Notornis, 2015, Vol. 62: 76-84
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Foraging ecology and dive behaviour of Pitt Island shags (*Stictocarbo featherstoni*)

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Abstract The foraging ecology of Pitt Island shag (*Stictocarbo featherstoni*) was studied using GPS archival and Time Depth Recorder devices deployed on incubating birds. Pitt Island shags foraged exclusively during daylight, with a tendency for males to forage mainly during mid-morning and late afternoon, and females in the early morning and around mid-day. Mean foraging distance from colonies was 5.2 km (range 0.4-18.2 km), with males (mean 9.7 km) foraging significantly further than females (3.7 km). Both sexes showed high foraging site fidelity. The depth of most (83%) dives > 5 m deep were similar to the depth of the preceding dive (within 30%), indicating that birds are almost exclusively benthic feeding with the small fluctuations in dive depth likely reflecting changes in seafloor topography. Mean dive depth was 6.6 m, with maximum depth 24.4 m, although 90% of all dives were shallower than 13 m deep. Mean dive duration was 22 s, with a maximum of 69 s, although over 90% of dives were shorter than 40 s. There was a positive relationship between dive duration and dive depth, where deeper dives had longer duration. Mean rest period was 19 s with a weak positive relationship between rest period and duration of the preceding dive. Mean percentage time underwater during each foraging trip was 50.1%, indicating relatively high foraging efficiency. Favoured foraging locations in shallow inshore waters is likely to be a response by birds selectively foraging in sheltered waters protected from oceanic swells. This may be a factor influencing population declines as it intensifies risk to birds as potential threats may be more concentrated in these areas.

Bell, M. 2015. Foraging ecology and dive behaviour of Pitt Island shags (*Stictocarbo featherstoni*). *Notornis 62 (2):* 76-84.

Keywords Pitt Island shag; *Stictocarbo featherstoni*; dive depth; dive duration; foraging ecology

INTRODUCTION

The Pitt Island shag (*Stictocarbo featherstoni*) is endemic to the Chatham Islands, New Zealand where they are found on all major islands of the group. Birds breed in small loose colonies of 1-40 pairs in eroded pockets, cracks and ledges on coastal cliffs (Bell & Bell 2000). They usually feed alone, in coastal waters up to 20 m deep although they have been recorded feeding in the brackish Te Whanga Lagoon (Marchant & Higgins 1990; Heather & Robertson 1996).

Received 27 November 2014; accepted 28 May 2015
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The population of Pitt Island shags has undergone a 40% decline in the past 15 years. In 1997, Bell and Bell (2000) recorded 729 breeding pairs but this declined to 547 pairs in 2003 (Bester & Charteris 2005). A further decline to 434 breeding pairs was observed in 2011 (Debski *et al*. 2012). As a result, the threat status of the species was recently changed to "National Critical" (Robertson *et al.* 2013).

The Pitt Island shag is closely related to the spotted shag (*S. punctatus*) of mainland New Zealand (Checklist Committee 2010). Originally, behavioural and morphological similarity grouped these species

within a "cliff shag" genus *Stictocarbo* (van Tets 1976; Siegel-Causey 1988), which also included the European shag (*Phalacrocorax aristotelis*), red-legged shag (*P. gaimardi*), rock shag (*P. magellanicus*), pelagic shag (*P. pelagicus*) and red-faced shag (*P. urile*). However, recent DNA sequencing indicates that "cliff shags" are not a monophyletic group and that the New Zealand species of this group are more closely related to other species in this biogeographic region (Kennedy *et al.* 2000; Kennedy & Spencer 2014). Consequently, spotted and Pitt Island shags are now considered more closely related to pied (*P. varius*), black-faced (*P. fuscescens*) and little black shag (*P. sulcirostris*; Kennedy & Spencer 2014).

Knowledge about the foraging ecology of the New Zealand *Stictocarbo* species is limited (Taylor 2000). Aspects of the foraging ecology of several of the other "cliff shags" have been studied (Frere *et al.* 2002; Gremillet *et al.* 1998; Kotserka *et al.* 2011; Quintana 1999; Wanless *et al.* 1991; 1993; 1999), but given recent genetic studies, it is not clear whether these reflect the foraging behaviour of the New Zealand species. This paper describes the foraging ecology of Pitt Island shag using GPS archival and Time Depth Recorder devices deployed on breeding birds on Chatham Islands. I then compare this to the information available on other species of "cliff shags."

