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New Zealand king shag (*Leucocarbo carunculatus*) foraging distribution and use of mussel farms in Admiralty Bay, Marlborough Sounds

PAUL R. FISHER*
27 Lud Valley Rd, Nelson 7071, New Zealand

LAURA J. BOREN
Department of Conservation, PO Box 10-420, Wellington 6143, New Zealand

Abstract To date there has been no published information describing the relative abundance, behaviour or distribution of the New Zealand king shag (*Leucocarbo carunculatus)* within mussel farm areas, despite the sensitivity of the species to human disturbance and the potential overlap of its range with proposed development of marine aquaculture. Four survey methods were employed as part of a multi-species research programme to develop methods for surveying marine mammals and seabird populations in aquaculture management areas. Two of the techniques, involving continuous time-lapse photography of mussel farms and boat-based surveys through coastal farms were developed for this study. Time-lapse cameras showed that mussel farms buoys were used by king shags as temporary resting sites only. King shags were recorded on 36% of the farms (n = 44) from 13 surveys within inner Admiralty Bay. The low number of sightings within mussel farms suggests that farms are not important foraging or resting areas for king shags, at least in Admiralty Bay. The foraging range and density of king shags was not known before farms were developed, so no direct comparison or impact assessment can be made. Boat-based surveys were used to estimate the density of foraging shags, which showed that daily locations of foraging birds at sea can vary considerably on consecutive days and over the season. Previous environmental surveys to assess impacts of mussel farms on foraging areas are therefore unlikely to adequately represent the entire foraging range or most important feeding areas. The number of breeding pairs, chicks and nests was also found to vary considerably at colonies, dependent on when counts were undertaken during their protracted breeding season. Open water mid-bay aquaculture (shellfish and finfish) potentially poses a greater threat to king shags than 'coastal ribbon development', in terms of loss of open water habitat from farm structures, and loss of foraging habitat through modification to the water column (*e.g.,* turbidity) and seabed. Given the lack of knowledge about the king shag population dynamics, diet and prey availability, there is an urgent requirement for more research to fill these gaps and also understand how we can conserve important shag feeding areas and associated marine environment through sustainable management of aquaculture.

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Keywords king shag; *Leucocarbo carunculatus;* mussel farm, aquaculture, survey method

INTRODUCTION

The New Zealand king shag (*Leucocarbo carunculatus)* is a Nationally Endangered (Miskelly *et al*., 2008) species that is endemic to the Marlborough Sounds area of the South Island. The conservation status of the species is of concern because of the lack of information describing its productivity, feeding ecology and habitat requirements across its range. More detailed studies of its breeding biology and simultaneous counts across colonies have not been undertaken mainly because of the remote location of breeding colonies, and the sensitivity of the species to human disturbance. A survey of the marine avifauna of the Marlborough Sounds undertaken between Sep to Dec 2006 estimated a

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*Correspondence: *wildlands.nelson@xtra.co.nz*

