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A census of nesting pairs of the endemic New Zealand king shag (*Leucocarbo carunculatus*) in 2016 and 2017

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Abstract Following an initial aerial census of breeding New Zealand king shags (*Leucocarbo carunculatus*) in 2015, 2 further aerial censuses were carried out in 2016 and 1 census in 2017. In 2016, birds were photographed on 2 separate dates using a hand-held camera from inside a fixed wing aircraft. In 2017 the birds were photographed from a fixed-wing plane equipped with an automated camera system mounted below the aircraft. Photographs were independently assessed by 3 observers in 2016 and 2 observers in 2017. Nesting pairs were identified and the figures were averaged per colony for a final estimate of the number of active nests. The first census for 2016 was completed on 6 June and 89 active nests were estimated, compared with 117 nests counted on 1 July. For some colonies, breeding appeared to have just started in June 2016, so an underestimate of active breeders during the first aerial census was the probable cause. The 2017 aerial census was completed on 21 June and we identified 153 active nests. All follow up aerial surveys in 2016 and 2017 were well below the 187 active nests recorded in the 2015 study but within the historic variation. The exception to this trend is Trio Island, where no breeding colony was observed in 2017, the first time this has been recorded at this site.

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Keywords New Zealand king shag; *Leucocarbo carunculatus*; Marlborough Sounds; aerial census; breeding population

INTRODUCTION

IUCN currently classifies the endemic New Zealand king shag (*Leucocarbo carunculatus*) (hereafter king shag) as 'Vulnerable'; the population being 'very small or restricted' with < 1,000 mature individuals in a very restricted area of occupancy or number of locations (Birdlife International. 2016). Under New Zealand's national threat classification system, king shag is listed as 'Nationally Endangered' (Robertson *et al*. 2017), based on a restricted range and a small but apparently stable population of 250-1000 mature individuals. King shag is a full species within the blue-eyed (pink-footed) shag group (Kennedy & Spencer 2014).

An analysis of modern and prehistoric *Leucocarbo* specimens, from the North Island and northern South Island concluded that the king shag was formerly widespread along the Cook Strait, around southern coasts of the North Island and the northern parts of the South Island. The species experienced severe population and lineage

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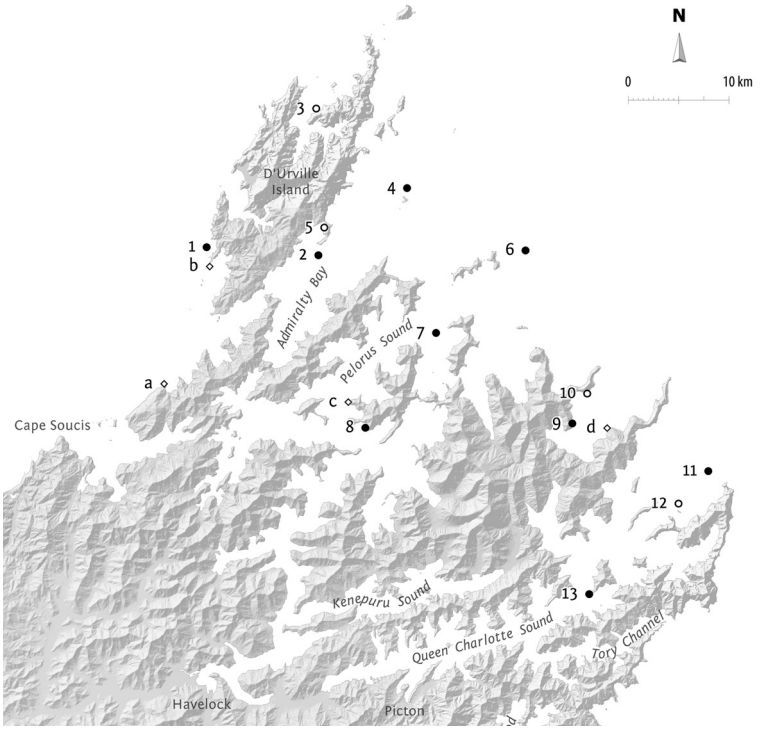

