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Population and breeding census of New Zealand king shag (*Leucocarbo carunculatus*) in 2015

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Abstract Prior to 1992 the total population of New Zealand king shag (*Leucocarbo carunculatus*) was estimated to be about 300 individuals. Between 1992 and 2002, colonies in the outer Marlborough Sounds, New Zealand were surveyed by boat and the total population was estimated to be 645 birds. About 92% of all birds occurred at Duffers Reef, North Trio Island, Sentinel Rock, and White Rocks, with an estimated 102-126 breeding pairs. A survey in February 2015 was the first to be conducted from the air. All colonies were photographed within 44 minutes prior to the morning departure and the total population was estimated to be 839 individuals. A total of 187 pairs/nests were recorded using aerial 3D images of all breeding colonies in June 2015. North Trio Island was the largest breeding colony with 33.7% of all nests, followed by Duffers Reef with 18.7% of all nests. Despite the larger revised population size, the species remains Nationally Endangered.

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INTRODUCTION

Of the 346 seabird species worldwide, 97 (28%) are globally threatened (Croxall *et al.* 2012); shags and cormorants (Phalacrocoracidae) are the fourth highest threatened family of seabirds in the world. The blue-eyed shags (*Leucocarbo*) are closely associated with nutrient-rich subantarctic marine upwellings and 7 species occur in the New Zealand region (Checklist Committee OSNZ 2010).

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New Zealand king shag (*Leucocarbo carunculatus*), hereafter king shag, is endemic to New Zealand and largely restricted to the Marlborough Sounds. It has one of the smallest populations of all the Phalacrocoracidae (Wetlands International 2015). Previously, some authors have considered both Stewart Island (*L. chalconotus*) and Chatham Island (*L. onslowi*) shags to be subspecies of king shag (Checklist Committee OSNZ 1953; Voisin 1973; Dorst & Mougin 1976), or conspecific with the Stewart Island shag (Worthy 1996), but Kennedy & Spencer (2014) reported that the king shag is a full

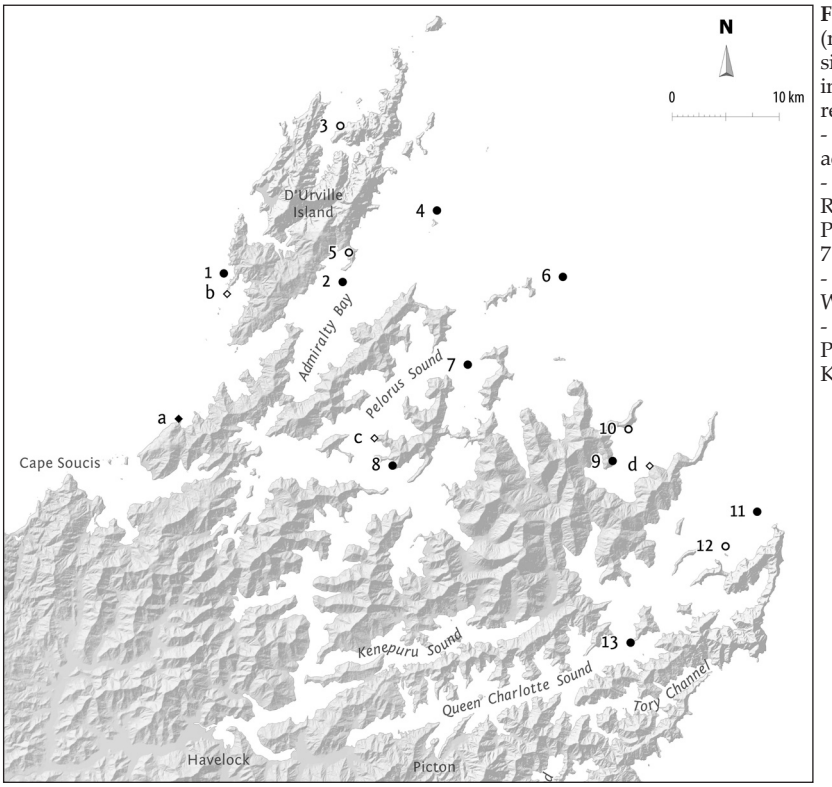

Fig. 1. Location of breeding (number) and roosting (letter) sites of New Zealand king shags in the Marlborough Sounds recorded since 1951 (open symbol - abandoned, closed symbol - active). 1 - Rahuinui Island; 2 - Stewart Island; 3 - Squadron Rocks; 4 - North Trio; 5 - D'Urville Peninsula; 6 - Sentinel Rock; 7 - Duffers Reef; 8 - Tawitinui; 9 - Hunia Rock; 10 - Taratara; 11 - White Rocks; 12 - The Twins; 13 - Blumine Island; a - Pahakorea Point; b - Hapuka Rock; c - Te Kaiangapipi; d - Blackhead Rock.

species, most closely related to the Bounty Island shag (*Leucocarbo ranfurlyi*).

