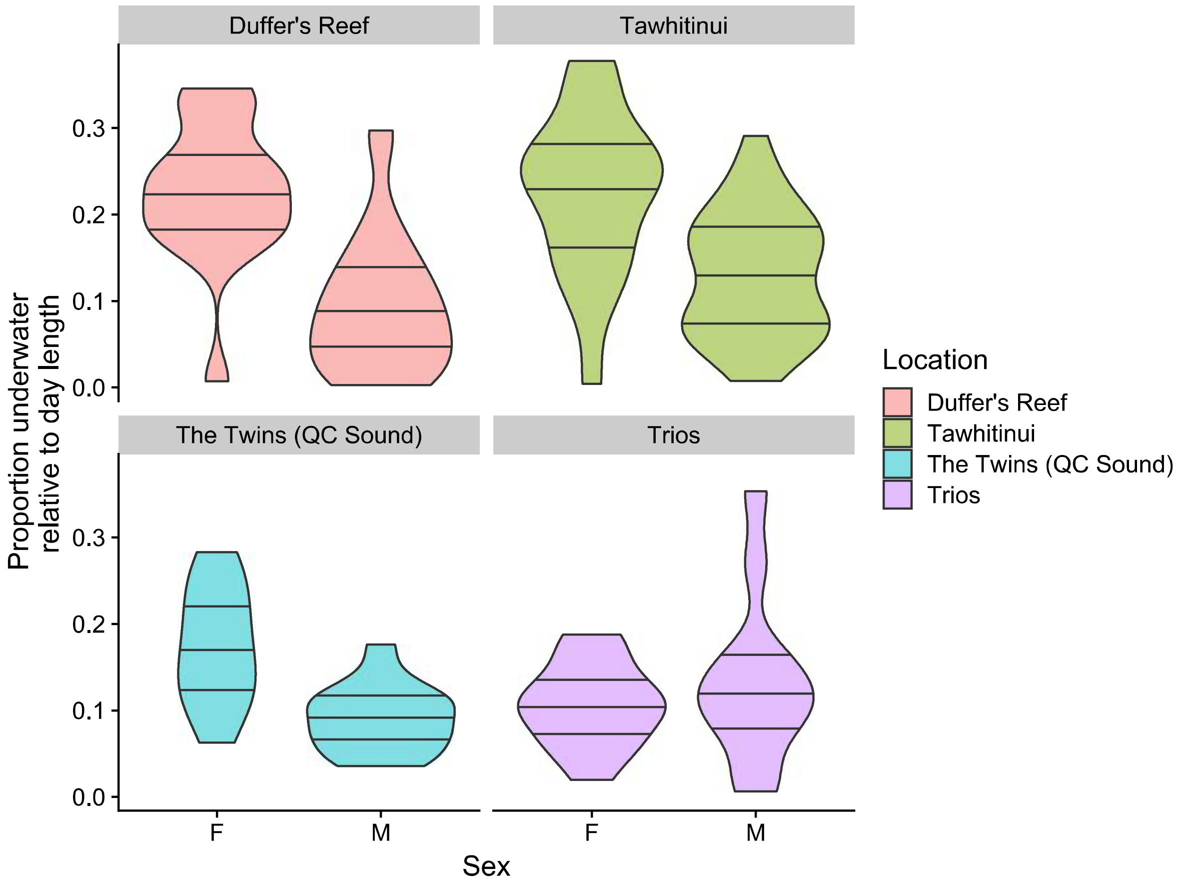
A similar pattern in dive duration was observed at Tawhitinui and Kuru Pongi/Trios with females diving longer on average than males (Tawhitinui female average 111.8 s ± 30.16 SD, male average 95.3 s ± 40.7; Kuru Pongi/Trios female average 136.2 s ± 42.6 SD, male average 103.8 s ± 48.2 SD). Whereas the average dive duration was longer for males from the Twins (115.7 s ± 40.7 SD) and reasonably similar between males and females from Duffer's Reef (female average 77.3 s ± 18.5 SD, male average 74.4 s ± 45.8 SD; Figure 7.7)

Figure 7.7. Violin plots depicting the distribution of time spent diving per dive (s), for males and females at each of the different colony locations. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles.



The proportion of time spent underwater averaged 0.14 ± 0.09 SD (range 0.003 – 0.38) of the day, with females spending a longer portion underwater than males on average (female average, 0.19 ± 0.09 SD, range 0.004 – 0.38; male average, 0.11 ± 0.08 SD, range 0.003 – 0.35; Figure 7.8). The pattern of females spending longer portions of the day in the water was present across birds from different colonies, except for birds from the Kuru Pongi/Trios, where on average males and females were similar (Kuru Pongi/Trios male average, 0.13 ± 0.10 SD, range 0.006 – 0.35; Kuru Pongi/Trios female average, 0.11 ± 0.05 SD, range 0.020 – 0.19), but with males exhibiting a far wider range.

Figure 7.8. Violin plots depicting the distribution of proportion of time spent underwater relative to day length, for males and females at each of the different colony locations. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles.



Discussion

Overall, males on average forage further afield, dive to deeper maximum depths and spend a longer time diving per dive. However, this trend appears to be somewhat dependent on what portion of Te Tauihu-o-te-waka/Marlborough Sounds the bird inhabitants. With colony location superseding these sex differences, or in some cases such as birds from Kuru Pongi/Trios, reversing them. Females also spend greater portions of their day underwater, but this too appears to depend on the colony location (i.e., males from Kuru Pongi/Trios spend unusually longer portions of the day underwater relative to other males located elsewhere). On top of general differences between sex and colonies, individuals were also highly variable in both the maximum depth, time spent diving, and the proportion of time spent underwater relative to day length, with birds exhibiting more individualised dive profiles (See figures in Appendix One).

Our results for King Shag match sex-based foraging behavioural traits recorded in their closest kin, other blue-eyed *Leucocarbo* shag species. With males generally foraging further from colonies and diving deeper than females (Green and Williams 1997, Bevan *et al.* 1997, Kato et al. 2000, Cook *et al.* 2007, Quintana et al. 2011, Cook et al. 2013), but not always the case (Quillfeldt *et al.* 2011, Camprasse *et al.* 2017a). In particular, our results highlight considerable individual variation, which appears to be a feature of blue-eyed shags - high individual foraging specialisation (Quintana *et al.* 2011, Camprasse *et al.* 2017b).

Van der Reis and Jeffs (2022) found differences between both sexes and colony location in prey composition of King Shag, but also wide variation amongst regurgitate samples. The large inter- and intra-individual variation in foraging behaviour found in King Shag may explain these differences. Wilson *et al.* (2022) noted considerable inter-individual differences in foraging success, differences that exceeded any differences predicted by empirical and theoretical inter-prey acquisition time distributions models. Wilson *et al.* (2022) concluded that more successful individuals were more choosey about when, how, and where they foraged, which gave them higher odds of being successful. Whilst Camprasse *et al.* (2017b) suggested shags deliberately re-visited the same areas as food patches were localised and predictable in time and space. Both our results and van der Reis and Jeffs diet results (2022) suggest King Shag exhibit similar foraging behaviour.

Overall, King Shag exhibit individualised foraging preferences over-riding sex-stereotyped behaviour. It is suspected that these differences between individuals are also likely to be dependent on the local bathymetry encountered – where the foraging environment becomes more uniform (such as around Kuru Pongi/Trios), sex specific differences appear to be reduced and individual foraging strategies become more pronounced.

Appendix One

Figure 7.9. Violin plots depicting the distribution in the maximum depth (m) during a dive, for all individuals. The horizontal dashed line indicates the 8 m threshold. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles.

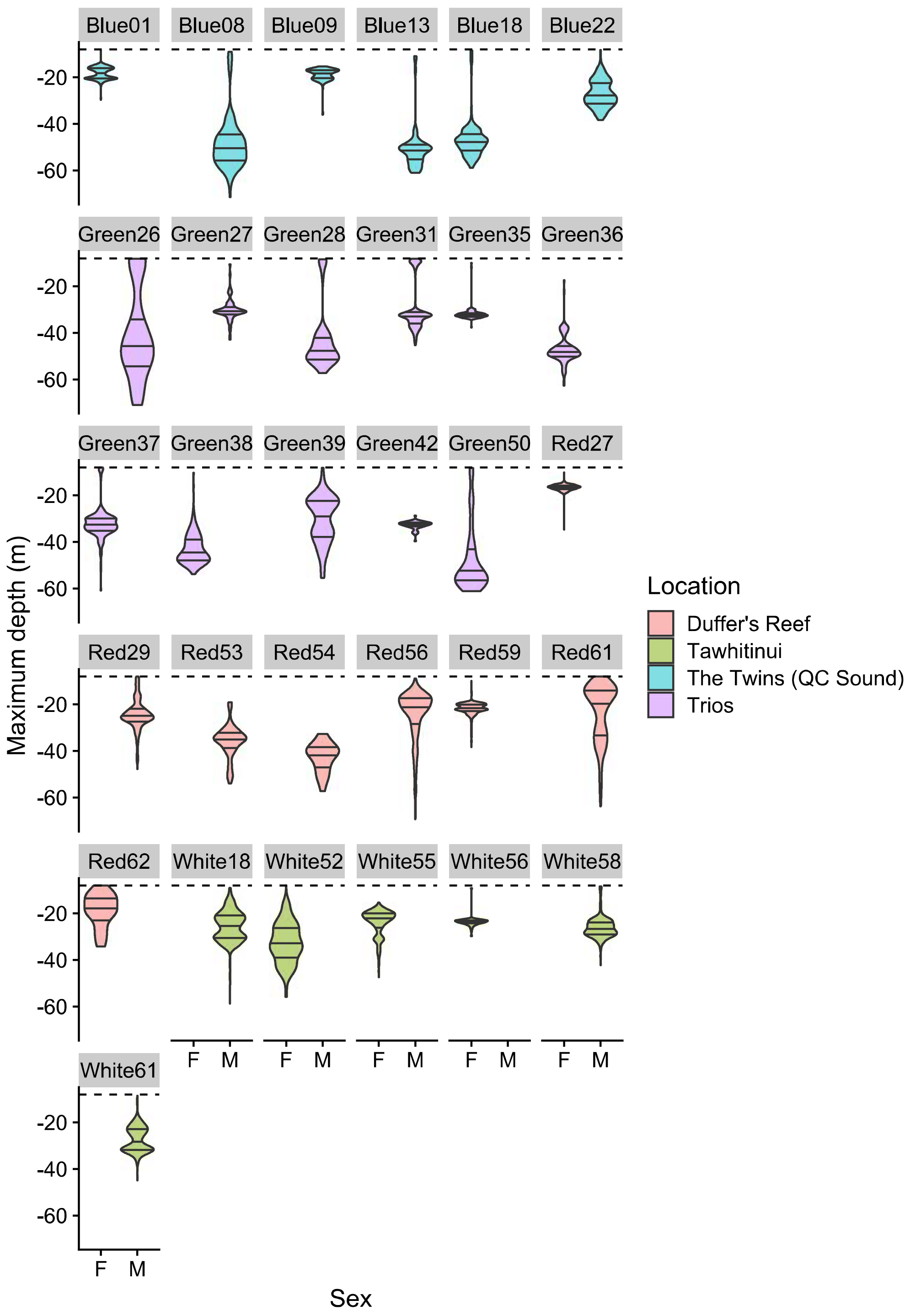


Figure 7.10. Violin plots depicting the distribution of time spent diving per dive (s), for all individuals. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles.