Fig. 1. Locations of king shag colonies in 2016 and 2017: 1 – Rahuinui; 2 – Stewart Island; 3 – Squadron Rocks (abandoned); 4 – Trio Island; 5 – D'Urville Peninsula (abandoned); 6 – Sentinel Rock; 7 – Duffers Reef; 8 – Tawhitinui; 9 – Hunia Rock; 10 – Tarata Point (abandoned); 11 – White Rocks; 12 – The Twins; 13 – Blumine Island. Past known roost sites are also shown: a – Pahakorea Point; b – Hapuka Rock; c – Te Kaiangapipi; d – Blackhead Rock.

extinctions, and resulting range contraction, probably after Polynesian arrival (Rawlence *et al.* 2017).

The king shag is a non-migratory species that roosts and breeds on 9 islands in the Marlborough Sounds; each site is occupied throughout the year (Fig. 1). The breeding season usually starts with courtship and nest building in March; by late-September most chicks have fledged. Annual variation in the timing of egg-laying, hatching and fledging is still very poorly known. For example, summer breeding by a small number of pairs has been recorded (Nelson 1971; Schuckard 1994). Population dynamics of all New Zealand blue-eyed shags have been poorly studied and this has been identified by the Department of Conservation as a research priority (Taylor 2000).

An initial aerial census of king shag populations was conducted in February 2015, followed by the first aerial census of breeding birds in June 2015. In both cases, the effectiveness of aerial photography for censusing king shag populations was demonstrated (Schuckard *et al.* 2015).

In both 2016 and 2017, funding was made available for further 2D aerial censuses, to assess inter-annual variability in the breeding activity of this species. The results of these second and third annual censuses of breeding birds are presented in this paper.

MATERIAL AND METHODS

On 6 June 2016, between 11:27–13:03 hr, aerial photographs were taken of all sites where king shags had previously been recorded nesting or roosting (Fig. 1). The results from this first census suggested that not all birds had started nesting. As such, a second aerial census for the 2016 season was carried out on 1 July 2016 between 14:26–15:21 hr. All potential colonies were covered during both flights.

The aircraft used in 2016 was a fixed-wing Cessna 180 and photographs were taken through a window with a hand-held Canon EOS 40D digital camera fitted with an 18–200mm lens. Over the colony, flight speed was decreased to about 60–80 knots and repeat passes were required to obtain a set of multiple pictures from each colony. Flight heights for the 2016 censuses were between 180–220 m above the king shag colonies, within the lower limits of the 2015 census. This more dynamic flight path was required to line up the plane's window for taking the pictures.

During the 2016 flights, a hand-held GPS

Table 1. Counts of breeding pairs of king shags, 2016 and 2017 during census. The means of each series of 3 independent assessments (Obs1, Obs2, Obs3) are rounded to the nearest whole number. Total is the sum of the locality means on each date. Row and column totals may not match because of rounding.

	6 June 2016				1 July 2016				21 June 2107		
Locality	Obs1	Obs2	Obs3	Mean	Obs1	Obs2	Obs3	Mean	Obs1	Obs2	Mean
Duffers	11	22	17	17	42	43	40	42	77	70	74
Trio	30	35	37	34	27	29	31	29	0	0	0
White	22	30	25	26	23	23	23	23	36	35	36
Sentinel	0	0	0	0	5	5	5	5	6	3	5
Rahuinui	0	0	0	0	4	6	1	4	21	21	21
Stewart I.	0	0	0	0	0	0	0	0	1	0	1
Hunia	3	3	3	3	1	1	1	1	1	1	1
Tawhitinui	10	10	10	10	14	14	13	14	12	11	12
Twins	0	0	0	0	0	0	0	0	5	5	5
Total	76	100	92	89	116	121	114	117	159	146	153