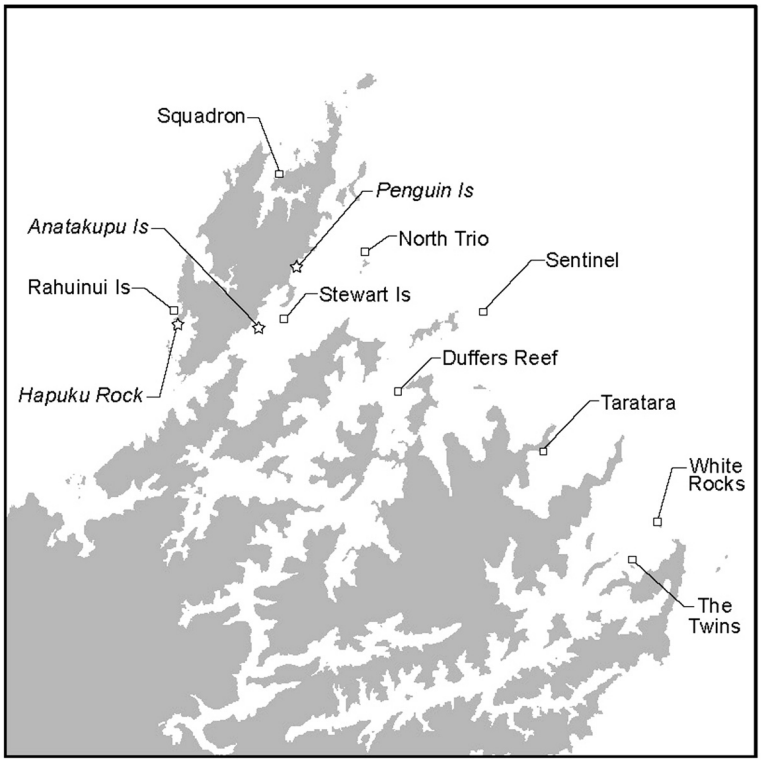

Fig. 1. Distribution of king shag breeding colonies (squares) after Bell (2010) and island roost sites (stars) identified during this study.

total adult king shag population of 687 birds (Bell 2010). A comparison of counts over a 10-year period (1992-2002) provided an average total population of 645 king shags, similar to historical records over the last 50-100 years (Schuckard 2006a).

The range of the king shag overlaps extensively with areas of marine farming. Areas used for marine farms are also used by shags for foraging and lie close to nesting and roosting areas but it is unclear what effect these activities might have on the species in the long-term. Preliminary studies have been published on their prey remains at Duffers Reef (Lalas and Brown 1998) and on colony attendance, breeding behaviour and foraging flight paths and distribution at the Duffers Reef and North Trio colonies (Schuckard 1994; 2006). There is no published information describing the relative abundance, behaviour or distribution of king shags in relation to mussel farms. To date, marine farm applications have assessed the relative impact of proposed mussel farms on king shag foraging areas and habitat requirements on a variety of unpublished sources, including site visits, reviews of available information, and the potential impacts from human activities based on the comparative ecology of other *Leucocarbo* shag species (expert evidence for Environment Court from Brown 2001; Lalas 2001).

The greatest intensity of mussel farming in New Zealand currently occurs in the Marlborough Sounds with ~900 consented Aquaculture Management Areas covering over 3,000 ha as coastal ribbon development. Reviews of possible effects (positive and negative) of mussel farms on king shags (Brown 2001; Butler 2003; Keeley *et al. 2009;* Lalas 2001; Lloyd 2003; Sagar 2011) have largely been based on anecdotal observations and best available information at the time.

This study was part of a multi-species Cross Departmental Research Programme to develop methods for surveying marine mammals and seabird populations in aquaculture management areas. Four methods were employed to investigate the effects of mussel farms on marine fauna. This paper describes the results of these methods for king shags along with a 5th method focusing specifically on king shags. The aim of this paper is to provide new information on king shag foraging distribution and presence within mussel farms, and to conduct a temporal comparison of king shag counts at local breeding colonies.

METHODS

Boat-based line transect surveys were used to systematically survey the distribution of king shags within Admiralty Bay and Current Basin (40° 50′-

40° 57′S, 173° 46′ - 173° 59′E), providing a temporal comparison to the distribution of foraging shags in this area from 2001-2002 (Schuckard 2006a). Boat-based coastal strip surveys through all the mussel farms within inner Admiralty Bay provided a measure of the number of king shags present, their behaviours and occupancy rates of farms. Land-based time lapse cameras over-looking 4 mussel farms were used to sample when king shags were present during daylight hours. Visual observations were undertaken at the same farms to estimate bird attendance times.