King shags roost and breed on a limited number of islands in the Marlborough Sounds which they occupy throughout the year, the breeding season usually being from March to September (Schuckard 1994). Previous surveys of king shags have been made by boat. It is thought that surveys prior to 1992 (Nelson 1971; Butler 2003) underestimated the total number of birds in the population as they were not made at dawn, and thus did not include birds that had departed the colony to forage (Schuckard 2006). Between 1992 and 2002, Schuckard (2006) surveyed colonies by arriving offshore before dawn and counting birds before their departure to sea. These counts resulted in significantly higher numbers than previous reports (Schuckard 2006). Due to the wide geographical spread of king shag colonies in the Sounds, boat surveys generally do not allow for simultaneous counts and so total population estimates have been made over extended periods (Schuckard 2006; Bell 2010). The one exception was on 10 December 1997 when the 4 main colonies were surveyed before the morning departure, however, this was not a full survey and the smaller colonies were assessed on different dates.

One of the conditions of consent to New Zealand King Salmon to expand their salmon farming operation in the Waitata Reach, Pelorus Sound, required the preparation of a King Shag Management Plan (KSMP), to ensure that there is no reduction in the population of king shags in the Marlborough Sounds (Anon. 2013). Two of the 3 consented farms are in the Waiata Reach; a known feeding area for king shag, particularly those from Duffers Reed (Schuckard 1994). To provide statistically relevant information in the long term and to account for natural and external influences a baseline survey of the total population was required. Based on the recommendations of MacKenzie (2014), the following monitoring actions were adopted for the KSMP: (1) aerial surveys should replace boat-based surveys as the primary method for detecting changes in king shag populations and should be used as a baseline for measuring potential effects of the activity of the salmon farms in the Waitata Reach on the king shag population, and (2) aerial surveys should be initially conducted every 3 years on all colonies, including Duffers Reef, North Trio Island, White Rocks, Sentinel Rock, Rahuinui, Stewart Island, Hunia Rock and Tawhitinui (Schuckard 2015; Fig.1).

METHODS

To minimise the time taken to complete a full census of all king shag colonies, two aerial surveys of all

Table 1. Details of photographs taken for New Zealand king shag surveys February and June 2015.

Colony	11 February 2015				16 June 2015			
	Time	Altitude (m from sea level)	Sun angle	Per pixel on ground (cm)	Time	Altitude (m from sea level)	Sun angle	Per pixel on ground (cm)
Rahuinui Island	0711	354	3.7	1.8	1232	189	25.7	1.6
Stewart Island	0719	387	5.2	2.0	1223	224	25.7	1.9
North Trio	0722	395	5.9	2.1	1116	211	23.8	1.8
Squadron Rocks	-	-	-	-	1108	189	23.3	1.6
Sentinel Rock	0727	446	6.9	2.3	1124	186	24.2	1.6
Duffers Reef	0731	392	7.6	2.0	1133	195	24.5	1.7
Tawhitinui	0738	384	8.6	2.0	1213	195	25.5	1.7
White Rocks	0750	383	11.4	2.0	1157	197	25.2	1.7
Hunia Rock	0755	458	12.2	2.1	1147	191	24.9	1.6

king shag colonies took place in 2015. The first was flown on 11 February to obtain a total population count; this fulfilled the requirement for a baseline census for the KSMP. The second was flown on 16 June and aimed to count the number of breeding pairs/nests.

Aerial Surveys Ltd. was contracted to undertake both surveys. For the first flight in February a Cessna 402 aircraft was fitted with a Vexcel UltraCam Eagle photogrammetric camera (260 megapixel camera with a 100mm lens) and the aircraft was flown 354 to 458 m above sea-level over the colonies (Table 1). A flight management system on board was linked to the camera allowing pre-loading of GPS coordinates of sites to be photographed. For the June flight, a Cessna 206 aircraft was fitted with an UltraCamLp photogrammetric camera, (92 megapixel camera with a 70 mm lens) and the aircraft was flown 186 to 224 m above sea-level over the colonies (Table 1). Photographs were taken in stereo pairs by flying a second pass. Stereo imagery is normally captured on a single pass creating overlapping frames that are spatially positioned to the ground surface using aerial triangulation techniques so the image frames can then be viewed in stereo (3D). In this instance, due to speed of the aircraft, it was not possible as the camera was not quick enough to take the second overlapping shot. The higher image quality of the UltraCam Eagle camera meant that although February photographs were taken at higher altitudes the final images were of a similar pixel resolution as the UltraCamLp camera (1 pixel = 1.8-2.3 cm GSD (Ground Sample Distance) for population survey and 1 pixel = 1.6-1.9 cm GSD for breeding survey (see Table 1).