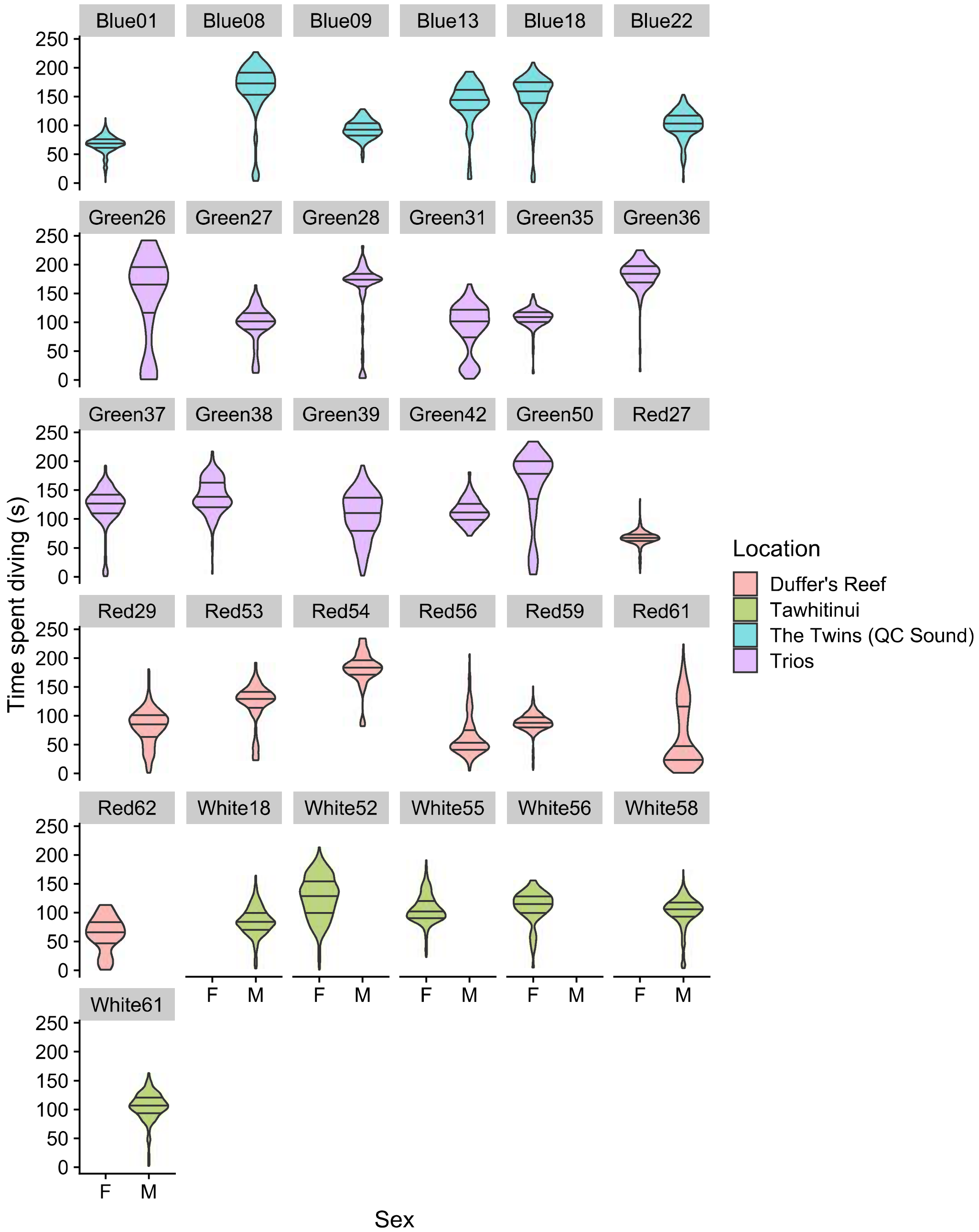
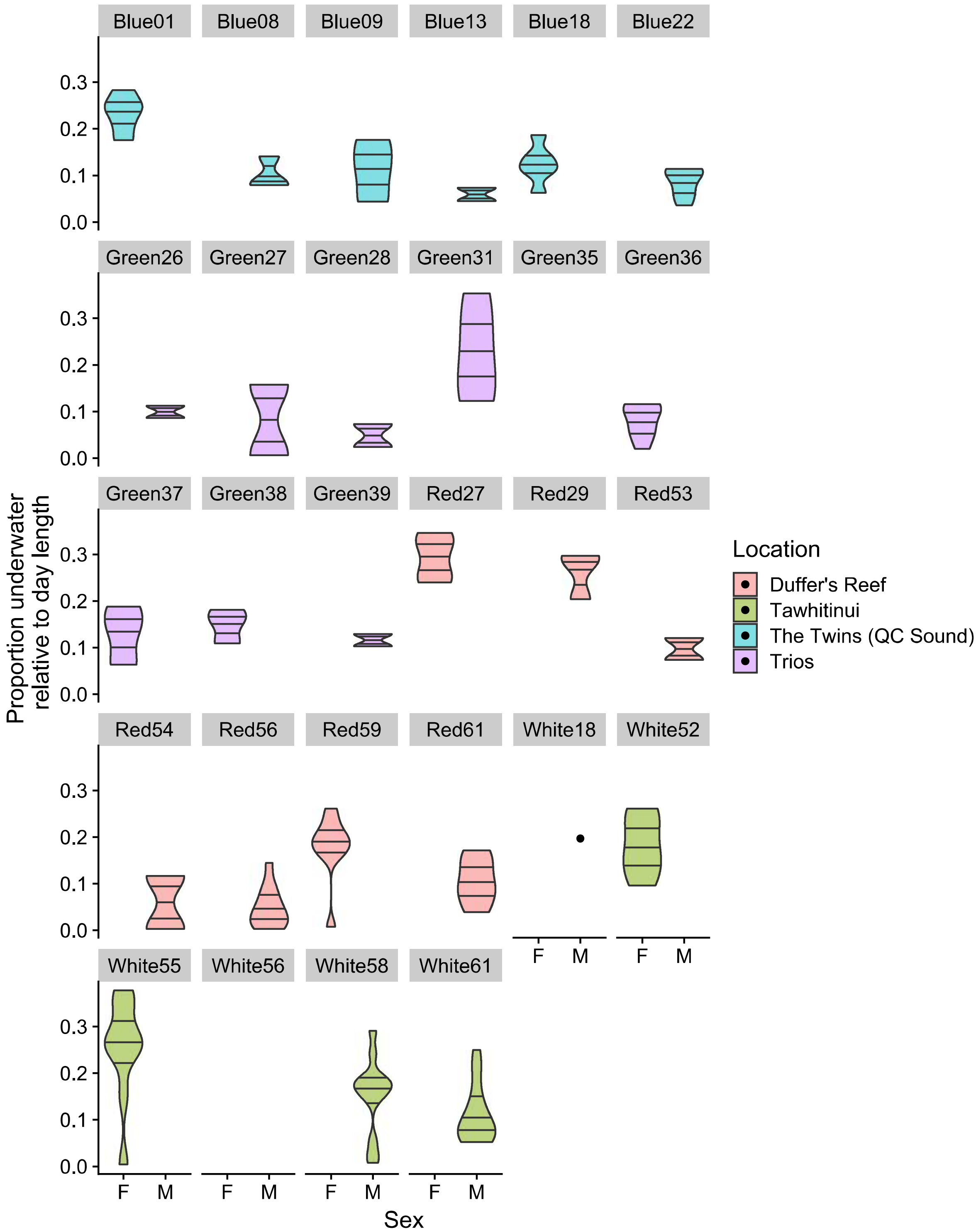


Figure 7.11. Violin plots depicting the distribution of proportion of time spent underwater relative to day length, for all individuals. Horizontal lines within violin plots indicate the median (middle line), and the lower and upper quartiles. Note, individual White-18 was only represented by a single record after the 75% data retention cut-off.



Chapter 8. Spatial-temporal foraging overlap of mussel farms and kawau pāteketeke/King Shag (*Leucocarbo carunculatus*).

Mike Bell and Simon Lamb

Summary

We investigated the spatial-temporal foraging overlap of mussel farms and kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) in Te Tauihu-o-te-waka/Marlborough Sounds derived from GPS data. Of 43 birds tracked, 56% foraged within a mussel farm, although this was influenced by the extent of mussel farming in proximity to the colony birds were tracked from – for example there is little mussel farming in Tōtaranui/Queen Charlotte Sound. From birds fitted with GPS devices where data was recovered, most King Shag from Duffers Reef (10 of 13 birds tracked) and Tawhitinui (11 of 11) foraged within farms, whereas only a single bird from Kuru Pongi/North Trios and The Twins foraged within farms. Both later sites have little mussel farming within foraging range proximity to the colony. Considering differences in the length of time a bird was tracked, King Shag spent on average 31% ± 39% SD (range 0-100%) of their foraging time within marine farms; with females on average spending slightly more time than males foraging in marine farms (female average 33% ± 40% SD range 0-100%; male average 31 ± 38% SD range 0-100%) per day tracked. However, there was a high degree of variation between individuals, and daily plasticity amongst birds. This is the first quantitative data on King Shag foraging within mussel farms and shows that mussel farms do not cause habitat exclusion. It is expected that mussel farms have a neutral impact on King Shag.

Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) are restricted to Te Tauihu-o-te-waka/Marlborough Sounds (Marchant and Higgins 1990) and are listed as Nationally Endangered (Robertson et al 2021). For these reasons, there has been strong conjecture over the impacts of aquaculture on the species. With mussel farming in the Te Tauihu-o-te-waka/Marlborough Sounds considered likely to be detrimental to King Shag (Butler 2003), although there has been little research on the actual effects (Butler 2003, Keeley *et al.* 2009, Fisher and Boren 2012).

Despite a lack of evidence, some groups believed that marine farms prevented King Shag from accessing important benthic foraging habitat. This resulted in King Shag becoming a point of contention when applying for resource consent, with a number of applications ending up before the Environment Court (i.e. https://www.stuff.co.nz/business/104827048/king-shags-seal-the-fate-of-two-marlborough-mussel-farms). Due to the 'threatened' classification and the protection offered to threated species under the NZCPS 2010, on several occasions the Environment Court employed a precautionary approach and declined consent applications on the basis of avoiding potential effects on King Shag. The Marlborough Coastal Plan identifies over 350,000ha of seabed as potential foraging areas, in which any actual or potential adverse effects of any activity on King Shag feeding need to be considered (Urlich 2020a, Urlich *et al.* 2022).

With GPS tracking of King Shag being undertaken to understand the foraging ecology of the species, this provided an opportunity to investigate the use of mussel farms by King Shag. This chapter presents the results of spatial-temporal foraging overlap of mussel farms and King Shag.