Boat-based line transect surveys

Line-transect surveys were employed to investigate the abundance and distribution of seabirds in the Admiralty Bay and Current Basin areas, from a 6 m rigid inflatable boat, the *MV Manaia.* Observations were made from a height of 2 m above the sea, travelling at 10 knots and recorded using a Sony® IC Recorder Dictaphone. Observers were stationed on the deck in front of the wheel house on port and starboard. Each observer surveyed a 90 degree sector from bow to beam and recorded all shags seen from the boat within their detection strip, which extended 200 m out from the boat's track (*i.e.,* the transect line). Birds could be on or above the water. Both observers had 7x50 (Nikon®) binoculars and laser range-finder (Bushnell®). The information recorded included the start and finish time, weather conditions, and for each sighting, the age class (see criteria below) and behaviour of each individual, the distance off the transect line (measured from the beam – side, or from the bow – front), and proximity to a mussel farm. Shag behaviour was assigned to one of the following modes: resting on mussel float, feeding on mussel float, swimming on surface, feeding on surface, foraging by surface diving, in flight, resting/roosting on land and feeding on land. Shags at sea were further categorised by location, between mussel lines, between farms, at sea within 200 m of the farm boundary, or at sea outside of farm (>200 m from farm boundary). Data were transcribed from the voice files using the Batsound® programme. The sonar, GPS track and environmental data were recorded for each leg of the survey. A randomisation programme was run each month to determine the start time, start vertex, direction and order that transects would be carried out. Surveys were carried out 3 times per month weather permitting, except Mar 2006, when 5 surveys were run. Data collection began in Feb 2006 and continued until Mar 2007, resulting in 38 surveys.

The geographic locations of king shag sightings were derived from the GPS boat survey track. Each sighting was allocated to a 600 x 600 m grid overlay of Admiralty Bay. The total number of animals sighted within each grid was then standardised by the amount of survey effort within the same grid (*i.e.,* number of surveys). Standardised sightings were then used to produce a hierarchical grid that demonstrated any gradients in density across the study area with ArcGIS Spatial Analyst (v9.3). Each grid estimate represents an expected density (number of birds per grid area) based on the standardised sighting data. As each grid was the same size, grid results are comparable across months, seasons and/or to previous density estimates. The grid size for density calculations was also set at 600 m x 600 m (0.36 km^2 grid) as it represents the approximate viewing area of observers from the boat at any given time. The search radius of the density kernel was fixed at 1 km to ensure the final density estimate for any particular grid was only influenced by nearby sightings on the same transect or nearby transects. This radius only overlapped other transects around shoreline turning points and within the Current Basin where transects were spaced closer together. The overall spatial extent of the density analyses was limited to the survey area in order to confine any density interpolation to the actual area surveyed. Density data were analysed by date, behaviour and medium (*i.e.*, sighted on land vs water). It should be noted that no correction has been made for potentially missed birds and that data are interpolated. The available grids (total area = 106.26 km^2) were those that fell within 1 km of any transect line, so do not represent exactly where birds were seen.

Boat-based coastal mussel farm observations-Inner Admiralty

Boat-based surveys of seabirds within coastal mussel farms were undertaken in inner Admiralty Bay (IAB) to compare with land-based observations. During boat surveys one observer stood on the front of the boat while the skipper navigated 2 transect lines of ~5 nautical miles each at a speed of 5 knots and staying ~150 m from shore where possible. The 1st transect started at Clayface Point on the western side of IAB and ended in Elsie Bay after traversing through 18 mussel farms. The 2nd transect ran from Kokowhai Bay on the eastern side of IAB and ended in Elsie Bay and traversed through 26 mussel farms. The direction of the transect was considered "forward" if running north to south, and "reverse" vice versa. Start points and direction of the surveys were alternated. The mussel farms were numbered 1 to 44 starting from Clayface Point and ending at Kokowhai Bay (Fig. 2).

The GPS track and entry-exit times for each mussel farm were logged to describe the vessel's track. Environmental information was recorded using a Dictaphone including the start and finish time, weather conditions, the farm number and