A boat visit to Duffers Reef on 29 January 2015 was used to determine the timing of shag departures from the colony. Observations of departing shags were recorded in blocks of 5 minutes starting at 0615 h NZDT (before sunrise) and continued until 1115 h, by which time the majority of birds had departed. A record was kept of the time of departure of all birds from the site and this information was then used to plan the flight time for the population census, such that all colonies were photographed before the time of the main departure from the colony. Sunrise on 11 February 2015 was at 0645 h and the aircraft flight between 0711 h and 0755 h was timed so that all colonies would be photographed before 0800 h (Fig. 2A). Additional departure observations were made during a second boat visit to Duffers Reef on 27 February 2015.

The breeding survey was flown on 16 June 2015 between 1107 h and 1234 h. It was not necessary to fly over the colonies at first light during the breeding season as nests are usually readily apparent and sitting birds are present all day. Furthermore, the later timing meant that light conditions were better for photography.

A single digital image of each site was provided by Aerial Surveys Ltd. and the 3 authors independently counted the birds at each site. The 2D photographs of the colonies were independently assessed by the 3 authors (Table 3). Evidence of breeding was: bird sitting on nest, pair of birds standing beside nest bowl, unoccupied but well formed nest with egg/chick in nest. The stereo pair images taken for the breeding survey were also assessed by 2 of the authors using digital photogrammetric software (Table 3).

RESULTS

Total population census

On 29 January 2015, a total of 298 king shags were counted from a boat at Duffers Reef. Only 2 birds