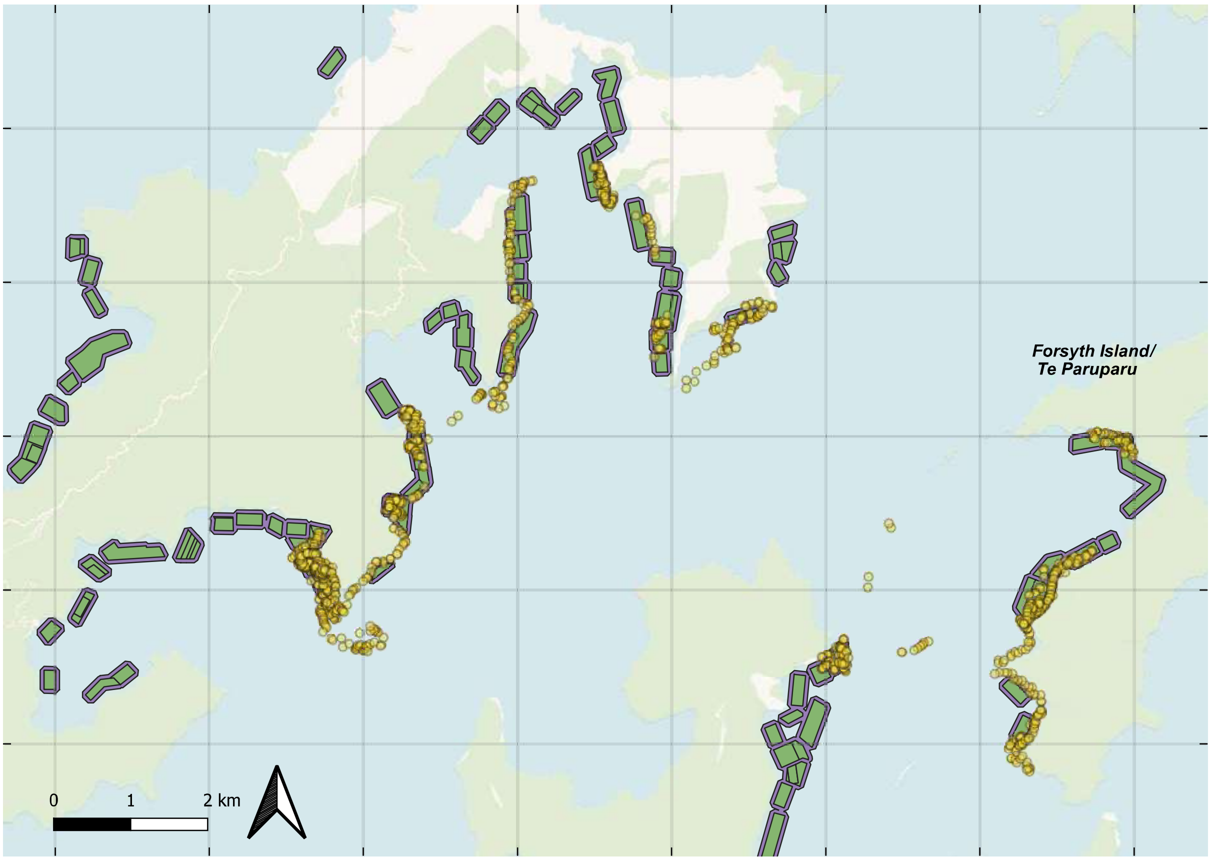
Methods

We investigated the spatial-temporal usage of mussel farms by King Shag whilst foraging within the Te Tauihu-o-te-waka/Marlborough Sounds. We used publicly available spatial data on mussel farm lines present within Te Tauihu-o-te-waka/Marlborough Sounds (data available from the 'Environment' section of the Marlborough District Council smartmaps service: https://smartmaps.marlborough.govt.nz/smaps/ - accessed and downloaded on 30-May-2022).

To ensure our area included all farm structures (warps and anchors), allowed for line movement (due to currents, tide, and wind), and extent of biodeposition (mussel faeces, pseudofaeces and shell litter), we extended mussel line polygons by overlaying a 50 m buffer around each mussel line polygon in QGIS (QGIS Development Team (2022) using the 'create buffer' function. In areas of low flushing or shallow water depth, typical of areas where King Shags have been tracked foraging, the typical extent of biodeposition is <50m from farm boundaries (Keeley *et al.* 2009).

Where the 50 m buffers overlapped, areas were combined into a single polygon and therefore defined as the mussel farm's 'footprint'. When combined and a 50 m buffer added this produced a total of 197 mussel farm footprints. To investigate foraging overlap of King Shags with marine farm footprints we identified those marine farm footprints that had at least 1 GPS fix classed as foraging behaviour (Figure 8.1, see chapter 7 for definitions of behavioural classification) and calculated for each King Shag, and for each marine farm footprint it interacted with, the time of entry, exit, and thus duration of time spent foraging within the marine farm footprint using the recurse package (Bracis *et al.* 2018) in R (R Core Team, 2022) using the 'getRecursionsInPolygon' function. We then cross referenced each classification of foraging behaviour by the King Shag as to whether it occurred within or outside the marine farm footprints. From this data we then quantified the relative time spent foraging within marine farm footprints to the total time spent foraging per day a king shag was tracked.

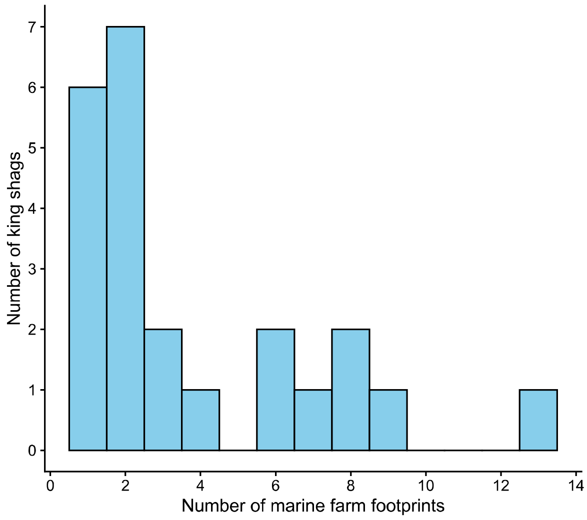
Figure 8.1. Example of a King Shag (Red 61 – a male) foraging within marine farm footprints. Yellow points are GPS positions of Red 61, classed as 'foraging' behaviour (other activities e.g., roosting, swimming etc, are not shown). Green polygons indicate individual mussel lines, and purple polygons indicates the 50 m buffer applied to mussel lines (i.e., the marine farm footprint). Red 61 utilised the highest number of marine farm footprints during foraging (13 in total).



Results

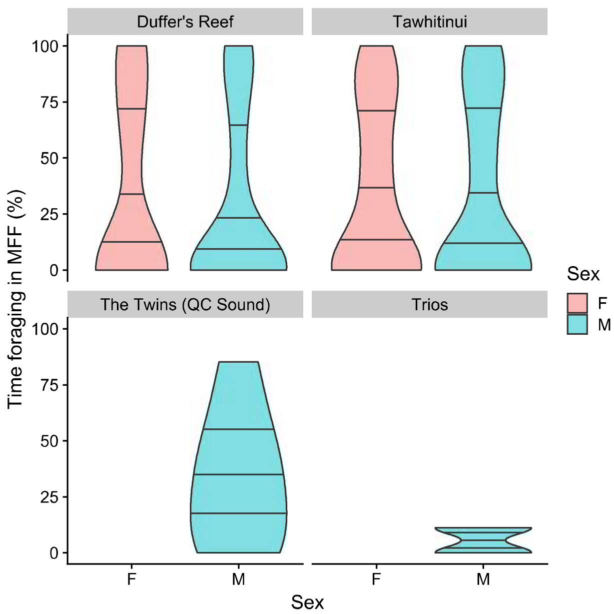
Of the 43 King Shags that were tracked, 23 (56%) birds exhibited at least 1 GPS fix classed as foraging behaviour within marine farm footprints (of which the recurse analysis was able to be applied to). This includes one (of six) tracked from Tōtaranui/Queen Charlotte Sound, one (of 12) tracked from the Trios, 10 (of 13) tracked from Duffer's Reef and 11 (of 11) birds tracked from Tawhitinui. Overall, birds tended to forage within one or two marine farm footprints (57% of birds), with the rest foraging within three or more farms. One bird (Red 61), foraged almost exclusively within marine farm footprints (Figure 8.1), and visited a total of 13 different marine farm footprints (Figure 8.2). The median number of farms foraged within was 2 (range 2-13).

Figure 8.2. The number of marine farms utilised by king shags for foraging during their tracking.



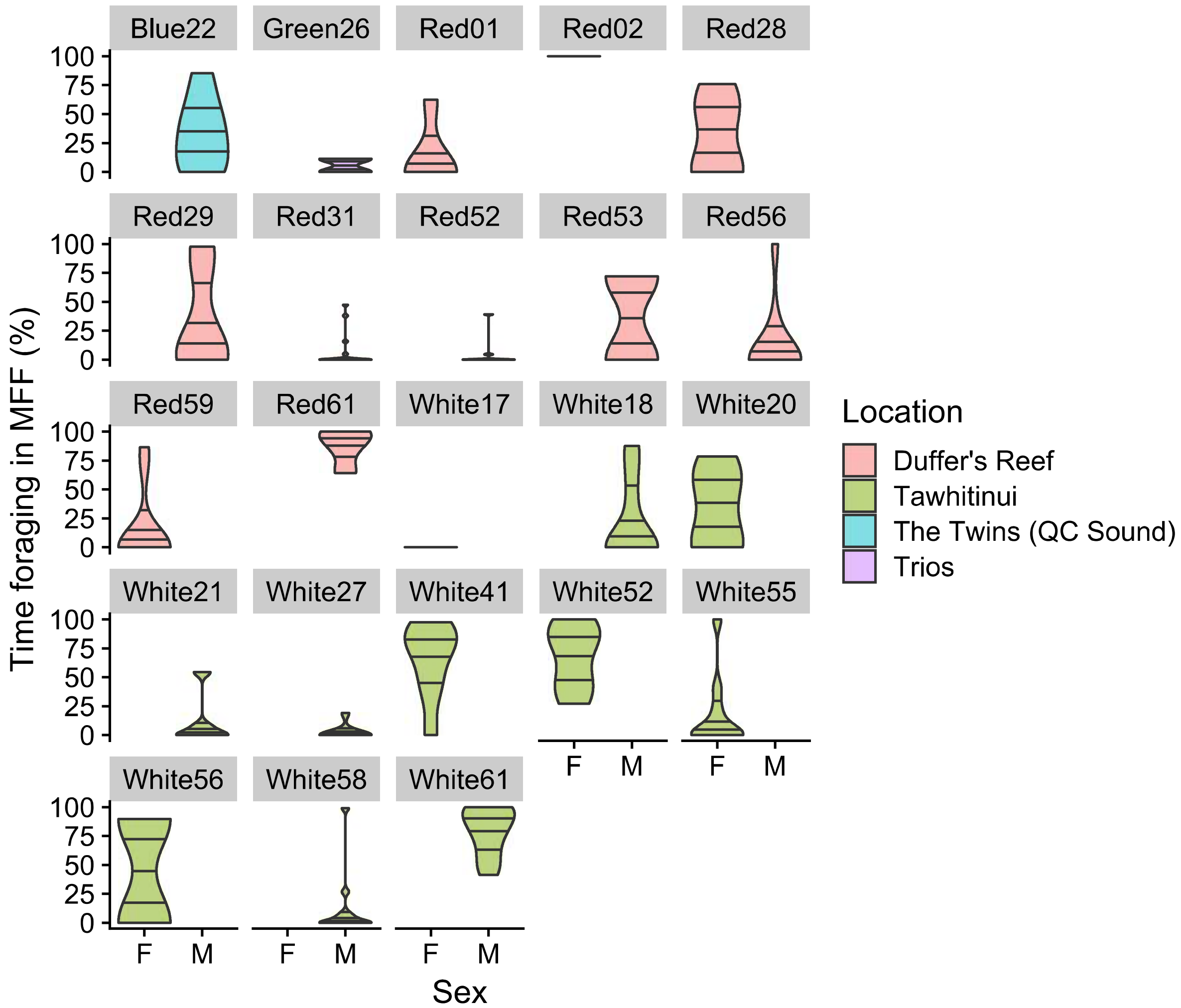
Taking into account differences in the length of time a bird was tracked for (mean 640 minutes ± 314 SD, range 45-1019 minutes tracked per day), King Shag spent on average 43% ± 26% SD (range 0-97%) of the tracked day foraging, with 31% ± 39% SD (range 0-100%) of that time foraging within marine farm footprints. Both males and females from the Duffer's Reef and Tawhitinui Colonies overlapped in the proportion of time spent foraging within marine farms (Figure 8.3), with females on average spending slightly higher than males foraging in marine farms (female average 33% ± 40% SD range 0-100%; male average (31% ± 38% SD range 0-100%) per day tracked.