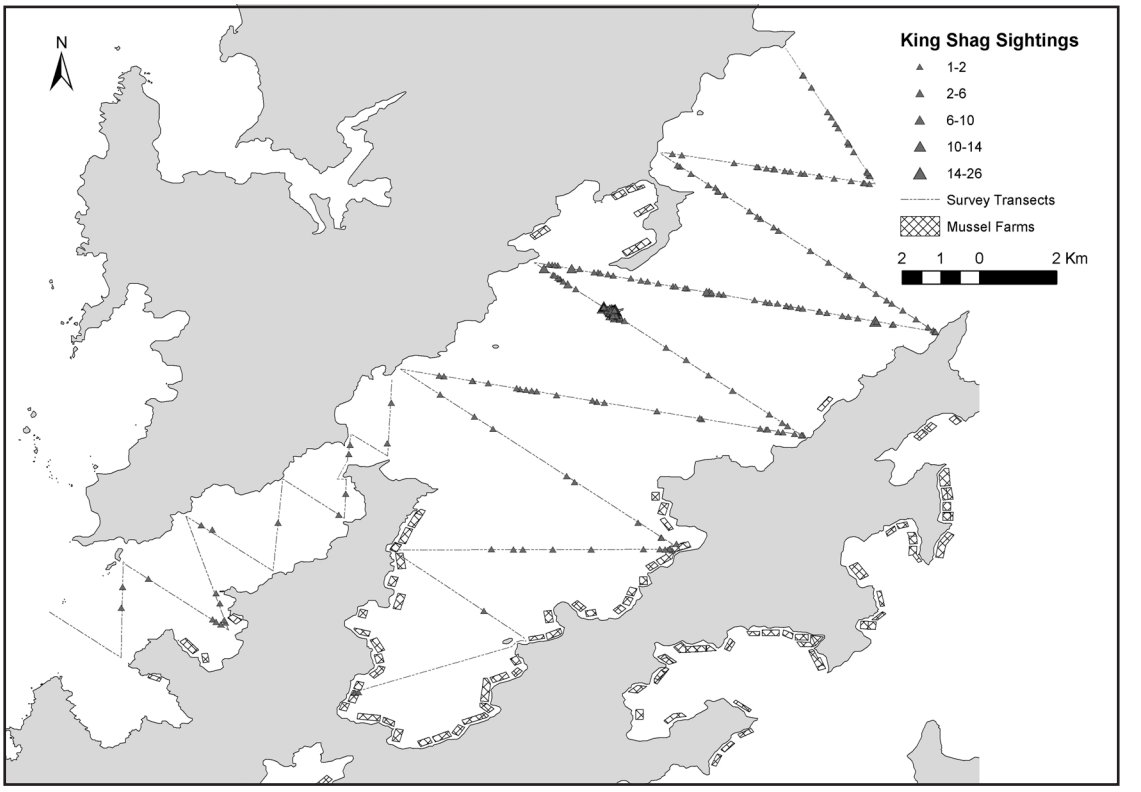

Fig. 2. Distribution of king shag sightings from boat-based line transects, Feb 2006 to Mar 2007 (n = 38 surveys of Admiralty Bay and Current Basin).

presence or absence of shags. The data, including the number, behaviour of shags and location with respect to farm, were analysed using the same criteria for boat based line transects. A total of 13 surveys were carried out, 1 in Nov, and 3 per month from Dec through Mar.

Time lapse photography – Inner Admiralty

Time lapse digital photographs of mussel farms were taken using a Canon Powershot S3 camera with 12x optical zoom and 6 megapixel resolution. Six cameras were placed on hills overlooking mussel farms 1 to 4 (Fig. 2) screwed to warratahs with a ball-joint tripod head and housed in a plastic box with removable lid. Initially, photos were taken at each site to assess the level of zoom to be used in order to maximise the number of mussel floats in the frame while still being able to identify species present. Once the desired image was found this was printed and laminated and used every time the cameras were deployed in order to set up the camera at the same settings. To make camera set-up faster, a distinctive float (*e.g.*, corner position or different colour) was included in the frame. The "Program" setting of the cameras was used and the "Intervalometer" feature was set to take an image once every hour to a maximum of 100 (Oct-Nov 2006) which resulted in 4 day sessions. From Dec 2006 to Mar 2007, the cameras were programmed to take an image every 30 minutes to a maximum of 100, resulting in 2 day sessions. The images were downloaded at the end of every session and data describing environmental conditions, image capture time, number of occupied buoys and species were transcribed and managed in Microsoft Access. A total of 3779 images were collected in 41 days, over 6 months (Oct - Mar). These images were taken between 6 cameras, on 4 different farms.