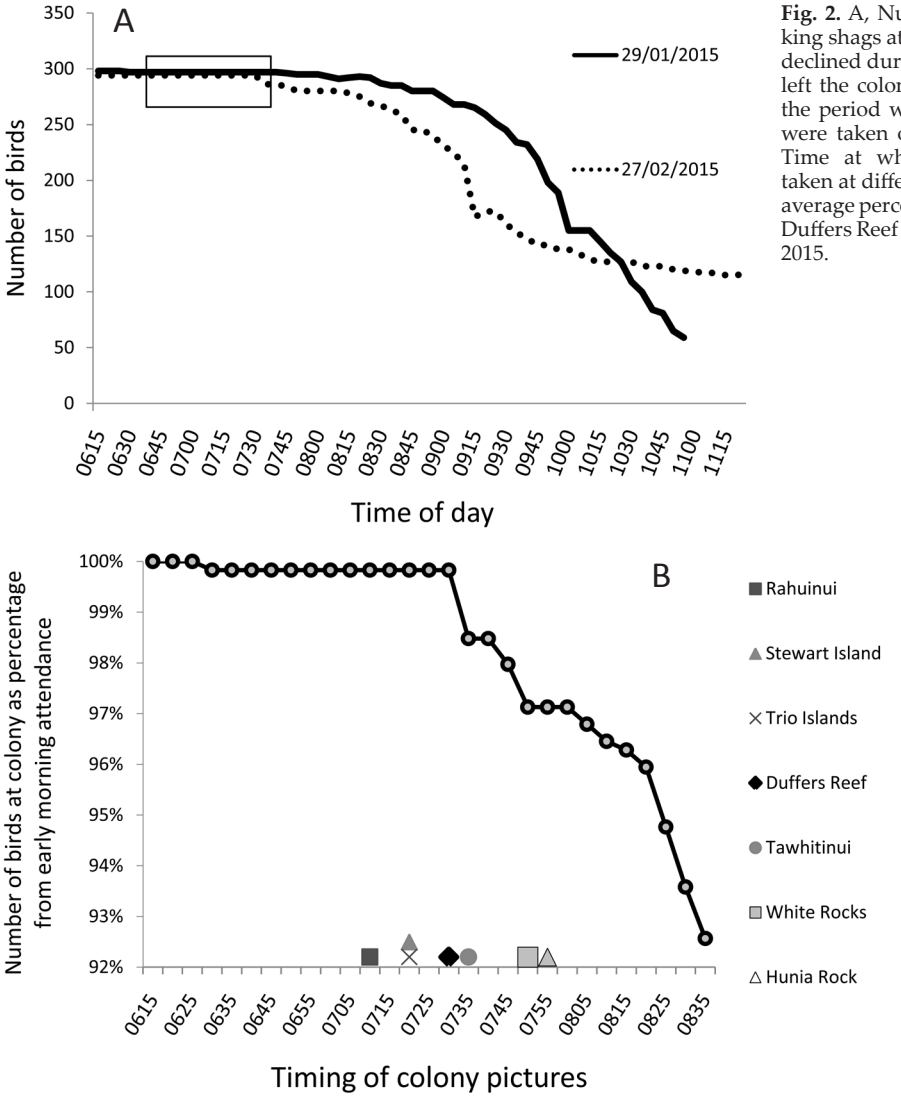

Fig. 2. A, Numbers of New Zealand king shags at Duffers Reef – numbers declined during the morning as birds left the colony to forage. Box shows the period when aerial photographs were taken on 11 February 2015. B, Time at which photographs were taken at different conies compared to average percentage of birds attending Duffers Reef at 29 Jan 2015 and 27 Feb 2015.

departed from the colony between 0630 h and 0745 h and the main departures started at 0745 h (sunrise was 0628 h). On 27 February, 294 birds were again counted from a boat and departures started at 0735 h (sunrise was at 0705 h) (Fig. 2A). The 2 departure counts from Duffers Reef were averaged (Fig. 2B) and used as a proxy for departures from all the colonies. It was thought that the majority of birds would have still been at over-night roosts at colonies when the survey was flown. By 0740 h less than 0.5% of the birds had left Duffers Reef and all colonies apart from White Rocks and Hunia Rock were photographed before that time (Fig. 2B). The latter 2 colonies were photographed when an average of 2.9% of the shags had left Duffers Reef to forage. It was apparent that the main departure of birds from Duffers Reef did not begin until after 0815 h, thus it was expected that only small numbers of birds, if any, would have departed before the aerial survey. No correction factor has been applied to counts made from the photographs; however, we recognise that a small number of birds may have been missed, in which case the total population would be slightly larger than presented here.

On 11 February 2015, 8 colonies were photographed within a 44-minute period: Duffers Reef, North Trio Island, White Rocks, Sentinel Rock, Rahuinui, Stewart Island, Hunia Rock and Tawhitinui (Table 1). Squadron Rocks was not included in this survey, but was surveyed on 16 June (see below).

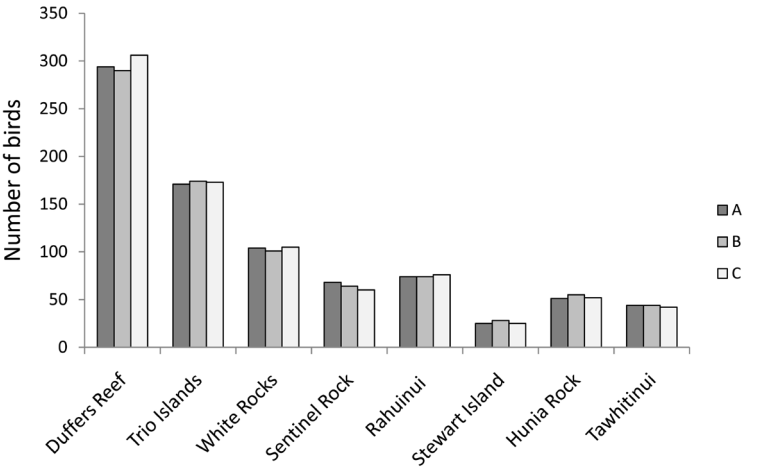

Fig. 3. Number of New Zealand king shags present at each colony on 11 February 2015 as determined from aerial photographs by 3 observers (indicated as observers A, B, and C).

Table 2. Numbers of New Zealand king shags recorded at each colony photographed 11 February 2015, assessed from aerial photographs by 3 observers (A, B and C).

	A	B	C	Average of 3 observers
Rahuinui Island	74	74	76	75
Stewart Island	25	28	25	26
North Trio	171	174	173	173
Squadron Rocks	-	-	-	-
Sentinel Rock	68	64	60	64
Duffers Reef	294	290	306	297
Tawhitinui	44	44	42	43
White Rocks	104	101	105	103
Hunia Rock	51	55	52	53

Table 3. Numbers of New Zealand king shags pairs/nests recorded at each colony photographed 16 June 2015, assessed from aerial photographs by three observers (A, B and C) and assessed from stereo paired aerial photographs by 2 observers.