was used to record the flight path and provide a consistent time reference for each series of photos. This enabled the colonies to be accurately located. The photographs of each colony from both flights in 2016 were analysed by 3 independent and experienced assessors (RS, MB and PF). They distinguished between the following: (1) shags sitting horizontally on nests (thought to be either incubating eggs or brooding small chicks); (2) nests with one or more chicks clearly visible (with or without attendant adults); (3) birds standing upright by an empty nest, not incubating; and (4) those birds roosting away from nests. Nests with 2 birds close together (1 apparently incubating and the other standing) were counted as a single occupied nest. The results presented here focus on the first 2 of these 4 categories, considered to be active nests. The final number of active nests per colony is the mean of the counts made by the 3 photo assessors.

On the 21 June 2017, aerial photographs were taken of all known king shag nesting or roosting sites, also from a Cessna 180. The flight paths for 2017 were pre-set like in 2015. A Canon EOS 5DS r was used with a 50-mm lens operating with a shutter speed of 1/2500 sec, an aperture of f5.6 and ISO of 640. The camera was triggered using a predetermined flight plan (AeroScientific FlightPlanner®) via a GPS and AeroScientific Aviatrix® trigger box and associated Flight Management Software. Flight height above sea-level for the 2017 census was between 152–183 m. Aircraft speed varied between 70–90 knots and ground resolution between 1.3–1.5 cm (median = 1.5 cm). The analysis of the 2017 aerial photographs followed the same procedures used in 2016 except this was done by 2 assessors (RS and PF).

RESULTS

All aerial censuses of nesting king shags (6 June 2016, 1 July 2016 and 21 June 2017) were flown under ideal conditions, with light winds and clear skies.

Breeding season censuses 2016

The first 2016 census produced an estimate of 89 active nests, the highest and lowest counts per observer being 100 and 76 respectively (Table 1). The second 2016 census on 1 July gave a higher and more consistent estimate, with 117 active nests (observer range = 114–121), due largely to an increase in the numbers of active nests at the Duffers Reef colony, and small numbers of pairs now nesting on Sentinel Rock and Rahuinui (Table

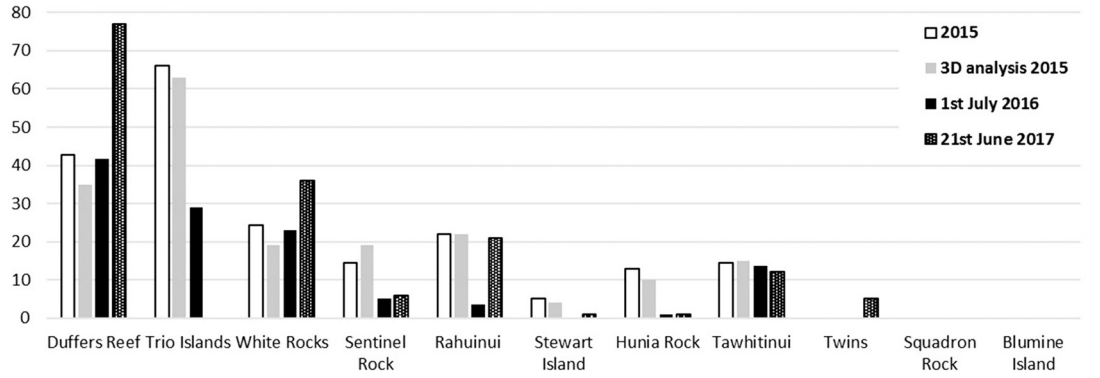

Fig. 2. Comparison of counts of active nests of king shags in 2015, 2016 and 2017 using different approaches: mean of 3 independent assessments of 2D photographs taken on 16 June 2015 (open bars); 3D analysis of stereo-photographs taken in 2015 to determine active nests (grey bars); mean of 3 independent assessments of photographs taken on 1 July 2016 (black bars); and mean of 2 independent assessments of photographs taken on 21 June 2017 (stippled bar).