Land based observations – Inner Admiralty

Land-based observations were undertaken to determine the mean length of time birds spent on mussel floats. This involved an observer with a pair of 7x50 binoculars (Nikon®) sitting on the hill above a mussel farm for 90-120 minutes or until light was no longer adequate for observing. This was carried out on 5 occasions between Dec and Feb and resulted in observations on 89 birds at mussel farms 1, 2 and 3. Upon arrival, the number of birds present and number of mussel farms in view was recorded.

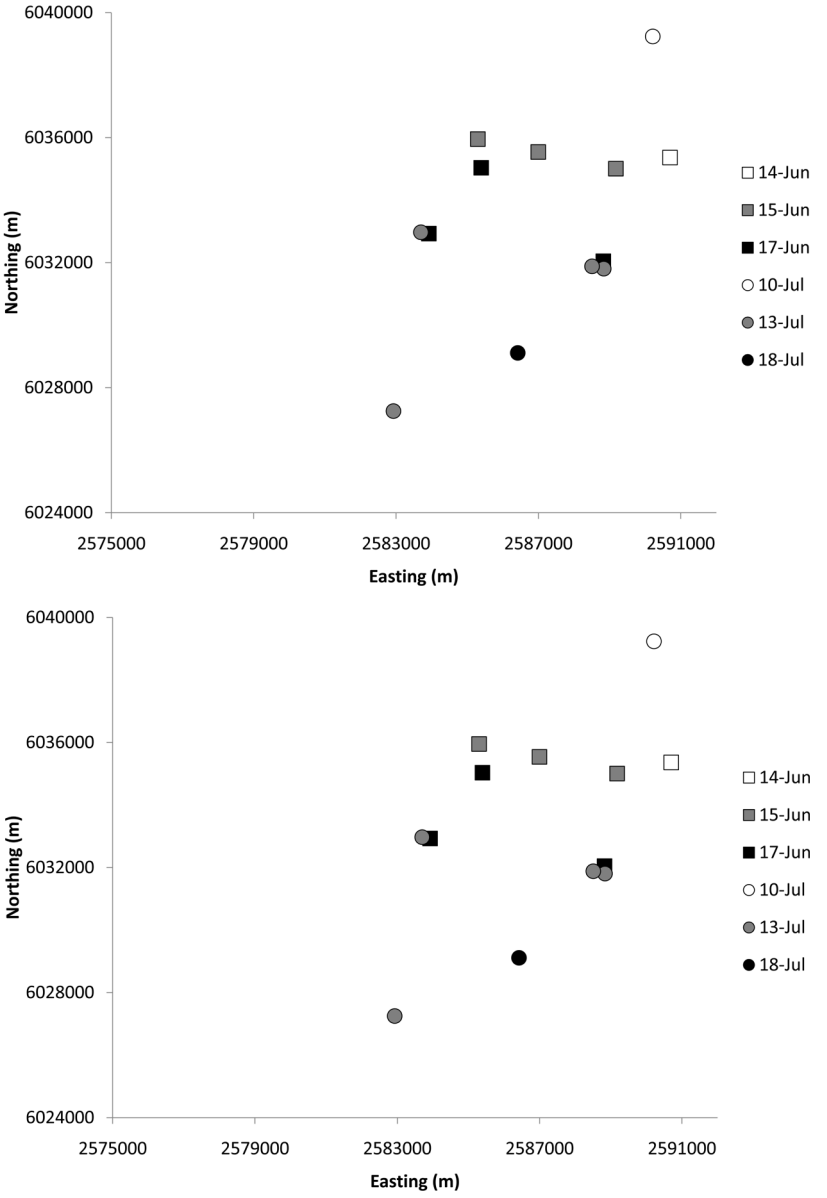

Fig. 3. Geographic locations of foraging king shags recorded from daily line transect surveys in June-July (breeding; upper figure) and January-February (non-breeding period; lower figure). The X-Y plots illustrate that shag foraging areas may change over short time scales (days) such that occasional surveys over several days are therefore unlikely to adequately represent the entire foraging range or most important areas.

Using all occurrences sampling (Altmann 1974) the time when a new individual arrived and when any individual left the mussel farm was recorded.