	A	B	C	Mean count 2D images	Mean count 3D images
Rahuinui Island	22	22	22	22	22
Stewart Island	5	5	5	5	4
Trio Islands	64	68	66	66	63
Squadron Rock	0	0	0	0	0
Sentinel Rock	16	11	16	14	19
Duffers Reef	49	39	40	43	35
Tawhitinui	14	15	14	14	15
White Rocks	23	22	28	24	19
Huinia Rock	10	15	14	13	10

The photographs were independently assessed by the 3 authors (Table 2). The total of the lowest count by any observer at each colony was 814 birds and the total of the highest count by any observer was 856 birds, a variation of 2-3% (Fig. 3). The mean count for each colony was totalled for the final assessment. In February 2015, the total population estimate for king shags was 839 individuals (Fig. 4).

Duffers Reef was the largest colony with 35.4% of all the birds while North Trio Island had the second highest number with 20.6%.

Two sites that were known to hold small numbers of king shags within the past decade were excluded from the aerial survey, but were inspected by boat. The first site was a colony in the Queen Charlotte Sound known as The Twins (Fig.1). This was identified as a new colony in 2006 (Bell 2010), however, on 1 June 2015 no birds were present and there was no sign of recent attendance. The second site was a small breeding colony on the southern tip of Blumine Island (Fig.1). This site was occupied by king shags between 2000 and 2001 but abandoned by December 2001 (Schuckard 2006). On 1 June 2015 there were 9 birds of 3 different age classes present but with no evidence of current breeding. This small colony was not included in the February and June aerial surveys and the 9 birds are not included in the 839 birds counted.

Breeding season survey

The aerial survey of nesting king shags was flown on 16 June 2015. Nine colonies were surveyed, including Squadron Rocks (Table 1). Most/all colonies had one or more loafing individuals which were not included in the count. The mean count for each colony gave a total of 202 nests, the highest and lowest counts being 218 and 187, respectively (Fig.

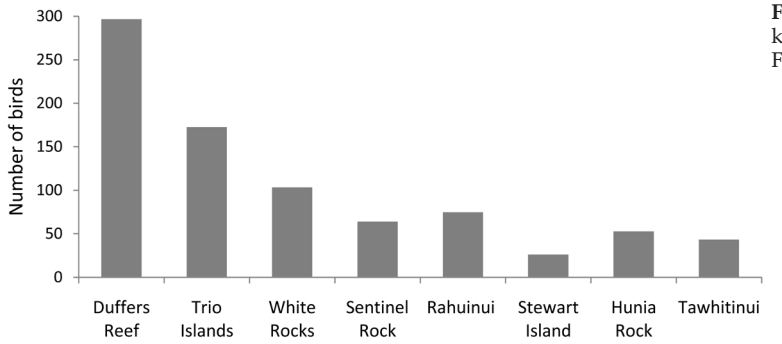

Fig. 4. Number of New Zealand king shags present at each colony 11 February 2015 (total = 839).

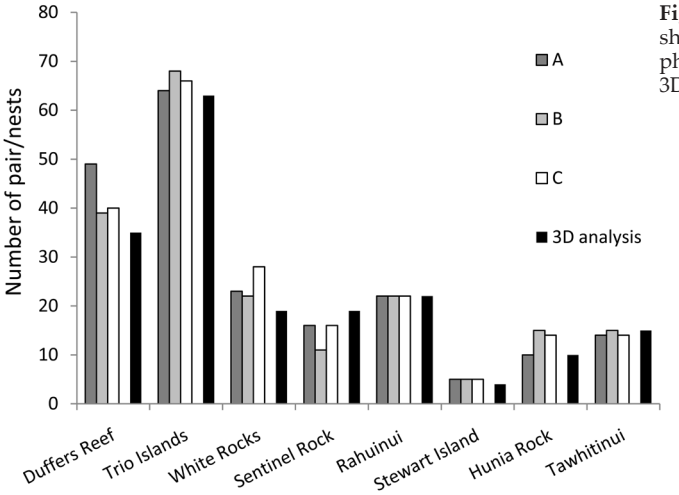

Fig. 5. Number of pairs/nests of New Zealand king shags present at each colony on 16 June 2016 aerial photographs assessed by 3 observers compared to 3D image analysis (black, total 187 nests/pair).