Figure 8.3. Violin plots of the percentage of time spent foraging in marine farm footprints (MFF) relative to the time spent foraging per day by male and female King Shags from Duffer's Reef (n=10), Tawhitinui (n=11), The Twins (Tōtaranui/Queen Charlotte Sound (n=1)) and Kuru Pongi/North Trios (n=1) colonies that foraged within mussel farm footprints. Horizontal lines represent median (middle line) and upper and lower quartile ranges.



Between individuals, King Shag were highly variable in the proportion of time spent foraging with marine farm footprints (Figure 8.4). With some individuals foraging almost exclusively within marine farm footprints (e.g., Red 61), whereas other that foraged within marine farm footprints, did so very rarely (e.g., White 17). In other cases, some individuals were highly plastic in whether they spent large amounts of time foraging with within marine farm footprints (e.g., Red 29).

Figure 8.4. Violin plots of the percentage of time spent foraging in marine farm footprints (MFF) relative to the time spent foraging per day by each individual recorded utilising marine farm footprints during foraging. Horizontal lines represent median (middle line) and upper and lower quartile ranges.



Discussion

For the first time, this study provides quantitative data on the use of mussel farms by foraging King Shag. Of all birds tracked, 56% exhibited foraging behaviour within marine farm footprints, spending on average 31% of their time foraging in farms. However only one bird from both Kuru Pongi/North Trios and The Twins foraged in an area with mussel farms, so were likely to encounter farms. Of birds which foraged in areas of Te Tauihu-o-te-waka/Marlborough Sounds in proximity to mussel farms (foraging range within 2km of a mussel farm), 23 of 26 birds (89%) foraged within farms. For these birds that did forage in mussel farms, on average of 39% of their foraging time was spent within mussel farm footprints.

Male and female King Shag showed a similar amount of time utilising mussel farms, but there was a high degree of variation between individuals, and plasticity amongst birds. This mirrors the highly individualistic foraging behaviour described for the species (Chapter 7).

All King Shag foraging in areas of mussel farms, roosted on mussel farm buoys between foraging bouts. In areas with mussel farms, King Shag appeared to prefer to roost on floats than on the shore. Potentially being surrounded by water, floats provided safer roosting locations for King Shag.

Aquaculture is a globally increasing activity and can affect the environment in both positive and negative ways (Gallardi 2014). For marine seabirds, the impacts may not all be bad. Internationally the impact of suspension culture has been recorded as positive or neutral on marine bird species (Roycroft *et al.* 2006). It is difficult to determine if our results are positive, as we do not know if foraging in mussel farms improved foraging success. However, we report that mussel farms do not exclude King Shag from foraging habitat, and that farms are used by a large proportion of the population, and for a significant proportion of some individuals foraging. Mussel farms are likely neutral to King Shag, and if a farm is within a King Shags foraging range, it will be utilised to some degree, depending on the individual temperament of the bird.

Chapter 9. The effect of a storm system on kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) diving behaviour.

Mike Bell and Simon Lamb

Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) is restricted to Te Tauihu-o-te-waka/Marlborough Sounds (Marchant and Higgins 1990) and face a range of threats (Taylor 2000). King Shag are central placed foragers and have a restricted foraging range (Chapter 7), travelling to and from a roost site daily to feed. In addition, King Shag are benthic foragers with bottom dwelling fish species comprising all their diet (van der Reis and Jeffs 2020).

As a benthic visual foraging seabird, King Shag foraging efficiency may be impacted by sedimentation and turbidity. Studies both in Aotearoa and internationally have linked turbidity to foraging ability of pursuit-diving seabirds, with increasing turbidity negatively impacting foraging ability (Lukies *et al.* 2021). In other instances, high sediment inflow events may be linked to cases of mortality (Lukies *et al.* 2021). For instance, a mass-mortality event of developing Kororā (little blue penguin; *Eudyptula minor*) chicks in Wellington was thought to be caused by the interacting effects of a warmer waters coupled with high sediment inflow from the Hutt River, which hampered adults' ability to find enough food (Lukie *et al.* 2021). The sheltered waters of Te Tauihu-o-te-waka/Marlborough Sounds are especially vulnerable to sediment inflow (Urlich 2020) and King Shag may therefore be at increased risk from sediment run-off.

There has been a ten-fold increase in sediment accumulation rates in inner Te Hoiere/Pelorus Sound since the early-1900's. Eroding subsoils from predominately from forestry and farming, but also from other land use (road and track formation) and stream bank erosion are the main contributors of catchment-derived sediments (Swale *et al.* 2021). There has been a significant increase in pine forestry in Te Tauihu-o-te-waka/Marlborough Sounds and Te Hoiere/Pelorus catchment, predominantly on steep erosion prone land (Urlich and Handley 2020). Soil disturbance associated with forestry harvesting has caused erosion and run-off into the coastal waters of Te Tauihu-o-te-waka/Marlborough Sounds and resulted in excessive deposition of fine sediment onto estuarine and subtidal benthic habitats (Urlich 2020; Urlich and Handley 2020).

The impacts of sediment run off were investigated using GPS data from King Shag tracked during an extreme weather event which saw significant sediment run off in Te Hoiere/Pelorus Sound in July 2021. It was hypothesised that the storm would discourage King Shag from foraging both during the event, and immediately after due to increased water turbidity. Predicting that the proportion of the day spent foraging would reduce, and then return to pre-storm levels in the days following. A second hypothesis was that the storm event would reduce the ability for shags to forage efficiently. Predicting that dive metrics such as time spent underwater per dive, and maximum depth per dive would change in relation to the storm event. Because of low sample sizes (3 birds), we did not statistically test these hypotheses and results are descriptive only.

Background of storm event

During 17 July 2021 an intense storm system passed through the northern South Island causing wide-spread flooding throughout Marlborough (Radio New Zealand 2021). During the storm, the Pelorus River (the main river flowing into the Te Hoiere/Pelorus Sound) reached a peak at 11:00am, with a flow rate of 1728 $m^3 s^{-1}$ at Daltons (Figure 9.1., data from Marlborough District Council). The Daltons River gauge uses upstream recorders in the Rai and Pelorus River but does not include the Wakamarina catchment (not recorded during the storm), so data presented does not include all inputs into Te Hoiere/Pelorus Sound (Emma Chiball, Environment Systems and Data Analyst, Marlborough District Council *Pers. Comm.* May 2022). This event caused widespread slips and erosion (Radio New Zealand 2021) (Figure 9.2) and led to a significant sediment plume being ejected into Te Hoiere/Pelorus Sound (MB, personal observation from 19 July).

Figure 9.1. Flow levels of the Pelorus River measured at Daltons during the July 2021 storm event (Data from Marlborough District Council).

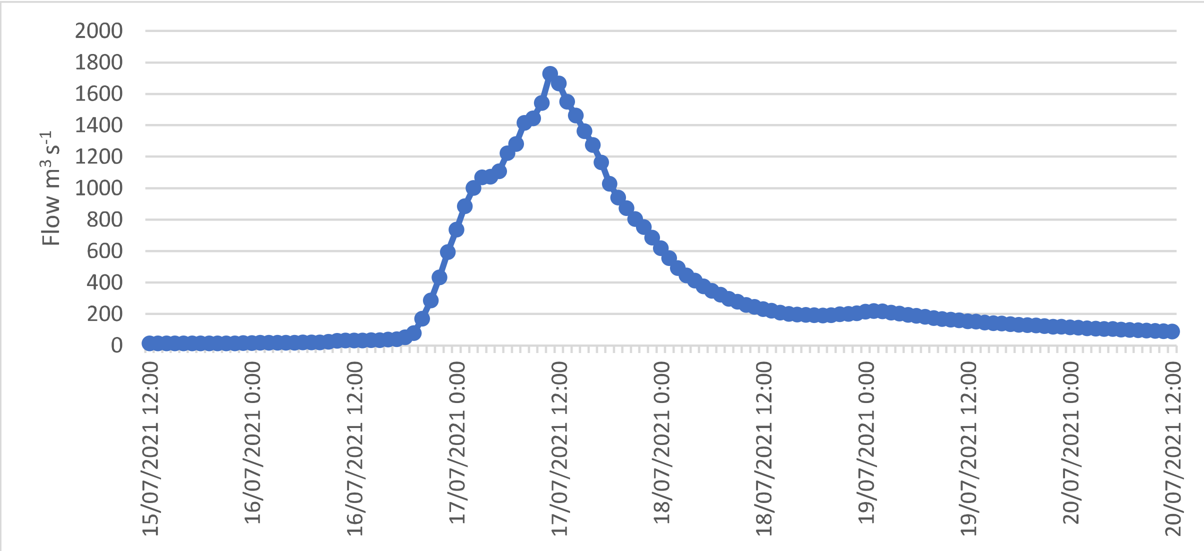
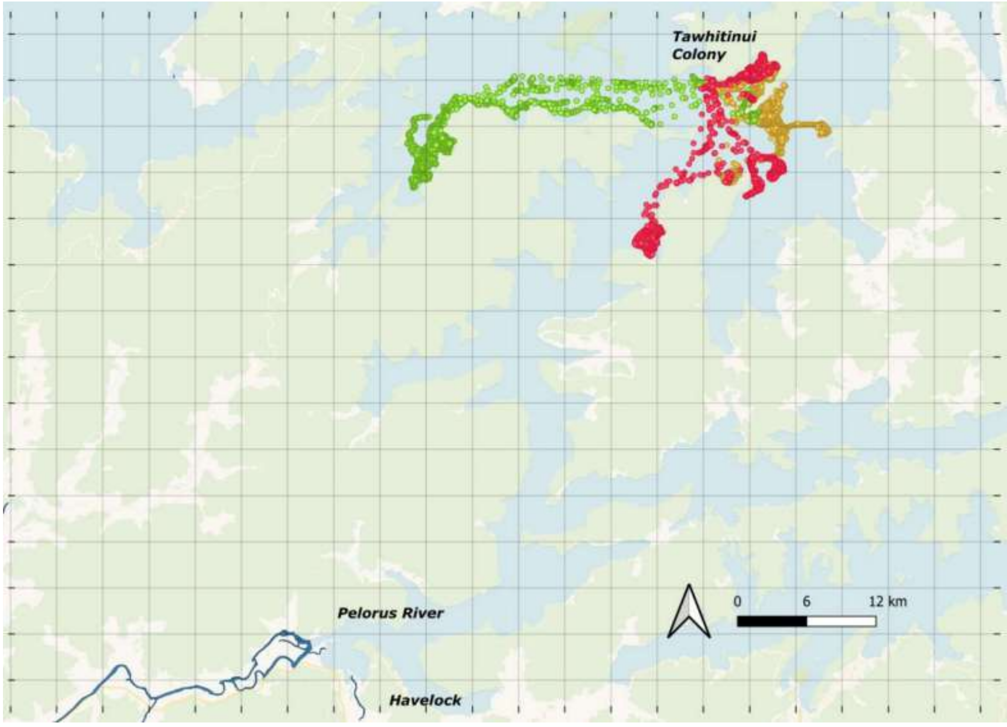


Figure 9.2. the July 17th storm caused widespread slips through Te Tauihu-o-te-waka/Marlborough Sounds. Image from www.stuff.co.nz/marlborough-express/125969940/new-team-on-way-to-help-marlborough-build-road-to-recovery.