METHODS

During the 2012/13 breeding season, the diving behaviour and foraging areas of the Pitt Island shag were studied by deploying GPS archival and Time Depth Recorders (TDRs) devices on incubating birds.

Study sites

Pitt Island shags were caught at 2 locations on Chatham Island. The first study area was in the north east, at Point Munning and Te Whakuru Island (-43.736839 S -176.197617 E). At these sites birds were breeding in small sub-colonies of 5 – 10 pairs, with nests found on ledges of low schist outcrops. This site had easy foot access. The second site was at Waitangi, on the west coast of Chatham Island (-43.943221 S -176.570192 E). Birds bred in small sub-colonies of 2-6 pairs on ledges and small caves on coastal sandstone cliffs. Many nests were inaccessible, and a ladder was used to access them.

Capture

Both the GPS and TDR devices required the bird to be recaptured for device recovery and data download; consequently, nest sites which provided adequate access to enable multiple captures were selected. All birds were caught on their nest, either by hand, crook or hand net. Once caught, eggs were covered with a cloth to prevent predation by gulls (*Larus spp.*) or weka (*Gallirallus australis*). The capture and GPS/TDR attachment/retrieval procedure took less than 10 minutes. Upon completion, eggs were uncovered and birds were released back onto their nest site. The sex of birds was determined by DNA testing of collected feather samples by Massey University.

GPS and Time Depth Recorder device deployment

All birds had both a GPS and a TDR device attached. The GPS device was a repackaged i-gotU GT-120 (Mobile Action Technology). The internal battery and microchip processor were removed from the original packaging, programmed to record a location every 1 min, and waterproofed by sealing it in plastic shrink wrap. GPS devices were attached with tessa tape to feathers on the central back of birds. TDRs were Lotek LAT2900, and following programming were attached to a plastic leg band designed specifically for shags (Interrex, Poland).

Data analysis

As Pitt Island shags are only known to forage during daylight, foraging areas were determined by using GPS fixes recorded between 0600 h and 2000 h (reflecting local sunrise and sunset at the midpoint of the study of 0608 and 1836 h, respectively). Separation of foraging and commuting fixes was based on speed calculated between at sea fixes (to exclude fixes of birds back at the colony or at other roost sites), where track log speeds < 0.1 ms^{-1} were considered to be birds on the water foraging. Mean time at the surface between successive dives (referred to as the "recovery period"), excluding prolonged rest periods exceeding 6 minutes. Recovery period is the time birds spent at the surface between successive dives during foraging trips. Periods between dives > 60 s were considered rest periods, where birds stopped foraging. These are excluded from recovery period analysis.

To determine if shags are pelagic or benthic feeders, the difference between maximum dive depth and the depth of preceding dive was calculated for dives > 5 m deep. When this varied by < 30% the birds was considered to be benthic feeding with small fluctuations likely representing changes in seafloor topography. Variation > 30% was considered to represent individuals engaged in pelagic diving with birds foraging at various depths in the water column and not reaching the sea floor. For foraging trips which had both GPS and TDR data, dive depth was compared to chart depth; however, this proved of limited value as charts of foraging areas are too low resolution to enable detailed comparison.

Commuting speed was calculated between GPS fixes 1 minute apart on tracks between colonies and foraging areas. The first fix after departing a colony