Table 4. Two simultaneous counts of New Zealand king shag at the 4 main colonies compared (1997 and 2015).

	10 December 1997	11 February 2015
Duffers Reef	205	297
Trio Islands	201	173
White Rocks	138	103
Sentinel Rock	55	64
Rahuinui	n.c.	(75)
Stewart Island	n.c.	(26)
Hunia Rock	n.c.	(53)
Tawhitinui	n.c.	(43)
Total	599	637

5) (Table 3). The variability of nest counts (~16%) was greater than counts of individual birds (above) which highlights the difficulty in identifying nests at the level of detail available in the 2D images. Detail was significantly improved with the 3D images and analysis by 2 of the authors identified 187 nests, which we consider to be an accurate count. King shags breed between 2 and 33 m above sea level (Fig.6), with 80% of the population breeding lower than 14 m above sea-level (Fig.7). North Trio Island was the largest breeding colony with 33.7% of all nests, followed by Duffers Reef with 18.7% of all nests.

DISCUSSION

The total number of birds counted on 11 February 2015 is the highest count ever of king shag, but it remains unclear whether this reflects a genuine increase in the population. Previous surveys of king shag between 1992 and 2002 indicated an average total population of 645 birds, with 92% being located at 4 colonies: Duffers Reef, North Trio Island, Sentinel Rock, and White Rocks (Schuckard 2006). A survey of these 4 colonies on 10 December 1997 counted 599 individuals (Schuckard 2006), 38 fewer than the 637 counted in February 2015 (Table 4), which could indicate that there has been a small increase in numbers. Bell (2010) found that in 2006 there were more birds at Rahuinui than at Sentinel and this pattern has