Methods

Over the period of this storm, three King Shag (White 55 (female), White 58 (male) and White 61 (male) were wearing GPS devices, providing an opportunity to examine potential storm/turbidity effects on foraging behaviour (Figure 9.3). For each bird, we examined the proportion of time foraging (relative to other activities) and changes in maximum dive depth, duration of diving and across this time period.

Figure 9.3. The outflow of the Pelorus River (deep blue lines) into the Te Tauihu-o-te-waka/Marlborough Sounds. Overlayed are the GPS fixes of White 55 (red), White 58 (green) and White 61 (yellow).



Calculation of behaviour

For each full day a bird was tracked, the cumulative duration of each activity was calculated (roosting, swimming, flying, and foraging, see Chapter 7 for definitions behavioural classification), the proportion of time spent foraging relative to the other activities. As the GPS device was automatically switched off during the night to save power, proportions of activity were therefore calculated against the length of time the device was recording for. Because King Shag tend to 'sulk' (exhibit atypical behaviours e.g., excessive roosting, likely in response to the effects of handling), following release, we truncated the data until the bird started exhibiting foraging behaviour (for White 55 and White 61, this occurred approximately 5 h after release, but for White 58, foraging activity was not exhibited until 13 July, two days post release). Additionally, for White 55, the proportion of time spent foraging on 21 July was not calculated as the device stopped recording part way through the day (and did not resume).

Results

Of all the birds tracked – White 55 appears to have been most affected by the storm event – and completely stopped foraging on the day of the storm (Figure 9.4) and stayed at the colony (Figure 9.5), whereas the other two birds continued to forage at relatively the same rate as the days on either side of the storm. White 55 also appeared to forage slightly shallower and tended to do shorter dives after the storm.

The proportion of time spent foraging by White 58 fluctuated from day to day throughout its tracking. The median maximum depth tended to become shallower leading up to the storm event, and decrease thereafter, with some days after the storm White 58 exhibiting wide variation in maximum dive depth (Figure 9.6). The duration of dives exhibited by White 58 tended to be uniformly distributed throughout its tracking (Figure 9.6). These slightly shallower dives likely reflect the foraging location utilised during this time. GPS fixes of White 58 on 17 July indicate a high concentration within Tawa Bay, and indeed the bird did not leave Tawa Bay throughout the storm event, suggesting that during this period Tawa Bay provided some shelter for foraging.

For White 61, the maximum dive depth tended to be shallower leading up to the storm and then in the days following, tended to dive to greater depths with minimal variation in comparison to days previous (Figure 9.7). The time spent foraging tended to somewhat shorter in comparison to the days before and days following the storm – however there was considerable overlap in the distribution of dive times throughout its tracking (Figure 9.7). Similar to White 58, White 61 stayed and foraged within a single bay (Kauauroa Bay) on the day of the storm (Figure 9.8), suggesting that this bay also provided some shelter.

Figure 9.4. The proportion of time spent foraging (top panel), maximum depth (m) (middle panel) and the duration of dives (s) (bottom panel) for each bird (White 55: first column, White 58: second column: and White 61: third column) recorded over the 17 July 2021 storm (grey box).

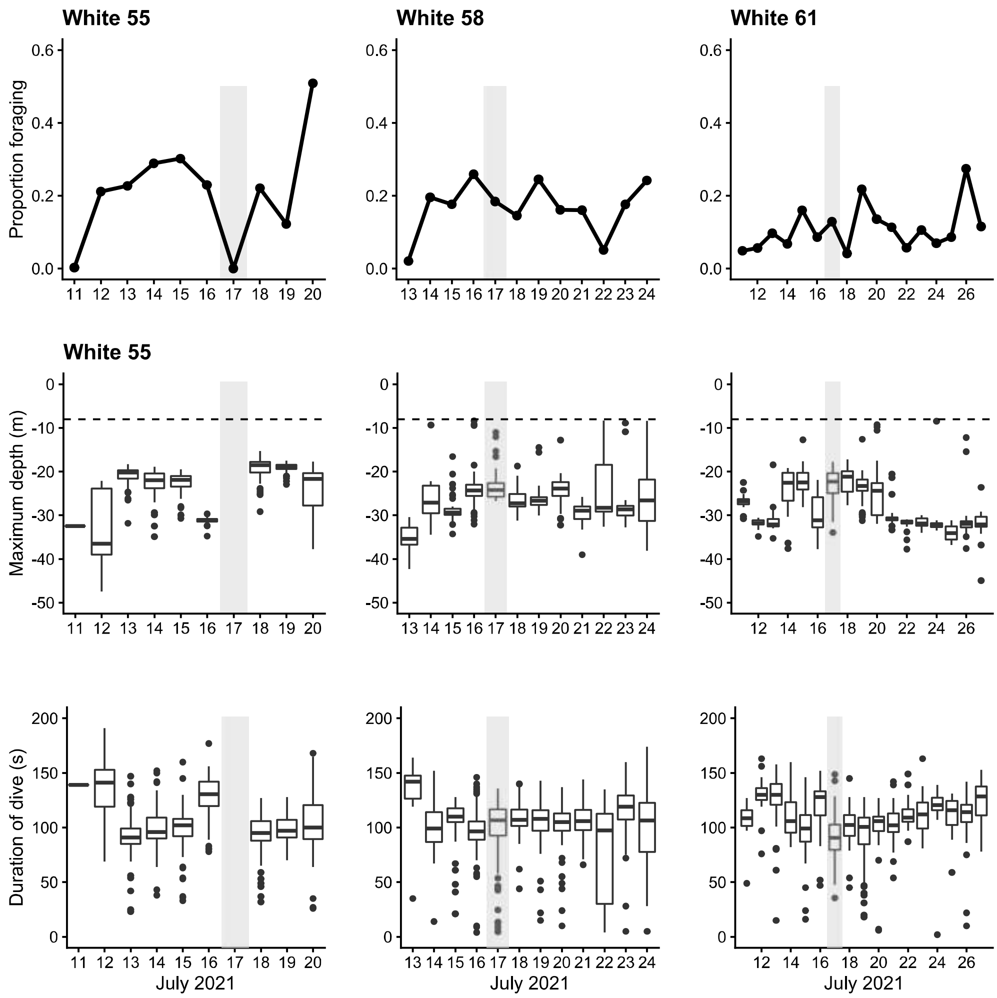


Figure 9.5. Tracking of White 55 from 11 July to 20 July 2021. Points indicate GPS fixes with blue points indicating GPS fixes taken on the day of the storm (17 July 2021) with red points indicate GPS fixes on all other days tracked. The Tawhitinui Colony is highlighted with Maud Island/Te Pākeka for geographical reference.

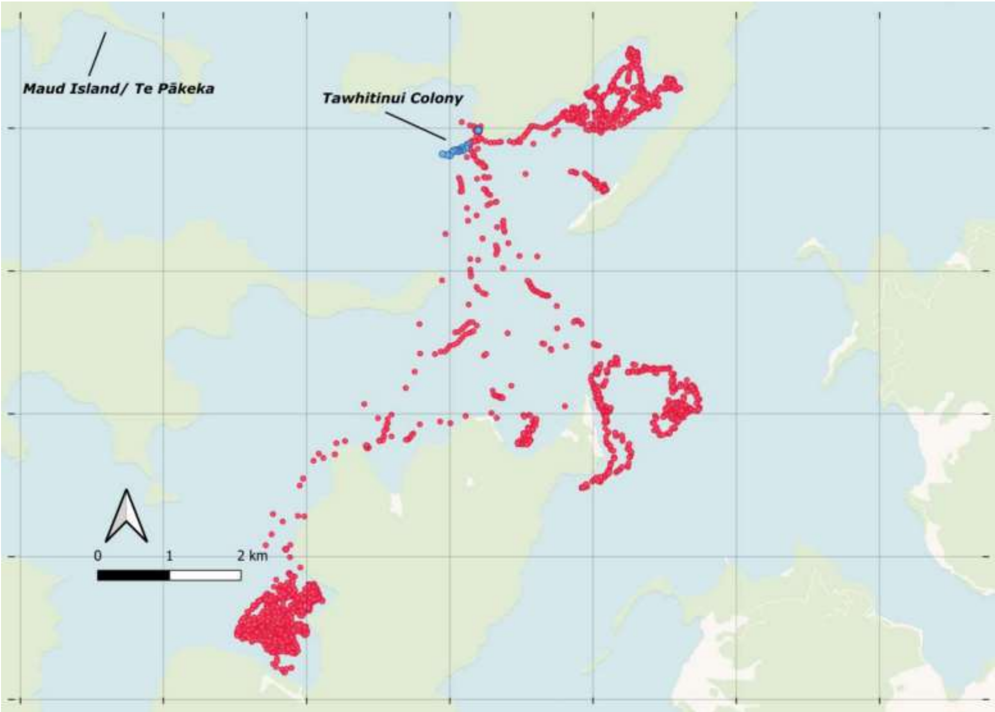


Figure 9.6. Tracking of White 58 from 13 July to 24 July 2021. Points indicate GPS fixes with blue points indicating GPS fixes taken on the day of the storm (17 July 2021) with green points indicate GPS fixes on all other days tracked. The Tawhitinui Colony is highlighted along with Maud Island/Te Pākeka, and Tawhitinui Island and Tawa Bay are highlighted for geographical reference.