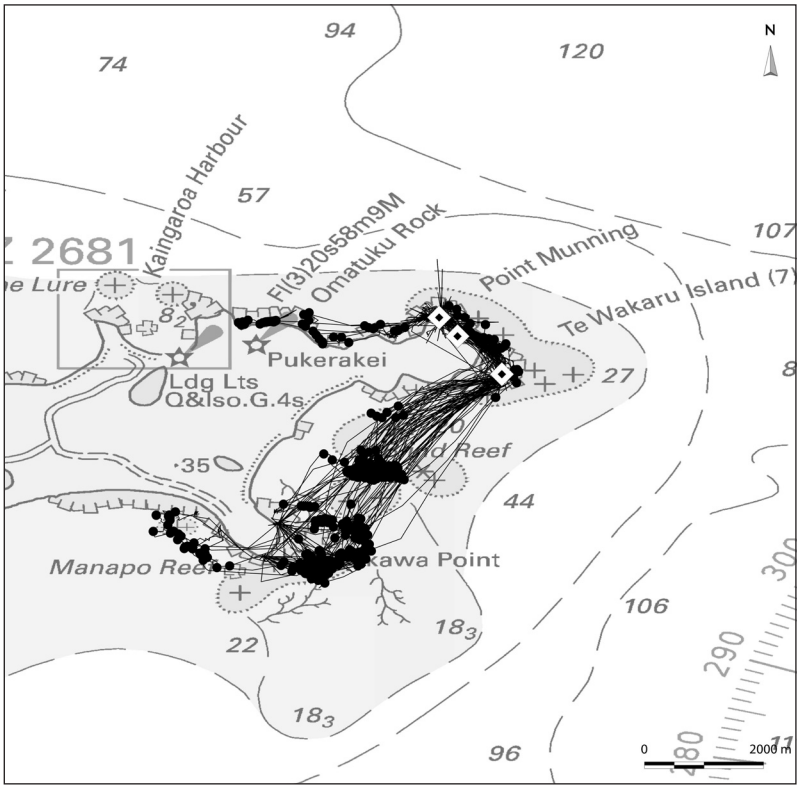

Fig. 1. Foraging areas of Pitt Island shag tracked from colonies at Point Munning and Te Whakuru Island; white diamonds indicate colony location, black dots foraging location, and black lines commuting tracks. Chart background by CC-By Land Information New Zealand.

or foraging area and the last fix before arriving were used to ensure the bird was commuting during the entire period between fixes. Time is represented as Chatham Island local standard time, 45 minutes ahead of New Zealand standard time.

RESULTS

Capture/re-capture rates and data recovery

A total of 27 birds was captured; 14 at Point Munning, 4 at Te Whakuru Island and 9 at Waitangi. Following release at the nest site, most birds quickly returned to incubation (mean 3.8 minutes; range 0-13 minutes).

A total of 17 birds was recaptured to recover devices; 8 at Point Munning, 4 at Te Whakuru and 5 at Waitangi. Again, after release, most resumed incubation immediately or shortly after (mean 2.9 minutes; range 0-8 minutes). Ten birds were not able to be recaptured; 6 at Point Munning and 4 at Waitangi. This was due to birds abandoning nests following predation; 5 nests were depredated by a possum (*Trichosurus vulpecula*), 1 by a feral cat (*Felis catus*) and 3 by an unidentified predator. In addition, 1 nest failed when the chicks died immediately after hatching.

Data were recovered from 15 of the 17 retrieved GPS devices, which provided data from 79 foraging trips. Data were recovered from 10 retrieved TDRs, with data covering 39 full foraging trips and 4 partial trips, with a total of 6709 individual dives recorded. Combined data from GPS devices and TDRs were recovered from 7 birds, providing linked data for 39 foraging trips.

Foraging ecology

Pitt Island shags from Point Munning and Te Whakuru Island primarily travelled to feed offshore from Okawa Point, though some birds foraged in waters adjacent to colonies (Fig. 1). Birds from Waitangi foraged around Waitangi, down the south coast and north to Whangamoe Inlet, Whangatete Inlet and Paritu (Fig. 2).

The mean foraging distance from the colony was 5.2 km (SD = 4.5; range 0.4 – 18.2 km, n = 80). The foraging range of females (mean 3.8 km) was significantly less than that of males (mean 9.7 km; t_{77} = 5.78, P < 0.001).

There was no significant difference between the foraging distance of birds breeding at Point Munning/Te Whakuru Island (mean 4.7 km) and those breeding at Waitangi (mean 6.1 km, t_{77} = -1.32, P = 0.19). Average commuting speed was 50.3 km h^{-1} (range 12.6 - 84.8) between foraging location and colonies.