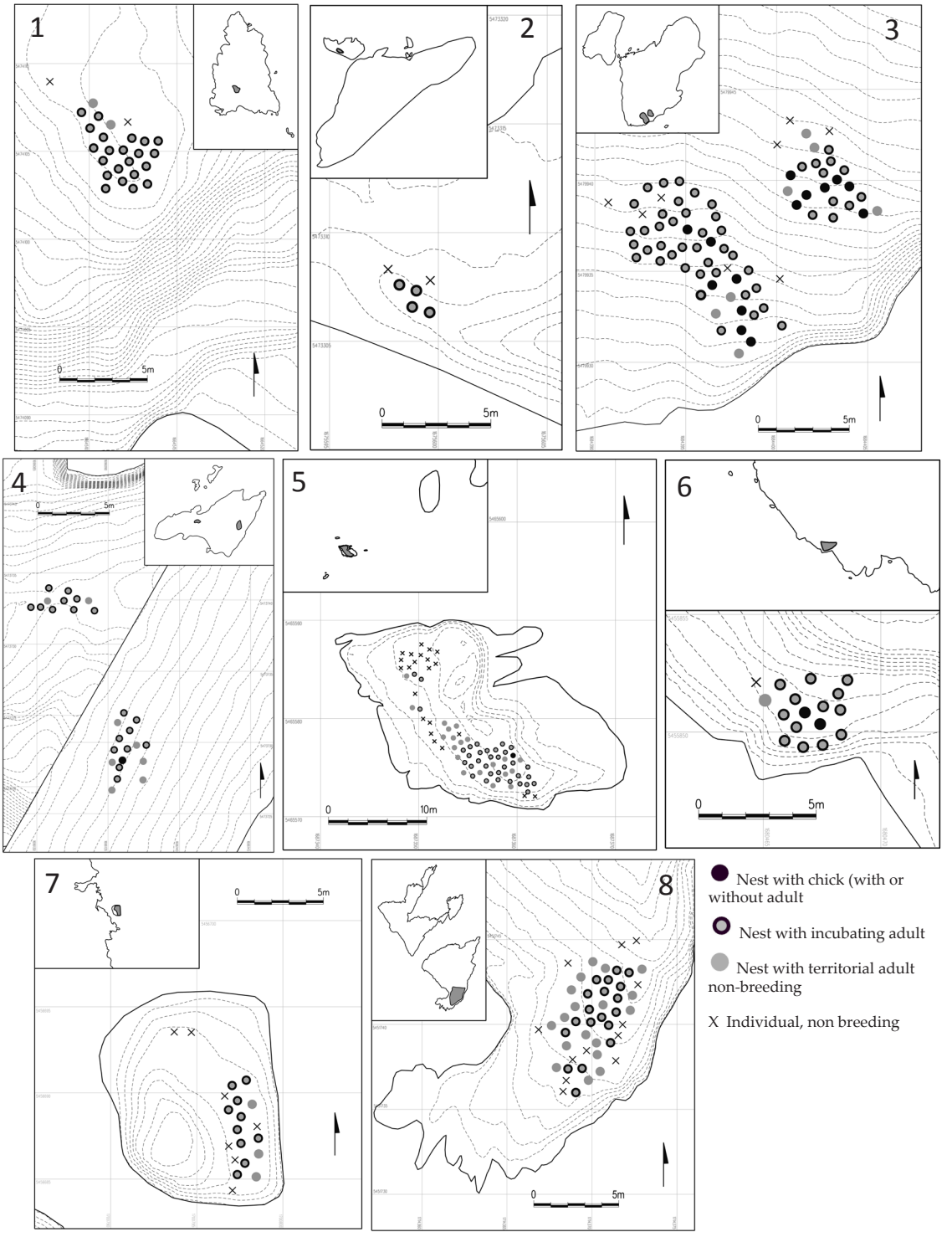

Fig. 6. Breeding colonies of New Zealand king shags at 16 June 2015 (contour lines at 1 m interval from sea level): 1 Rahuinui Island; 2 Stewart Island; 3 North Trio; 4 Sentinel Rock; 5 Duffers Reef; 6 Tawitinui; 7 Hunia Rock; 8 White Rocks. Maps produced by Aerial Surveys.

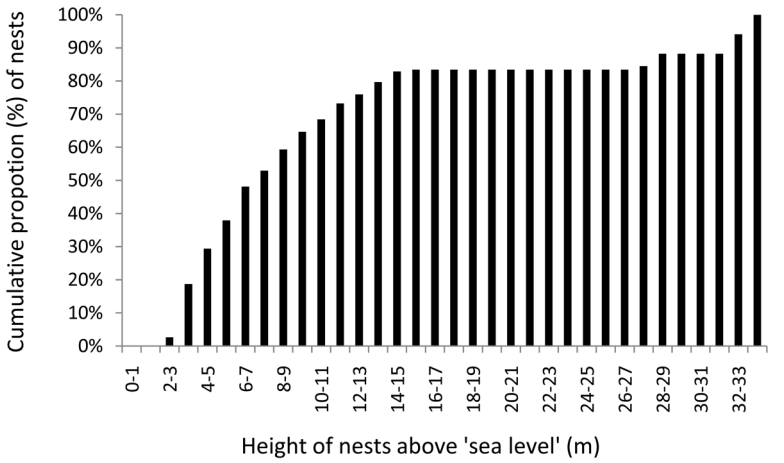

Fig. 7. Cumulative frequency distribution of height of king shag nests (n=187) above 'sea-level' on 16 June 2015.

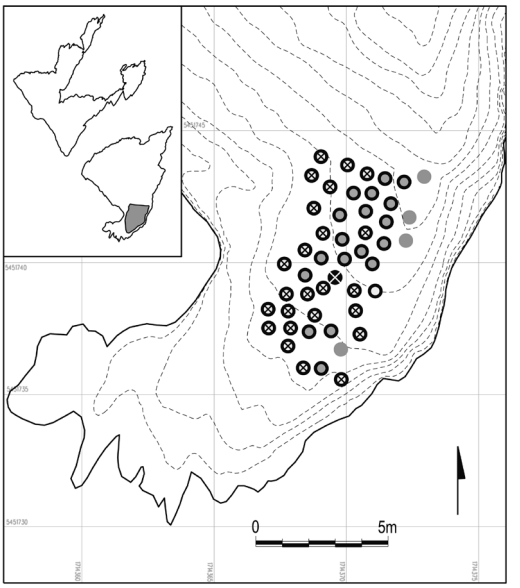

Fig. 8. Breeding colony of New Zealand king shags at White Rocks 1 June 2015 compared with aerial survey at 16 June 2015. ● Nest with territorial adult non breeding at 16 June 2015. ◉ Nest with incubating adult at 1 June 2015 and 16 June 2015. ○ Nest with incubating adult at 16 June 2015. ◎ Nest with incubating adult at 1 June 2015 (disappeared at 16 June 2015). ⊗ Nest with chick at 1 June 2015 (disappeared at 16 June 2015). Map produced by Aerial Surveys.

been maintained in the present survey. Schuckard (2006) previously noted apparent movement of some birds between colonies and this could have resulted in either under- or over-counting in previous surveys which often took place over several weeks, if not months. However, movement of birds between sites has been impossible to study due to a lack of marked individuals. The higher number found in February 2015 (839) compared to the 645 individuals estimated from previous surveys (1992 – 2002) and 687 in 2006 (Bell 2010) is most likely the result of better accuracy of the aerial survey technique compared to boat surveys, though an increase in the total number of shags cannot be ruled out. The timing of departure of king shags from Duffers Reef (Fig. 2) agrees with previous findings that few king shags departed the colony until about 1.5 hours after sunrise during January/February (Schuckard 1994). The count of all colonies in one morning and the inclusion of colonies that have not been counted before, provide the most accurate population estimate to date.