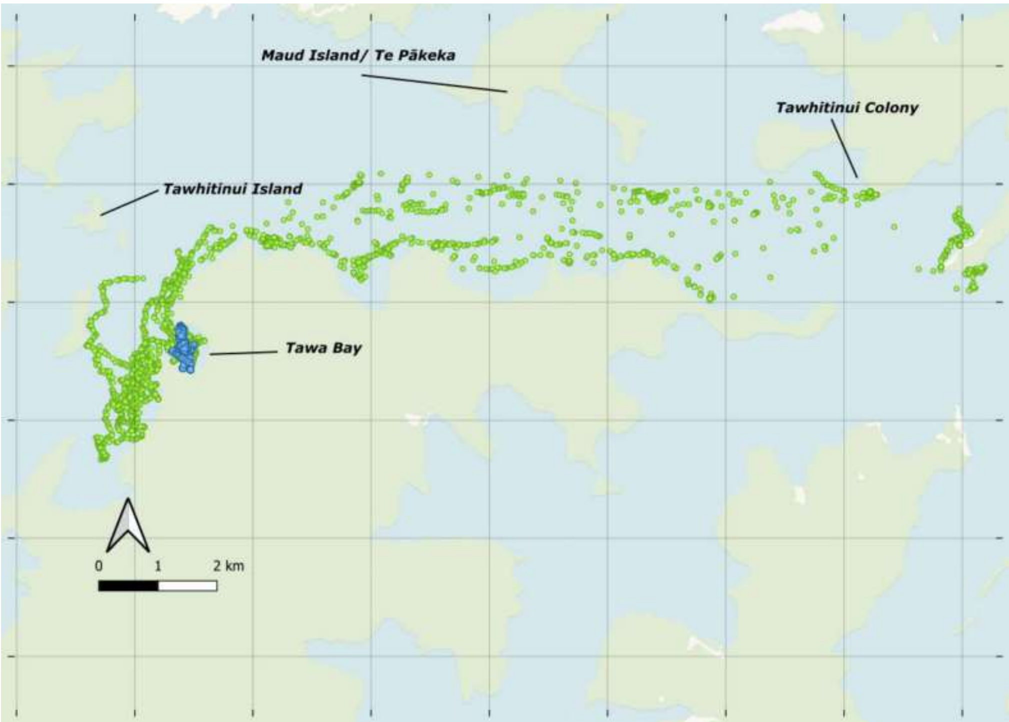
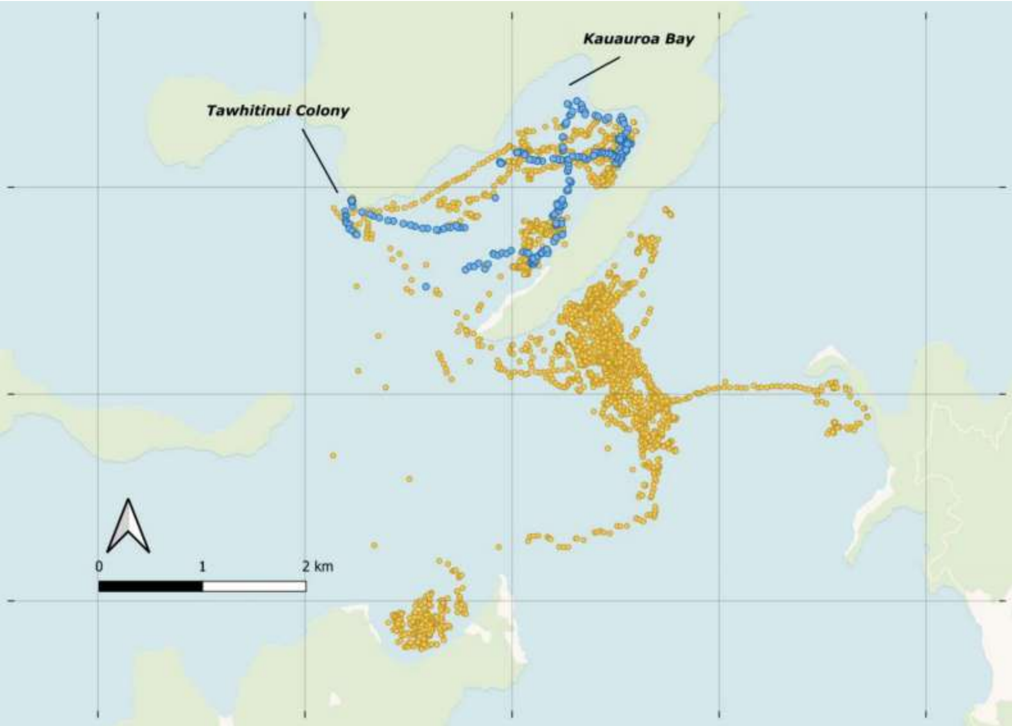


Figure 9.7. Tracking of White 61 from 11 July to 27 July 2021. Points indicate GPS fixes with blue points indicating GPS fixes taken on the day of the storm (17 July 2021) with yellow points indicate GPS fixes on all other days tracked.



Discussion

Although we are unable to explicitly test for differences in foraging behaviour prior, during and after the storm, it appears that this storm event did impact overall King Shag foraging efficiency. The tracked female (White 55) did not forage at all during the storm, and then foraged for longer, but at shallower depth for the 2-3 days afterwards. The two males both decreased their foraging range during the storm, although foraging duration was less impacted until the day immediately after the storm. Both males dived shallower the day of, and for the next three days after the storm. This change in behaviour appears to support the hypotheses that, the King Shags altered their initial behaviour in response to the storm event, and that the days following, King Shags further altered their foraging behaviour in response to increased turbidity in the environment.

These results suggest that this severe weather event impacted King Shag foraging efficiency for up to 3 days after the storm event; and highlights that sediment run-off is potentially a significant threat to King Shag. Most sediment in Te Hoiere/Pelorus Sound is derived from erosion due to land use change including forestry, farming, and stream bank erosion (Swale *et al.* 2021), and our findings highlight that land use, both adjacent to but also considerable distance from a species home range, can have significant implications for marine species and ecosystems.

As these data are merely a chance snapshot into a single event, more research is needed into understanding the longitudinal fluctuations in turbidity within Te Tauihu-o-te-waka/Marlborough Sounds and how this impacts King Shag foraging on a larger scale (especially since King Shags can show high between individual variation in their foraging preferences; see Chapter 8). Moreover, since the frequency of extreme climatic events (such as the flood that was experienced on 17 July

2021) are expected to increase over the coming decades (McGlone and Walker 2011, IPCC 2014), higher rates of sedimentation inflow can be expected to occur within Te Tauihu-o-te-waka/Marlborough Sounds in the future.

Chapter 10. GPS tracking reveals high rates of disturbance of kawau pāteketeke/King Shag within the Te Tauihu-o-te-waka/Marlborough Sounds.

Mike Bell, Patrick Crowe, Dan Burgin, and Samantha Ray

Summary

The GPS tracks of 28 Kawau pāteketeke/King Shag (*Leucocarbo carunculatus)* were assessed for disturbance, including birds tracked from Tawhitinui, Duffer's Reef, Kuru Pongi/North Trio, and The Twins. All but one of these birds were disturbed at some stage. Correcting for effort (days tracked) on average birds were disturbed 0.6 times/day (range 0 – 1.6 times/day), equating to birds being disturbed on average once every two days. From a total of 111 disturbance events recorded, 65 occurred at colonies, and 46 at roosting locations. The length of disturbance average 12.8 minutes (range 4-44 minutes), with half less than 10 minutes, and most (84%) less than 20 minutes. Disturbance events from roosting locations ($\bar{x}$ =14.9 minutes; SD=8.6) were significantly longer than those from colonies ($\bar{x}$ =11.3 minutes, SD=7.1). Most disturbance occurred on a Friday or Sunday, leading to the conclusion that recreational boating was the most significant cause.

Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) is highly susceptible to disturbance, and it is considered one of the threats to the species (Marchant and Higgins 1990; Taylor 2000). This was highlighted with the recent abandonment of the Sentinel Rock colony, which has been attributed to disturbance caused by an increase in recreational fishing around this islet (Chapter 1).

Human disturbance can have significant negative impacts on physiology, reproductive behaviour, reproductive success, and population trends of colonial seabirds (Carney and Sydeman 1999). Human disturbance on seabirds includes, but is not limited to, researcher effects, ecotourism, commercial and recreational fishing, and recreational boating. The problem is well documented, but difficult to eliminate, and conservation measures need to consider the extreme sensitivity of many seabird species (Anderson and Keith 1980). Although known to be at risk from disturbance, the amount of disturbance to King Shag has never been measured.

With the GPS tracking of King Shags to determine foraging behaviour (Chapter 7), this provided an opportunity to investigate and measure the amount, and degree of disturbance to individual birds. This report outlines the results of this work and describes the level of disturbance on King Shag.

Methods

Individual GPS tracks were analysed to follow birds' behaviour and were assessed to determine if birds were disturbed (Figure 10.1). Two types of behaviour were classified as disturbance events-

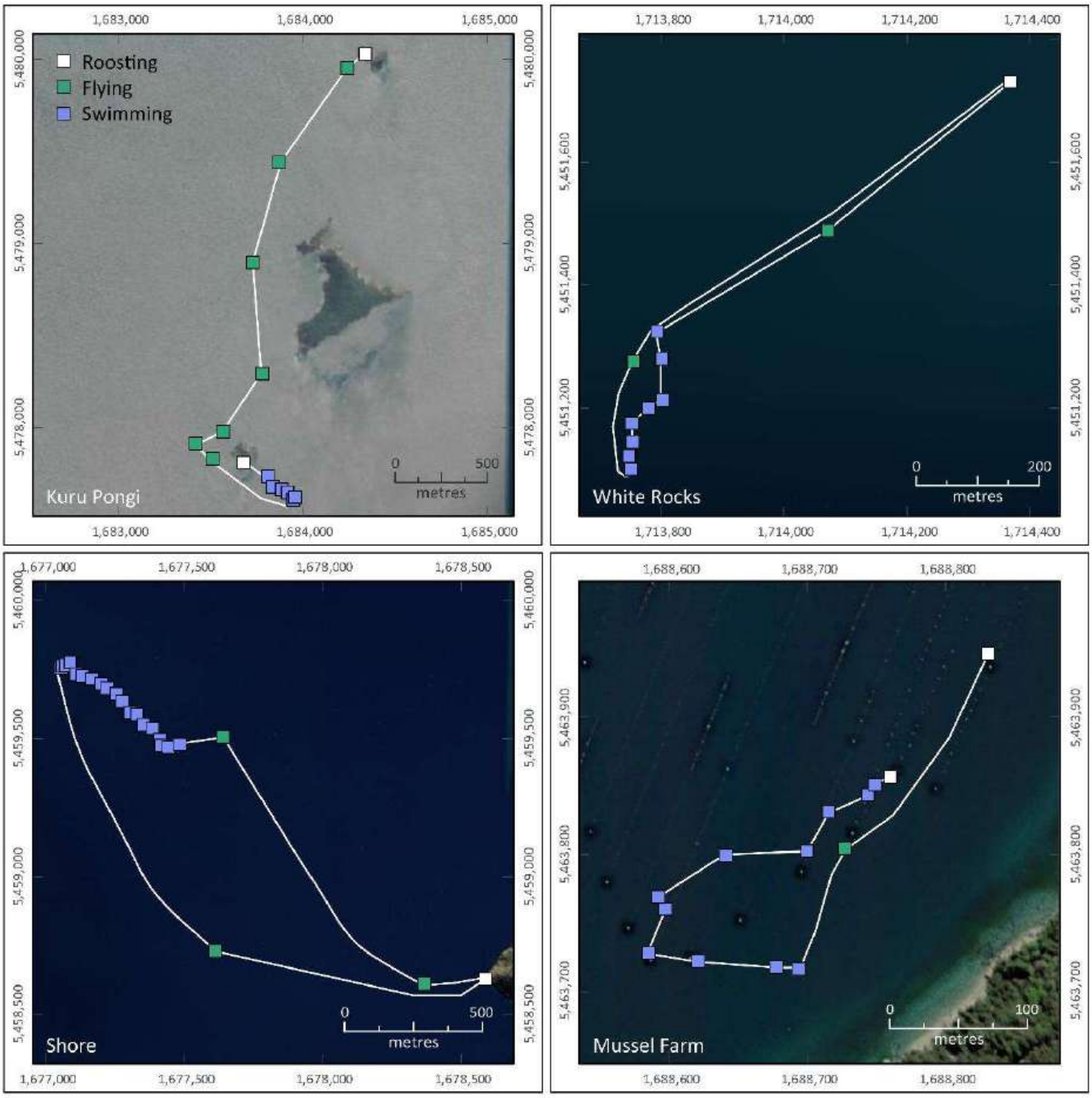
1. Disturbance from a colony – when a bird left the colony (either flying or swimming) and returned after a short period (<30 minutes) to the colony (Figure 10.2) or went directly to a new roosting location (either on land or on a mussel farm) without starting to forage (Figure 10.2). Any birds leaving the colony (either flying or swimming) that then went on to forage (regardless of the period spent foraging) was considered normal behaviour and was not recorded as a disturbance event.
2. Disturbance from a roosting location – when a bird left a roosting location (either a mussel farm or the shore away from a colony) and returned to a roost location after a short period (<30 minutes) or went directly to a new roosting location (either a mussel farm or the shore) without starting to forage or returning to the colony (Figure 10.2). Any birds leaving a roosting location (either flying or swimming) that then went on to forage or return to the colony was considered normal behaviour and was not recorded as a disturbance event.