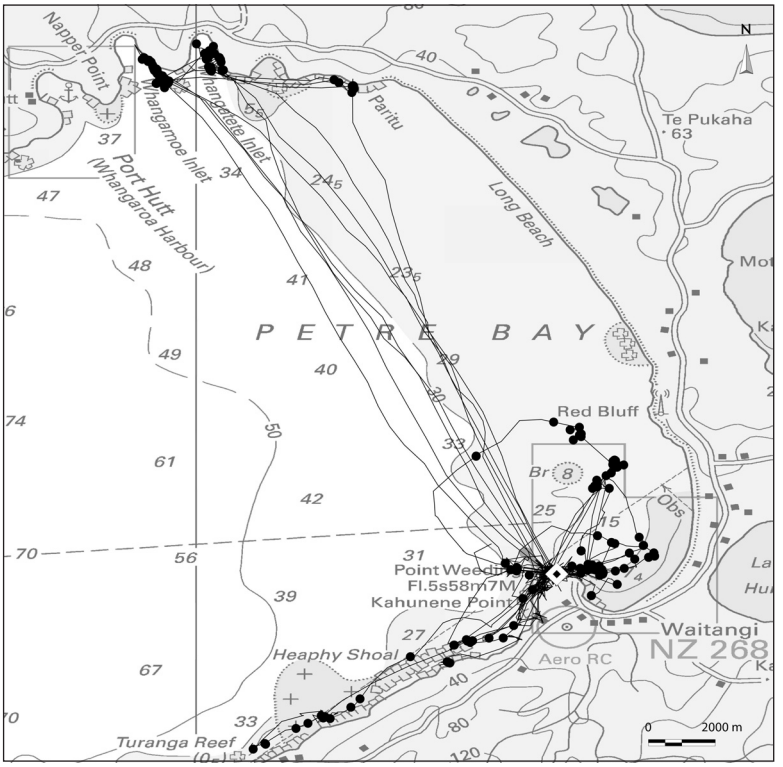

Fig. 2. Foraging areas of Pitt Island shag tracked from colonies at Waitangi; white diamond indicates colony location, black dots foraging location, black lines commuting tracks. Chart background by CC-By Land Information New Zealand.

Birds from Point Munning/Te Whakuru Island showed high foraging location fidelity with 78% of foraging trips being to the Okawa Point area (Table 1). Of the 10 birds tracked, 7 foraged exclusively at Okawa Point (Table 1). Only 1 bird foraged off the Point Munning coast and 3 around Te Whakuru Island.

Birds from Waitangi primarily foraged around Waitangi or travelled either north to Port Hutt Bays (Whangamoe Inlet, Whangatete Inlet and Paritu), or down the south coast (Table 1). Two birds foraged in only 1 location (Waitangi/Port Hutt Bays), whilst the other 3 foraged in 2 or 3 locations (Table 2).

Dive behaviour

Pitt Island shags foraged during daylight, with all dives recorded between 0603 h and 1906 h (local sunrise and set at the midpoint of the study was 0608 and 1836 h, respectively). There was an indication that males may have foraged more during mid-morning and late afternoon, whereas females foraged more in the early morning and mid-day (Fig. 3).

Pitt Island shags were recorded diving to a maximum depth of 24.4 m (female 22.7 m; male 24.4 m); however, 90% of all dives were less than 13 m deep (Fig. 4). Mean dive depth was 6.6 m (SD = 4.3 m, n = 6709), and there was no significant difference between female (mean = 6.7 m) and male dive depths (mean = 6.5 m; t_{6707} = -1.047, P = 0.295).

Mean dive duration was 22 s (SD = 13, n = 6709) and maximum dive duration 69 s. Dive duration was identical for females (mean = 22 s, SD = 13, maximum = 69 s, n = 4106) and males (mean = 22 s, SD = 13, maximum = 61 s; t_{6707} = 0.024, P = 0.981). More than 90% of dives were less than 40 s in duration (Fig. 5).

There was a significant relationship between dive duration and dive depth; dive duration increased linearly with dive depth (Fig. 6; r = 0.845; n = 6696, P < 0.001) with the best fit equation $y = 0.2823x + 0.3675$ (where y = dive depth (m) and x = dive duration (s)).

Mean time at the surface between successive dives (referred to as the "recovery period"), excluding prolonged rest periods exceeding 60 s, was 17.9 s (n = 6416). Recovery period was significantly longer for males (mean = 18.4 s, n = 3924) than females (mean = 17.5 s, n = 2492; t_{6414} = -4.2762, P < 0.001). There was a significant relationship between recovery period and dive duration of the preceding dive, with an increase in recovery period as dive duration increased (Fig. 7; r = 0.341; n = 6410, P < 0.001) with the best fit equation $y = 0.2254x + 12.851$ (where y = recovery period (s) and x = dive duration of the proceeding dive(s)).

Table 1. Foraging trips of Pitt Island shag from 3 study colonies on Chatham Island. Foraging location "Port Hutt Bays" refers to Whangamoe Inlet, Whangatete Inlet and Paritu.