1). The 2016 number of nests at Rahuinui, Stewart Island (Te kuru kuru), Trio Island, Sentinel Rock and Hunia Rock all declined compared with those recorded in 2015 (Fig. 2). This decline was substantial for Trio Island and Rahuinui, from 63 to 29 and 22 to 4 respectively. The number of active nests on Duffers Reef, Tawhitinui and White Rocks were similar to those recorded in 2015. No breeding was recorded on Stewart Island in either census in 2016 (Table 1).

Approximately 47 well-formed nests with empty nest bowls, together with the presence of non-incubating adults, was observed in 2016 at Duffers Reef, Trio Island, White Rocks and Rahuinui (Table 2). It is unknown if the empty nest bowls and non-incubating adults observed at Duffers Reef, Trio Island, White Rocks and Rahuinui in 2016 indicated further 'late breeding' or reflects early failures prior to our census.

Table 2. Counts of empty nests with 1 or 2 attending birds in July 2016

Locality	Attended Empty Nests
Duffers	21
Trio	7
White	12
Sentinel	0
Rahuinui	7
Stewart I.	0
Hunia	0
Tawhitinui	0
Totals	47

In 2016, survey aircraft disturbance of birds was recorded at 3 of the sites; Rahuinui, Stewart Island and Duffers Reef. At these colonies, photos indicated that some birds walked or flew off the nests, which was regarded as 'disturbance' (Nisbet 2000).

Breeding season census 2017

The 2017 census recorded 153 nests (observer range = 146–159; Table 1). White Rocks had the highest number of nests (n = 36) over the 3 years of surveys. Surprisingly, no breeding took place on Trio Island in 2017 (Table 1). By contrast, the breeding pairs on Duffers Reef almost doubled to 74. 2017 was the first year during this survey that king shag were recorded breeding on The Twins. Rahuinui and Tawhitinui had similar numbers compared with 2015 (Fig. 2). Sentinel Rock, Stewart Island, Hunia Rock continued to have low numbers of breeding pairs. Blumine Island and Squadron Rock were abandoned and no guano could be identified on the pictures otherwise revealing active roosting.

Variation among counts

To gauge variability between the assessors in relation to the mean, a coefficient of variation (CV)