The 187 breeding pairs account for some 45% of the total population; this compares with 39% of the estimated population breeding in the period 1992-2002. These figures need to be treated with some caution however. Observations at White Rocks in June 2015 showed that there had been a significant reduction in apparent breeding pairs between 1 June, when photographs were taken during a boat visit (Fig. 8), and 16 June when the aerial survey was undertaken – some 25 nests having been lost in the intervening 15 days (Fig. 8). On 16 June there were still some pairs attending sites where nests had been present on 1 June despite the nests having disappeared. The colony, which is situated on the southern side of the island, would have been exposed to stormy weather, in particular an event on 3/4 June when southerly winds up to 83 kph and waves >2.5 m coincided with a spring tide. Strong southerly winds were also recorded on 12 June (89 kph, waves >2.5 m) and 15 June (56 kph, waves >1.2 m) (Interislander Ferry *Aratere* Bridge Log Book 1 June 2015 - 16 June 2015). Many of the nests lost were situated in the lower section of the colony (4-6 m above the waterline) and thus would be expected to be potentially subject to wave action, however,

some nests higher on the island also disappeared (Fig. 8). King shag nests are comprised of vegetation cemented together with guano – it is possible that the difference in nest damage/loss may be related to differences in nest structure. Stealing of nest material from unattended nests is widespread in a variety of shags (Carter & Hobson 1988, Cooper 1986, Orta 1992, Green 1997), and although not specifically recorded for king shag, might account for nest disappearances if birds were disturbed by the storms. The loss of 58% of nests at White Rocks is significant; it is not known whether king shags lay replacement clutches, however, this is recorded in other Phalacracoracidae (Orta 1992). The White Rocks colony is not the lowest breeding colony, but is in an exposed part of the outer Marlborough Sounds .Whether or not other colonies were affected by these same storm events is unknown, but loss of nests at White Rocks is likely caused by exposure to southern storms.

It is not known what constrains king shags to this relatively small distributional zone (about 55 km by 35 km) in the Marlborough Sounds. Nor do we understand the environmental parameters that currently lock an entire species to 8 roosting/breeding rocks within a small foraging area. Some king shags have begun expanding to small satellite roosts/colonies where breeding in small numbers has occurred. Over time, some of these new satellite colonies have been abandoned (*e.g.,* Squadron Rock, Te Kaiangapipi, The Twins), while others have become established (*e.g.,* Rahuinui Island, Hunia Rock, Tawhitinui) or used on an irregular basis (Blumine Island). Similar short-lived expansions from the main breeding range have also been observed in the Galapagos cormorant (*Compsohalieus [Nannopterum] harrisi*). An inability to meet the daily food requirement for these satellite birds has been suggested as a reason why juveniles and adults move back towards their original normal range (Valle 1995). It is possible similar factors affect king shag.

IUCN currently classifies king shag as 'Vulnerable', the population being 'very small or restricted' with < 1,000 mature individuals with a very restricted area of occupancy or number of locations (IUCN 2015). BirdLife International (2012) notes "it has a very small population and is restricted to four very small islands, rendering it susceptible to stochastic effects and human impacts. If human disturbance or set-netting were shown to cause a population decline or fluctuations in numbers or locations, it would require up listing to Endangered". New Zealand has adopted a national threat classification system (Townsend *et al*. 2008) under which king shag is listed as 'nationally endangered' (Robertson *et al*. 2013), based on a restricted range and a stable population with 250-1000 mature individuals. Despite the larger population estimate for king shag resulting from the 2015 survey this species still qualifies for listing as 'threatened' under both the IUCN and New Zealand threat classification systems.

This study has demonstrated that aerial photography is a practical method for surveying king shags and the aircraft pilot reported no evidence of disturbance from overflying any of the colonies at the heights listed in Table 1. A comparison of counting birds using 2D and 3D stereo paired images showed that it was much easier at the camera resolution used to work with 3D images and we recommend that such images be used in all future surveys.

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