Colony	Trips	Distance (range) km	Foraging location					
			Point Munning	Te Whakuru	Okawa Point	Waitangi	South Coast	Port Hutt Bays
Point Munning	36	4.6 (1.1-9.1)	3 (8.3%)	8 (22.2%)	25 (69.4%)	-	-	-
Te Whakuru	15	6.1 (4.2-5.7)	-	-	15 (100%)	-	-	-
Waitangi	28	6.1 (0.4-18.2)	-	-	-	18 (64.3%)	3 (10.7%)	7 (25%)

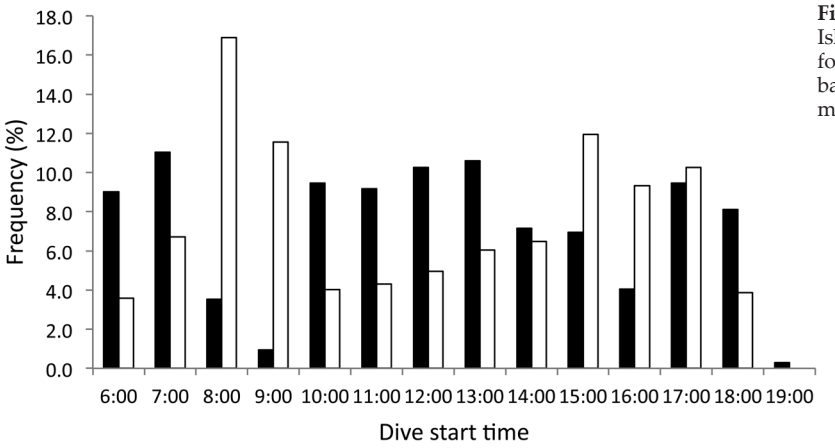

Fig. 3. Dive start times of Pitt Island shags, per hour, all foraging trips combined; solid bars are females, open bars are males.

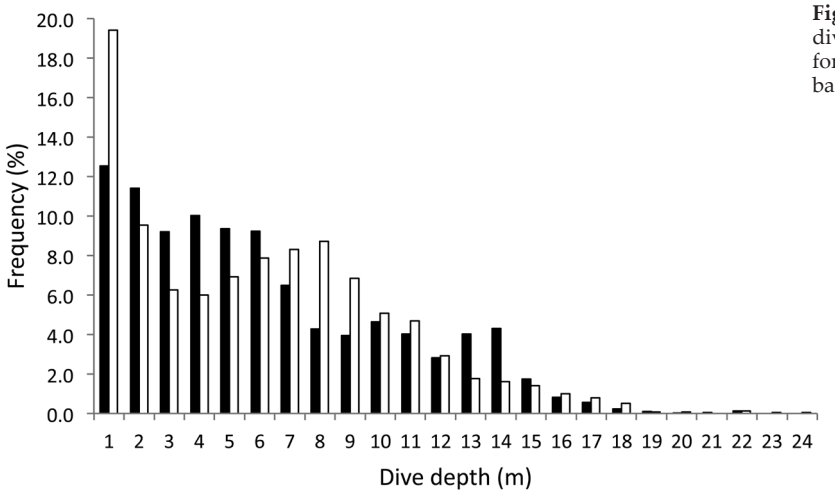

Fig. 4. Maximum depth of each dive of Pitt Island shag, all foraging trips combined; solid bars females, open bars males.

Most (83%) of the dives > 5 m deep were to a maximum depth similar to the depth of the preceding dive (within ± 30%; Fig. 8), with few dives being greater than ± 50% of the preceding dive. In addition, maximum dive depth for all linked GPS and TDR foraging trips were within depths shown on marine charts for the plotted foraging location.

Foraging efficiency

Mean percentage time underwater during each foraging trip was 50.1% (SD = 13.6, n = 57), with 41-70% of time spent underwater on 81% of trips (Fig. 9). There was no significant difference in time underwater between females (mean = 48.7%) and males (mean = 52.5%, t_{66}= 0.907, P = 0.37). In