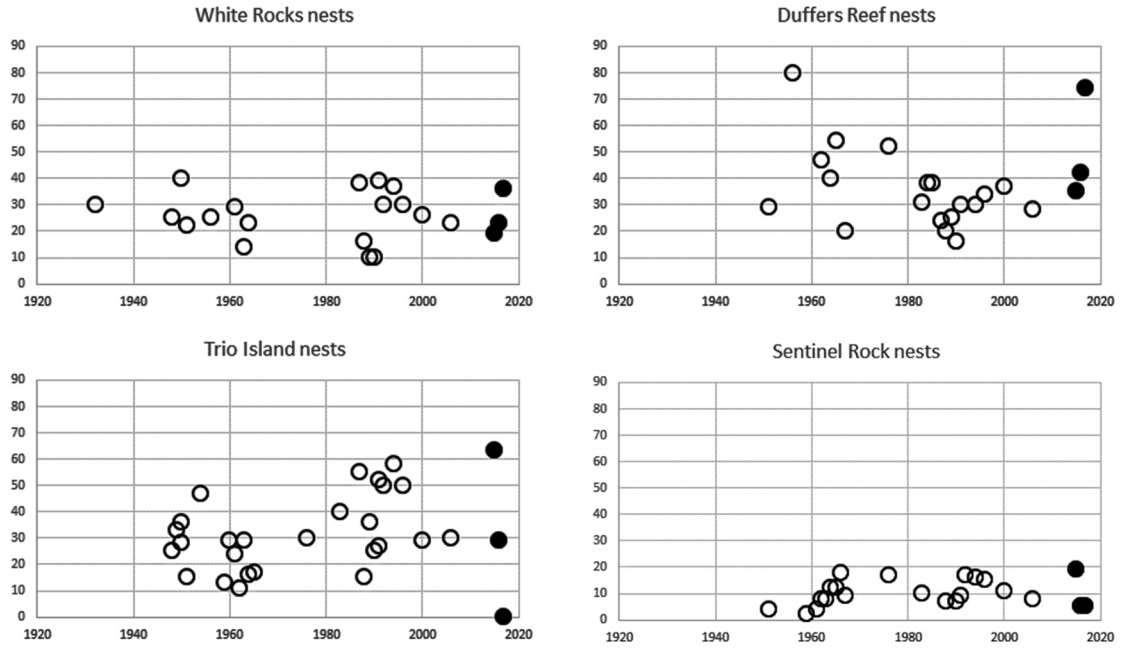

Fig. 3. Comparison of active nest counts of king shags in 2015, 2016 and 2017 (closed circles) with historic records (open circles) (Schuckard 2006).

was calculated. Variability among assessors was less for the second census in 2016 than for the first (overall coefficients of variation of 3.1% and 13.7% respectively: Table 1). For Trio Island, Duffers Reef and White Rocks (the 3 largest colonies), the range in coefficients of variation among observers was 10.6–33.0% in the June census, but only 0–6.9% in the July census (Table 1). Variation in 2017 was 6.0% overall, and 2.0–6.7 % for the 2 largest colonies (Trio Island did not have nesting birds).

Historical comparison of nesting king shags

The aerial census counts from 2015, 2016 and 2017 have been compared with the historical nest surveys of White Rocks, Duffers Reef, Sentinel Rock and Trio Island (Fig. 3 and 4), recorded since 1932 (Schuckard 2006). Whereas the methodology of counting nests in the past varied from nest counts made after landing, counts of nests while moored near the colony, to photographic analysis of pictures taken from a boat, the variation in nests recorded over the recent 3-year period, fits in the long-term annual nest variation since recording started. The only exception will be a lack of breeding birds on Trio Island in 2017, this has not been recorded before.

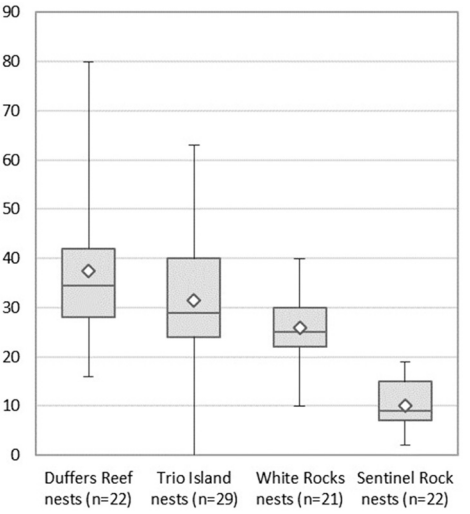

Fig. 4. Numbers of king shag nests from 4 long term surveyed colonies (1932–2017). The box-and-whisker plot shows the average (diamond shape) and median (black central line) values. The grey area encompasses the 25% and 75% quartiles of data, with the lower and upper 25% quartiles being represented by the upper and lower side 'whiskers'.

DISCUSSION

For breeding-pair censuses in particular, 3D images are considered to be the most accurate way to assess breeding stage and numbers of pairs, but they are also the most expensive technique (Schuckard *et al*. 2015). Compared with earlier multi-day boat censuses, the use of simpler 2D imagery during a 1-hour flight still substantially improves efficiency and accuracy in identifying and counting all nesting birds in the king shag population.

Flight heights in the 2015 census varied between 186–458 m above ground level, and no disturbance of the birds was reported by the pilot or was obvious when assessing the photographs (Schuckard *et al.* 2015). There was some evidence of limited flight disturbance of nesting birds at 3 colonies in 2016 but no disturbance was detected during the 2017.