As King Shag foraging is interspersed with periods of swimming and short flights between foraging bouts (Chapter 2), it is impossible to determine if such swimming and flying during foraging is linked to disturbance. As such investigating disruption to foraging was not included in this analysis, although it is almost certainly occurring.

To investigate the causes of disturbance boat movement data was used. A request to the mussel industry to provide data on the number of vessels working in Pelorus Sound during the tracking period birds of birds was requested. Two large companies provided data, so although this under-estimate the total number of industry boats on the water at any given time, it provides a pattern of daily activity. For recreational boats, we used data from the number of boats launched from Havelock Marina provided by Ports of Marlborough. As this data is from launching tickets sold, it will under-estimate numbers based on season ticket holders, again this data provides a pattern of daily recreational boat activity.

Figure 10.1. King Shag are sensitive to disturbance and will take to sea when approached at colonies or roost sites. Photo Dave Boyle.

Figure 10.2. Examples of King Shag GPS tracks classified as disturbance; clockwise from top left; disturbed from Kuru Pongi/South Trio this bird initially escapes to water swimming, then flies to Kuru Pongi/North Trio to resume roosting. A bird disturbed from White Rocks flies c800m south, then continues to swim south for 8 minutes before returning to the colony to roost. This bird is roosting on a mussel farm, is pushed off and flies 200m, were it circles around swimming to return to roost on a different section of the mussel farm. When roosting at Te Kaiangapipi Point this bird is disturbed, flies c.2km out to sea, starts swimming further out to sea, before flying back to the roost site.



Results

Five disturbance events attributed to researchers visiting colonies to download GPS tracking data from base stations were recorded, and these have been excluded from this analysis.

The GPS tracks of 28 birds were assessed for disturbance, including birds tracked from Tawhitinui, Duffer's Reef, Kuru Pongi/North Trio, and The Twins. All but one of these birds were disturbed at some stage, from between 1 to 17 times over the period they were tracked. Correcting for effort (days tracked) on average birds were disturbed 0.6 times/day (range 0 – 1.6 times/day), equating to birds being disturbed on average once every two days.

A total of 111 disturbance events were recorded from 27 birds; 65 events occurred at colonies and 46 at roosting locations; these events average 12.8 minutes (range 4-44 minutes). Half of disturbance events were less than 10 minutes, and most (84%) were less than 20 minutes (Figure 10.3)

Disturbance events from roosting locations ($\bar{x}$ =14.9 minutes; SD=8.6) minutes were significantly longer (T Test; t(109)=2.29, p=0.012) than those from colonies ($\bar{x}$ =11.3 minutes, SD=7.1).

Disturbance events did not occur evenly throughout the week, with more events occurring on a Friday and Sunday (Figure 10.4).

Figure 10.3. Proportion of length of disturbance event (minutes) of King Shag tracked in the Te Tauihu-o-te-waka/Marlborough Sounds.

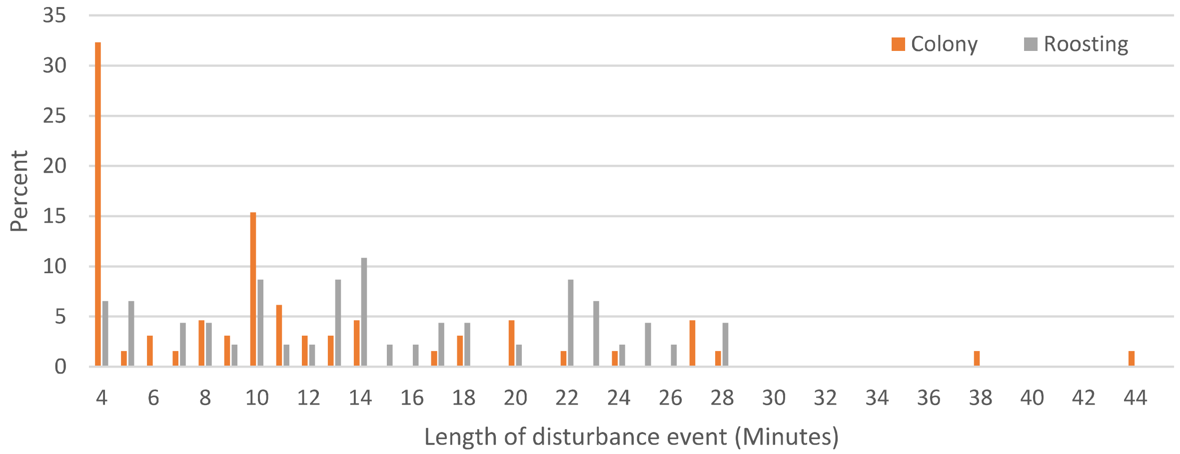
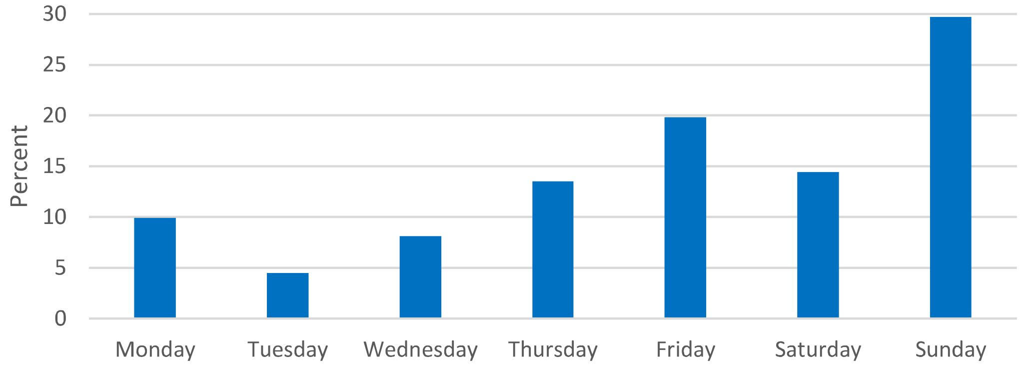


Figure 10.4. Proportion of King Shag disturbance events occurring on each day of the week.



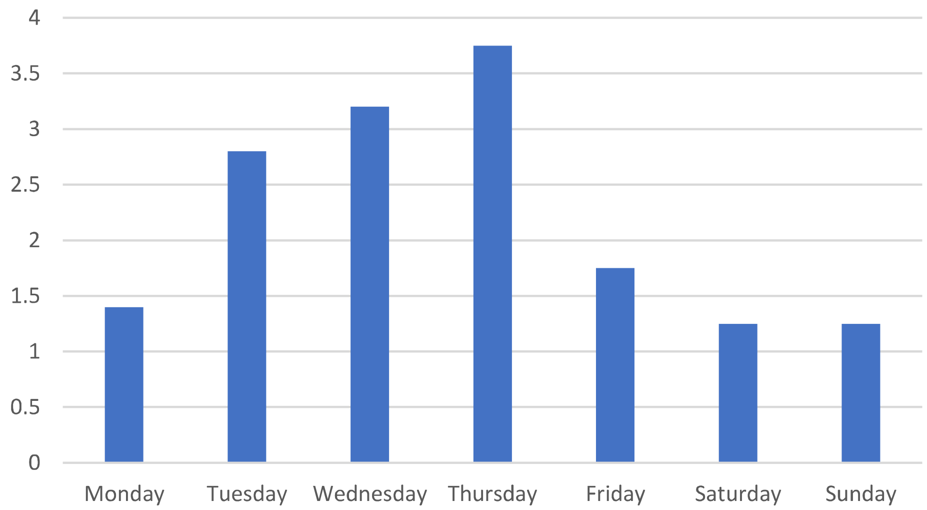
Correcting for effort there were similar levels of disturbance for different areas of the Te Tauihu-o-te-waka/Marlborough Sounds. With 0.5 disturbance events/day recorded in Queen Charlotte Sound, 0.4 events/day in Mid Pelorus Sound, 0.7 events/day in Outer Pelorus Sound and 0.7 events/day in Outer Admiralty Bay.

The GPS tracking detected three events at colonies involving multiple birds. At White Rocks on Friday 8 Oct 2021 three birds all departed at 6:50am returning within 5 minutes, and at the Trios on Sunday 6 March 2022 three birds departed at 6.30pm returning between 6-38 minutes later. Later, on the same day 5 birds departed at 8.10pm returning within 5 minutes.

During the periods king shags were tracked in Pelorus Sound and Outer Admiralty Bay, data from two large Havelock based mussel industry companies showed that activity was highest mid-week (Figure 10.5). Currently, only three Te Tauihu-o-te-waka/Marlborough Sounds based mussel industry companies work a four day on four day off rooster so are working weekends, with all other companies working during the week, mainly Monday to Thursday (Jonathan Large Pers. Comm.).

Unfortunately, data for recreational boat activity in the Marlborough Sounds is not available at this time, although anecdotal evidence suggests activity is higher from Friday to Sunday (or Monday on long weekends) (Steve McKeown, Havelock Operations Manager, Ports of Marlborough, *Pers. Comm*. June 2022).

Figure 10.5. Mean number of mussel industry vessels operating in Pelorus Sound during the period King Shag were tracked from Tawhitinui, Duffer's reef and Kuru Pongi/North Trio.



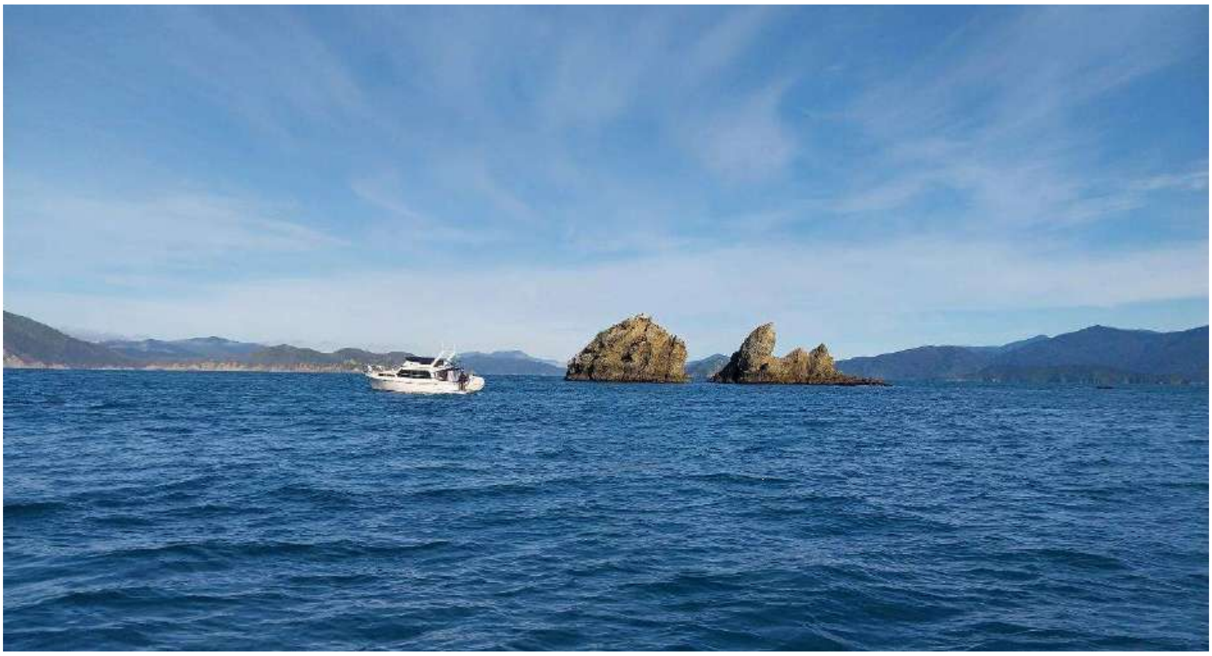
Discussion

Results show that King Shag are regularly disturbed, on average once every 2 days. The study found a higher level of disturbance than reported by Gummer (2021) using fixed cameras, which could be expanded by cameras only covering parts of colonies. Repeated disturbance can cause declines in productivity, but also impact individual fitness of both nestlings and breeding adults, leading to population declines (Labansen *et al.* 2021). The high level of disturbance experienced by King Shag could be at a level that is impacting the population.