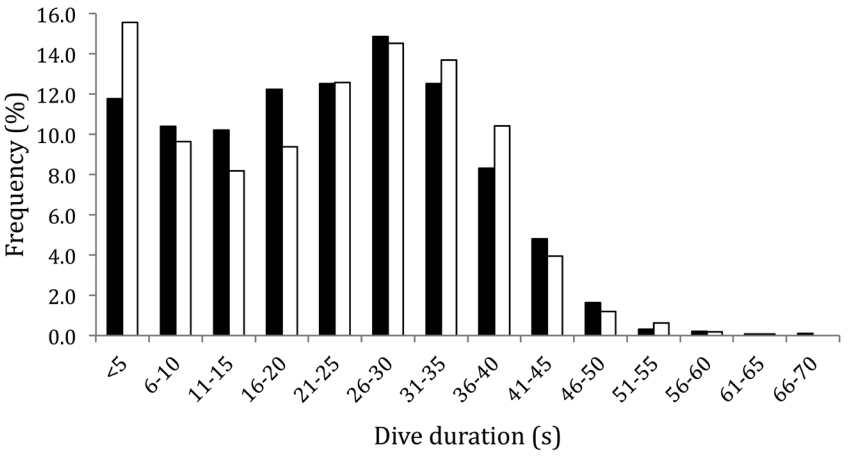

Fig. 5. Duration (s) of each dive of Pitt Island shag, all foraging trips combined; solid bars females, open bars males.

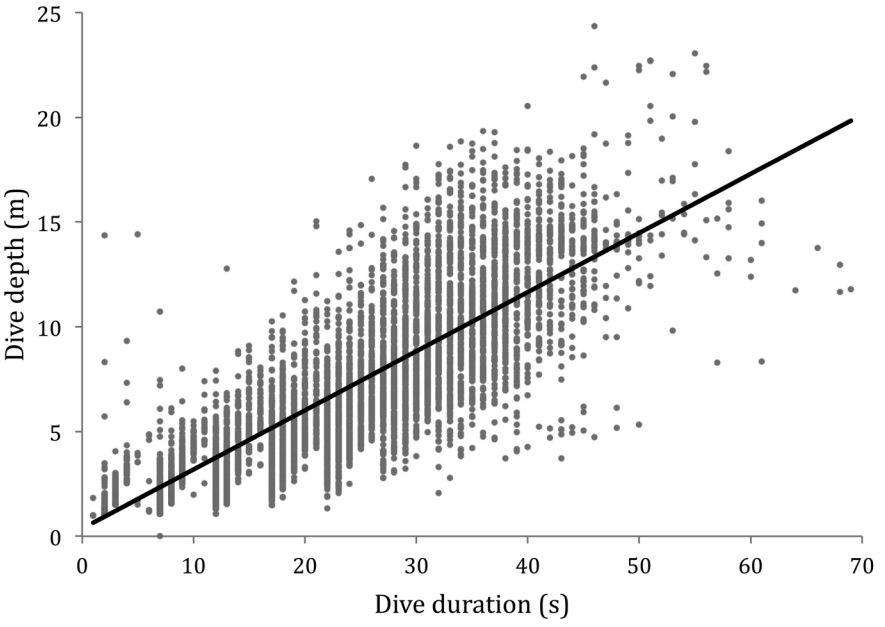

Fig. 6. Dive depth (m) as a function of dive duration (s) of individual dives of Pitt Island shag, all foraging trips combined.

addition, there is no significant difference in time spent underwater between birds breeding at Point Munning/Te Whakuru Island (mean = 49.2%) and those breeding at Waitangi (mean = 50.9%, t_{66} = 0.782, P = 0.437).

DISCUSSION

Pitt Island shags proved very confiding and approachable on the nest, enabling the capture and recapture of birds to be relatively straight forward. Birds quickly returned to nests, and no nests were lost due to the fitting and removal of tracking devices.

The tendency for differences in foraging times between males and females is likely to reflect timing of incubation shifts, and suggests that there are segregated incubation shifts. There is currently no data on the incubation cycle or parental division of labour of Pitt Island shags. Further study is recommended to investigate this apparent segregation.

Birds foraged considerable distances from colonies (mean 5.2 km, maximum 18.2 km), especially males (mean 9.7 km). The mean foraging distance recorded for Pitt Island shags was similar to other ecologically related species, such as 7.0 km in European shag (Wanless *et al.* 1991), 7.2 km in pelagic shag (Kotserka *et al.* 2011) and *c.*3 km in red-legged shag (Frere *et al.* 2002).

Pitt Island shags showed high foraging site fidelity with 9 of 17 birds feeding exclusively in a

Table 2. Foraging trips of individual Pitt Island shags tracked from 3 study colonies on Chatham Island. Foraging location "Port Hutt Bays" refers to Whangamoe Inlet, Whangatete Inlet and Paritu.