In 2015, the fixed-wing plane followed a straight, pre-set flight path. Photographic equipment was triggered as waypoints were reached during the flight. The 2016 census flights involved using hand-held cameras and did not follow a pre-set flight trajectory. The 2017 king shag census flight used a camera mounted through the aircraft and photography was controlled by a pre-set computer programme in a set-up more like the 2015 census flight.

The 2016 nest census estimated 89 active nests in June and 117 nests in July. This difference suggests that not all pairs had started nesting in June, or that some birds were re-laying following an earlier nest failure. The increase in the number of occupied nests between the 2 censuses was greatest for Duffers Reef, growing from 17 to 42 nests. The number of nests at Rahuinui, Stewart Island, Trio Island, Sentinel Rock and Hunia Rock in 2016 all declined compared with counts recorded in 2015 (Fig. 2). This decline was substantial for Trio Island and Rahuinui, from 63 to 29 and 22 to 4 respectively. The number of active nests on Duffers Reef, Tawhitinui and White Rocks were similar to those recorded in 2015. In 2017, the total number of nests increased to 153 compared to 117 in July 2016 but was not as high as the 187 recorded in 2015. In 2017, no breeding took place on Trio Island. By contrast, the number of breeding pairs on Duffers Reef almost doubled to 74. Also, the White Rocks had the highest number of nests (36) over the 3 years of surveys. Rahuinui and Tawhitinui maintained or restored their numbers near to those recorded in 2015. For the first time, over the 3 years, the Twins had breeding King Shags on the rock. Sentinel Rock, Stewart Island, and Hunia Rock maintained a very low number of breeding individuals whereas Blumine Island and Squadron Rock were abandoned.

The nest counts in 2015, 2016 and 2017 were the mean of the counts of active nests made by the photo assessors. In 2015, a method using 3D imagery was also used for a comparison. The number of active nests recorded was 202 (2D imagery) and 187 (3D imagery) (Fig 2), a difference of 16 nests. It was decided that the 3D imagery was the most accurate. Independent from using the 3D or 2D results from the 2015 nest counts, the number of nests for both 2016 and 2017 is considerably lower compared to 2015.

Variation in the counts made by the different assessors from the June 2016 photographs was considerable, up to 50% in the case of Duffers Reef (estimates ranged from 11 to 22 nests). The variation among the 3 assessors was much less in the July 2016 census, and the variability in counts was more comparable with the counts made in the 2015. The biggest difference was at Duffers Reef with 77 and 70 nests counted. A disparity also emerged at Rahuinui, where 2 of the assessors recorded 4–6 nesting pairs visible in the photographs taken in July 2016, while the third noted only 1. This illustrates one of the difficulties of aerial photographic assessment, getting consistency among observers in their interpretation of birds that are actively nesting (i.e. incubating eggs or brooding chicks, or nests with 1 or more chicks visible, with or without an accompanying parent). In the case of Rahuinui, photographs taken during the first flypast showed up to 6 birds sitting on nests in ways that suggested they were incubating eggs. On the second flypast, however, the birds all stood up, with some moving to the edge of their nests. Close examination of 1 of the images showed that all the nests were empty, except 1, which contained an egg. Two of the assessors based their count on what was visible on the first pass, to be consistent with the counts made at other colonies, whereas the third assessor took the later information into account. The birds seen initially sitting on nests were clearly occupying nest sites, probably preparing to breed. It may be more appropriate to refer to the results of these censuses in terms of the number of 'Apparently Occupied Sites' (Baker *et al*. 2015), thereby making allowance for cases where birds may appear to be nesting but which cannot be determined accurately without disturbance.

It is unknown if the empty nest bowls and non-incubating adults observed at Duffers Reef, Trio Island, White Rocks and Rahuinui in 2016 indicated further 'late breeding' or suggests early failures prior to our census. No breeding was recorded on Stewart Island in either of the 2016 censuses and only 1 nest in 2017. This is in contrast with 2015 when 4–5 nests were recorded (Schuckard *et al*. 2015). The biggest difference in the 3-year data set is the absence of breeders on Trio Island in 2017. At the same time, breeders on Duffers Reef almost doubled and breeding on The Twins was recorded for the first time since September 2006 (Bell 2010).