Although we could not determine the cause of disturbance, boats approaching birds are known to cause escape behaviour in King Shag like what we record from GPS tracks (Fisher and Boren 2012). This suggests that most disturbance is caused by boats approaching birds and/or colonies causing birds to take flight or swim away. We found most disturbance occurred from Friday to Sunday, a similar result found by Gummer (2021), a time when mussel industry activity is reduced, but recreational boating is increased. Most recreational boating is for fishing, and the greatest fishing effort is on weekends and public holidays (Hartill *et al.* 2007, Hartill *et al.* 2020). Suggesting that recreational fishing in Te Tauihu-o-te-waka/Marlborough Sounds is the primary source of disturbance.

Aotearoa has one of the highest boat ownership rates in the world (Croft and Button 2015), with an estimated 55% of the population involved in recreational boating, which is increasing year on year (https://www.maritimenz.govt.nz/recreational/documents/IPSOS-MaritimeNZQ1-2022-report.pdf). Increased personal boat ownership has accelerated impacts on colonial seabird species (Davenport and Davenport 2006), and higher levels of recreational boating in the sounds will undoubtedly led to increased disturbance of King Shag and heightened population stressors impacting this species. Actions to mitigate the impacts of disturbance for King Shag should be initiated (Chapter 11)

Figure 10.6. A recreational fishing boat in close proximity to the White Rocks King Shag colony, June 2022.



Chapter 11. Conservation management options for kawau pāteketeke/King Shag (*Leucocarbo carunculatus*).

Mike Bell

Introduction

Kawau pāteketeke/King Shag (*Leucocarbo carunculatus*) are restricted to Te Tauihu-o-te-waka/Marlborough Sounds and are the most threatened shag species in Aotearoa (Marchant and Higgins 1990; Taylor 2000, Robertson *et al.* 2021).

During this study, research has shown that productivity is 0.59 chicks /pair, with the key driver influencing productivity being adverse weather (Chapter 3). Juvenile survival is 29%, with survival lower in the more exposed colonies in outer Te Tauihu-o-te-waka/Marlborough Sounds (Chapter 5). Unfortunately, our research has not been of sufficient duration to determine annual adult survival.

Figure 11.1. Adverse weather is the key influence on productivity in King Shag. Birds breeding on Duffers Reef are especially impacted with the site being low lying; here, by mid-June 2022 all birds nesting on the western portion of the islet have already failed by due to adverse weather the preceding weeks.

Despite conservative productivity and juvenile survival, the King Shag population has increased between early 2000's and 2021 (Chapter 2). This suggests that productivity, juvenile survival, and adult mortality are in balance to allow gradual population growth, but anthropogenic climate change will likely result in ocean warming and acidification, an increase in frequency and magnitude of storm events, and shifts in wind patterns in New Zealand (McGlone & Walker 2011; IPCC 2014), which will likely negatively impact the King Shag population.

Furthermore, our research has highlighted the potential negative impacts on King Shag from human disturbance, primarily from recreational boating, and the potential negative impacts of increased sedimentation as a result of surrounding land use change and subsequent runoff.

Despite a gradually increasing population, King Shag remain listed as Nationally Endangered (Robertson *et al.* 2021). This is because the population remains small (<1,000 mature individuals), the species has a restricted range, and is facing the increasing threat of climate change (Robertson *et al.* 2021; and supporting information available at https://nztcs.org.nz/assessments/118698). To improve the conservation status of King Shag, the population would need to increase to >1,000 mature individuals.

To achieve this, conservation management should be aimed at addressing the current risks to King Shag. This report recommends two types of management actions; policy aimed at mitigating risks to the species, and direct conservation management aimed at increasing productivity and juvenile survival.

Recommendations: Policy

Mitigating against disturbance to King Shag

Our research has confirmed that King Shag are subject to high levels of disturbance from human activity (Chapter 10). With recreational boat ownership and participation increasing year on year in Aotearoa (See Chapter 10), and with a continued increase in the number of holiday homes within Te Tauihu-o-te-waka/Marlborough Sounds (Sutherland 2000); there is increasing human activity that we feel presents an increased risk to the King Shag population.

To prevent further sub-division to increase the number of holiday homes within Te Tauihu-o-te-waka/Marlborough Sounds should be considered in the Marlborough Environment Plan. The impacts of increased numbers of dwellings and potential adverse effects on King Shag should be part of the remit for environmental considerations in determining the use of the coastal environment and adjoining land. In particular, environmental planning should consider the recent expansion of King Shag inwards in both Pelorus and Queen Charlotte Sounds.

Mitigating against human disturbance at colonies of King Shag from boating activity should be explored, and appropriate actions instigated. Potential options include development of exclusion zones around colonies and the creation of marine reserves around colony sites, which would effectively remove recreational fishing boat presence.

Further education of both recreational boat users, and the wider public, to the high levels of human disturbance, and the risk of negative impacts to King Shag is further encouraged. Although this role largely falls to the Department of Conservation, both industry and recreational fishing organisations play a part in developing and delivering messaging around the need to give King Shag space.

Effects of land use

This research has found that King Shag foraging is impacted by adverse weather as well as the increased sedimentation through runoff from surrounding land use that in turn has reduced water quality in Te Tauihu-o-te-waka/Marlborough Sounds (Chapter 9). The sources of these sediments are largely forestry derived and their source can come from a considerable distance.

Although some action is underway to improve forestry practises, the Marlborough Environment Plan needs to consider the potential impacts of forestry both within Te Tauihu-o-te-waka/Marlborough Sounds, and in catchments which flow into the Sounds. There needs to be consideration of both the current impacts, and the future impacts from increased intensity, frequency, and duration of adverse weather events due to climate change (IPCC 2014) that will likely increase sedimentation thereby reducing foraging ability of King Shag.

Figure 11.2. Sediment runoff from forestry in the Pelorus Catchment spreading across inner Te Hoiere/Pelorus Sound. Image from https://www.stuff.co.nz/business/farming/111987424/sediment-science-at-odds-with-local-knowledge-over-sounds-forestry-debate

Recommendations: Practical conservation management options

Habitat enhancement and social attraction of the penultimate islet at Duffers Reef

This study has shown that productivity and juvenile survival on Duffers Reef are low, with Duffers Reef colony the lowest nesting site, with all nests <5m above sea level (Schuckard *et al.* 2015). To increase productivity and survival it is recommended to clear vegetation from the adjacent islet, and then use social attraction techniques to encourage King Shag to start using the site for breeding. Once vegetation has been removed, dummy nests should be established, decoys deployed, and an acoustic attraction unit (sound system broadcasting King Shag colony calls) should be set up.

Social attraction has become an important tool in seabird restoration projects (Jones and Kress 2011) and has been successfully used to establish new seabird colonies (Parker *et al.* 2007). Suzuki *et al.* 2015 successfully encouraged Double-crested Cormorants (*Nannopterum auritum*) to breed on islands c.25km from the initial colony following habitat enhancement and social attraction. Historical use of these islands by shags may have helped with colonisation.

Buck *et al.* (2005) found habitat quality was a significant factor in seabird colonies forming and growing. Although higher, the penultimate island in Duffers Reef is still relatively low (within the range of current breeding altitude), has areas of south facing slopes, and has been used historically (Nelson 1971). All these factors, in relation to current knowledge, ensures this island can be considered ideal King Shag breeding habitat.

As this proposal will require modification of the current vegetation on the island, consideration must be given to its legal status. Duffers Reef is a Wildlife Sanctuary under the Wildlife Act 1953, via the Wildlife Sanctuary (White Rocks, Duffers Reef, and Sentinel Rock) Order 1966 (https://www.legislation.govt.nz/regulation/public/1966/0131/latest/DLM24416.html). Although this protects the island, it doesn't prevent the removal of vegetation for habitat enhancement, but this would need written authority from the Director General.

If approved, habitat enhancement of the island should be carried out after breeding at Duffers Reef has ended, but prior to birds starting to occupy territories for the following breeding season. The best window for this would therefore be between October and December.

Figure 11.3. The penultimate island in the Duffers Reef chain offers the opportunity for habitat enhancement and social attraction techniques to develop a King Shag colony where breeding will be better buffered against adverse weather.

Trials of developing a breeding colony on a raft in Yncyca Bay

Figure 11.4. Six King Shag of various ages roosting on barge tied to a mussel farm in Yncyca Bay (Photo Ben Armstrong, Sanford).

During field work in Te Hoiere/Pelorus Sound in 2021 it was discovered that King Shag were using an old raft tied to a mussel Farm for roosting (Figure 11.4). It appeared that birds were mainly using the raft during the non-breeding season, with occupancy declining leading into breeding. First-year, two-year old and adult birds were all seen on the raft, although it was never determined if birds overnighted on the raft. Two banded two-year old birds found using the raft were birds which had not been seen at the colony for >12 months previously, suggesting that immature birds may be using the raft year-round.

Unfortunately, the barge condition further deteriorated, and in January 2022 it was removed from the mussel farm and disposed of.

As King Shag push further into the Te Hoiere/Pelorus Sound (Chapter 1), the establishment of breeding colonies is likely limiting further expansion into Kenepuru Sound. However, the development of new colonies deeper into Te Hoiere/Pelorus Sound is limited by potential breeding habitat. There are no offshore islets, and limited areas of exposed rockface where King Shag could establish a breeding colony in inner Pelorus or Kenepuru Sound.

With this in mind, the construction and deployment of a raft specifically designed to encourage King Shag roosting should be trialled by re-instating a custom-built raft in Yncyca Bay. Hopefully, if birds start roosting on the raft, this will lead to birds breeding on the raft.

Other closely related blue-eyed shags in Aotearoa have nested on man-made structures. The largest colony of Otago Shag breeds on Sumpter Wharf, Oamaru, which contains 42% of the breeding population of this species (Parker and Rexer-Huber 2022). With a history of roosting on such structures, breeding on man-made structures may be possible for King Shag.

A well-designed raft should be established at Yncyca bay during the breeding season (March-August), to provide a suitable roosting platform for birds post-breeding. This would provide a non-breeding roost for dispersing juvenile birds and may over time lead to breeding and further expansion into this area.

If this trial worked in Te Hoiere/Pelorus Sound, consideration should be given to attempting this in Queen Charlotte Sound. However, with considerably more recreational boating use in Queen Charlotte Sound, human disturbance may prevent birds using a raft.

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