Bird	Sex	Nest Location	Foraging location						Total
			Okawa	Point Munning	Te Whakuru	Waitangi	South Coast	Port Hutt Bays	
A01	M	Point Munning	2	-	-	-	-	-	2
A02	F	Point Munning	-	3	5	-	-	-	8
A03	F	Point Munning	4	-	-	-	-	-	4
A12	F	Point Munning	5	-	1	-	-	-	6
A15	M	Point Munning	5	-	-	-	-	-	5
A17	M	Point Munning	6	-	-	-	-	-	6
A18	F	Point Munning	3	-	2	-	-	-	5
A04	F	Te Whakuru	5	-	-	-	-	-	5
A06	F	Te Whakuru	5	-	-	-	-	-	5
A07	F	Te Whakuru	5	-	-	-	-	-	5
A22	F	Waitangi	-	-	-	4	-	-	4
A24	F	Waitangi	-	-	-	1	-	1	2
A25	M	Waitangi	-	-	-	-	-	5	5
A26	F	Waitangi	-	-	-	3	1	1	5
A27	F	Waitangi	-	-	-	10	2	-	12

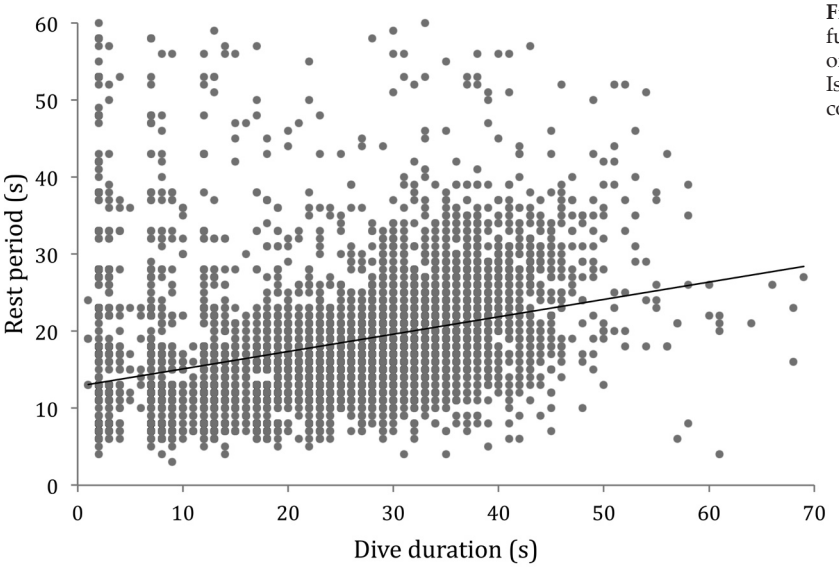

Fig. 7. Rest period (s) as a function of dive duration(s) of individual dives of Pitt Island shags, all foraging trips combined.

single area. In addition, most birds (14 of 17) showed a clear preference for a foraging area, returning to the same area on most foraging trips (60-100% of trips). High foraging site fidelity is generally well known for a range of cormorant species (Kotserka *et al.* 2011), and probably reflects a learned response to suitable foraging habitat and/or greater prey concentrations.

Pitt Island shags foraged mainly in shallow water (< 13 m) and diving consisted of short dives

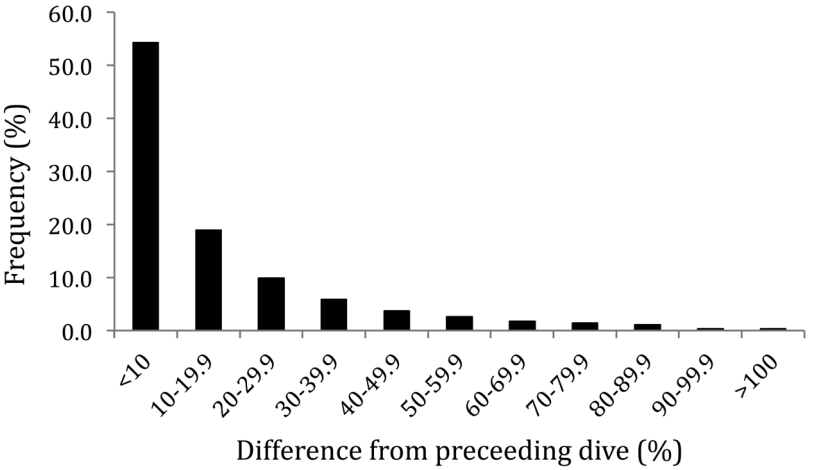

Fig. 8. Percentage difference of maximum dive depth from the proceeding dive of individual dives > 5 m of Pitt Island shags, all foraging trips combined.