Inter-annual, location-specific variations in breeding occupancy between colonies has not been recorded before in king shags. A widespread decline in breeding activity across all the colonies in a particular year might suggest some environmental change, but that does not seem to be the case here. A possible cause of this variation in breeding occupancy might be related to the presence of ticks (*Ixodes eudyptidis* and *Ornithodoros capensis*) in the shag nesting colonies. Tick infestations have been recorded in the past from Trio Island and Stewart (Te kuru kuru) Island (Nelson 1971). *Ixodes* ticks are also known from Stewart Island shag nests (Heath & Cane 2010) and various other New Zealand shag species (Heath *et al.* 2011). If there was a high incidence of ticks at king shag colonies, birds might abandon nesting attempts, possibly accounting for the absence of breeding on the Trio Island in 2017. Nest desertion as a result of high densities of argasid ticks *(Ornithodorus amblus)* has been recorded from a number of seabird species including Guanay Cormorants *(Phalacrocax bougainvilli)* (Duffy 1983; King *et al*. 1977). Where ticks can act as vectors to cause numerous diseases and even can result in the death of seabirds, the occurrence of seabird ticks in New Zealand seabird colonies is most common in spring and summer, outside the breeding period of king shag (Heath 2006). Assessment of the scale of tick infestation (and that of other ectoparasites), which could adversely affect king shag, is strongly recommended.

Weather events and the relative exposure of shag colonies to these might also play a role in the variation seen in breeding occupancy. In June 2015, 58% of nests on White Rock were lost, apparently because of an extreme weather event, in which southerly winds of up to 83 kph and waves >2.5 m coincided with a spring tide (Schuckard *et al.* 2015). Several storms of similar intensity occurred prior to the June 2016 census, but none coincided with a spring tide (Interislander Ferry *Aratere* bridge logbook 15 May 2016 - 6 June 2016). We have no evidence of a similar extreme weather event to that recorded in 2015 affecting the 2016 or the 2017 census.

The variation in nests recorded over the recent 3-year period of aerial surveys overlap considerably with the long-term variation since recording started in 1932 (Fig. 3). The annual variation in frequency of breeding but also breeding success and population changes are important parameters for future management of king shag. Current limited data collection from king shag colonies do not allow us as yet to correlate the number of nesting birds with environmental conditions. The current conservation assessment of the king shag lacks key information on important features (Taylor 2000) such as population structure, resilience to environmental changes and immunocompetence. To date, it has not been possible to link the fluctuations in the breeding activity to environmental conditions. In species such as Brandt's cormorant (*Phalacrocorax penicillatus*), survival and reproduction declines during warm-water years (including those associated with El Niño) occurred as a result of declines in fish abundance (Nur & Sydeman 1999).

In a changing marine environment, a relatively small, potentially stable number of king shags is not necessarily synonymous with a secure future for the species. Compared with past approaches, which relied largely on sporadic population assessments, annual aerial censuses of breeding birds will provide important information to improve on future management planning of king shag. But, as these censuses have shown, snapshot data can also be problematic, because of underlying intra- and inter-annual changes in the numbers of breeding pairs. Nevertheless, knowing that such changes do occur, particularly in the short term, emphasises the need for more research into the population dynamics of this species.

Our study suggests that aerial photography is a practical and probably more cost-effective method for censusing nesting king shags compared with traditional boat-based censuses. Disturbance from a plane flying at a constant speed and height around the colony creates less disturbance than boat or land-based counts, and is preferable for long-term population assessment. The presumption that birds on a nest are 'effective breeders' needs checking. Fixed time-lapse camera deployment on one or more colonies could alleviate these concerns considerably.

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