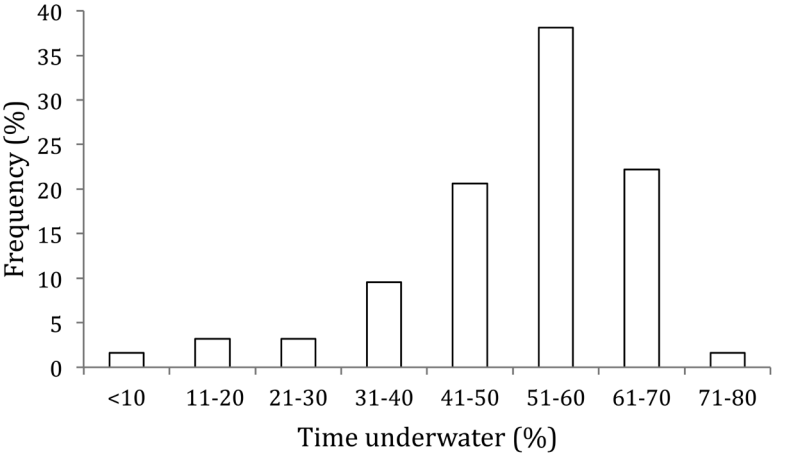

Fig. 9. Proportion of time spent underwater during each foraging trip of Pitt Island shags, all foraging trips combined.

(23 s) followed by a short recovery period (19 s). Dive duration was correlated to dive depth; however, recovery time was not well correlated to duration of the preceding dive. Mean dive depth was less than that recorded for other closely related species, such as < 15 m in red-legged shag (Frere *et al.* 2002), 17.3 m in pelagic shag (Kotserka *et al.* 2011), and 11.2-20.3 m in European shag (Gremillet *et al.* 1998, Wanless *et al.* 1999). Mean dive duration was also less than that of other closely related species, such as 27 s in red-legged shag (Frere *et al.* 2002), 30 s in spotted shag (Stonehouse 1967), 38-62 s in European shag (Gremillet *et al.* 1998, Wanless *et al.* 1993), 47 s in rock shag (Quintana 1999) and 52 s in pelagic shag (Kotserka *et al.* 2011). The differences in foraging parameters of Pitt Island shag from other ecologically related "cliff shags" may reflect the marine habitat in the Chatham Islands. Inshore shallow feeding may be a response to these small birds (female 1 kg, male 1.2 kg) taking advantage of foraging areas in calm inshore waters outside the influence of oceanic swells. The shallow depth of these calm waters results in the relatively shallow mean dive depth and resulting shorter dives than documented in other species.

This study found that during incubation Pitt Island shags repeatedly return to favoured shallow inshore foraging areas, probably as a response to the Chatham Island marine environment and prey availability. The restricted foraging locations may increase risk to birds due to prey fish declines (natural or human induced), pollution (including potential oil spills), or fisheries by-catch, if these foraging sites become affected. However, this study was restricted to 2 sites during incubation; Pitt Island shag breeding is between August-January (Marchant & Higgins 1990) with colonies occurring throughout the island group (Bell & Bell 2000; Bester & Charteris 2005; Debski *et al.* 2012). Further research into seasonal and regional differences are required to determine if and how foraging ecology is influencing population declines.

Predation of nests appeared to be high. Between 22 September and 12 October, 12 of 18 nests were predated at Point Munning, 4 of 32 at Te Whakuru Island, and 6 of 12 at Waitangi, representing a 35% predation rate in just 3 weeks. Debski *et al.* (2012) concluded that at seas factors were probably behind shag population declines in the Chatham Islands; however, the high predation rates recorded suggest other factors may be important drivers of population declines, particularly at breeding sites on the main Chatham Island. It is likely that several issues are impacting negatively on the population leading to the declines recorded and further investigation is warranted.

ACKNOWLEDGEMENTS

I am grateful for the support of Chatham Island landowners who freely allowed access across their property to undertake this research; in particular Bruce Tuanui, Jack Daymond, Jim Murrison, and Abe Neilson. Kelvin Floyd produced the maps, and Mark Frasr assisted in the field. This project was funded by the Department of Conservation's Conservation Services Programme (project POP2012-08). Additional funding was provided by the Royal Forest & Bird Society following a grant from the Mohamed bin Zayed Species Conservation Fund and I am grateful for this support. This paper was improved following review by Claudia Mischler, Rob Schuckard, Igor Debski and Kris Ramm, along with editorial reviewers.

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