Survey of king shag breeding and roosting sites

Counts of king shags and their nests were undertaken from the boat using binoculars (Nelson 1971). A Canon® 5D digital camera with 100 mm lens was also used to take high resolution (12 Mp) photographs. The digital images were used to provide a record and to validate the visual counts of adults, chicks and recent fledglings from the 2006 winter and spring breeding attempts; and juvenile/subadult birds that fledged in 2005 breeding attempts. Chicks were distinguished by the presence of feather 'down' on the neck and head, with a pale gape or fresh dark remiges, (*i.e.*, nestling plumage). Recently fledged (<6 months from hatching) juvenile birds could be distinguished by absence of down and fresh dark brown plumage. Subadults were categorised as birds with worn or pale brown remiges that had fledged from the previous year. A nest was defined as a scrape with material, which varied in size and shape. Nests were located on or behind boulders and ledges or slopes of rock faces. A total nest count was undertaken, because it is

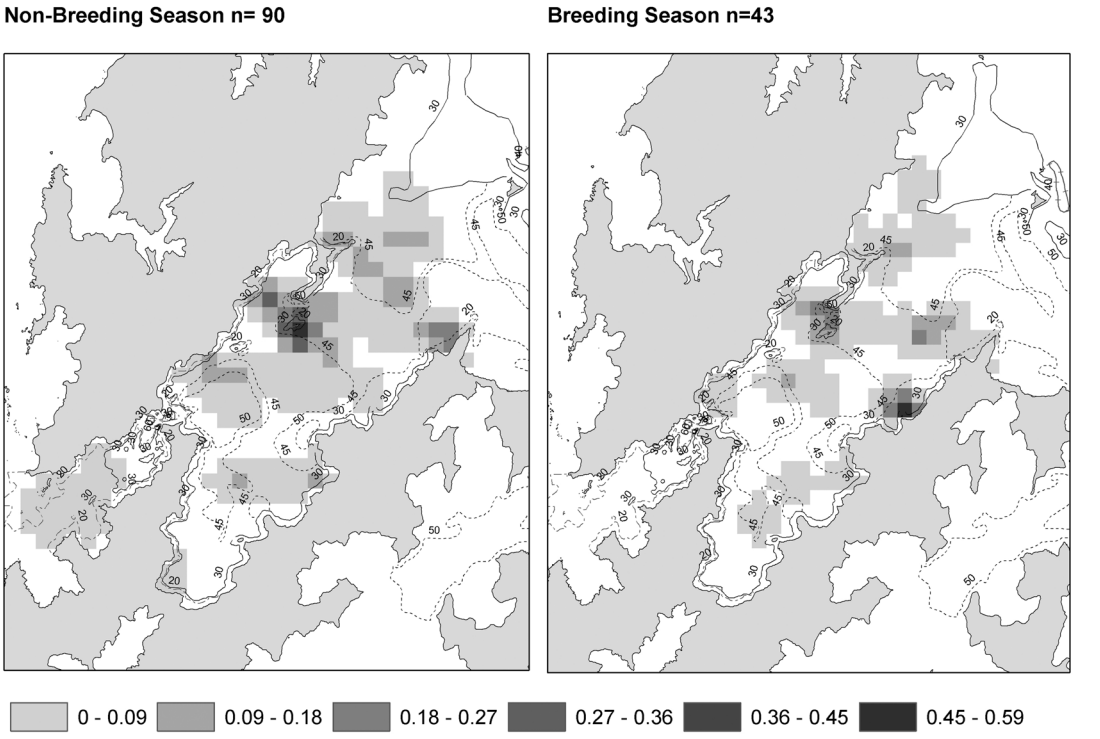

Fig. 4. Density of king shags foraging at sea plotted per 600 m^2 grid, standardised for effort.

difficult to distinguish whether nests were active, particularly when birds flew during our approach or were inactive nests from a previous breeding attempt. Occupied nests were distinguished by the presence of a bird standing, resting or displaying incubation behaviour. Chicks were observed in and close to nests. King shags observed on the main pinnacle of Stewart I, the southern cliff face and the 2 neighbouring islands of Anatakupu and Penguin were all considered the part of the Stewart I colony.

RESULTS

Boat-based line transect surveys

King shags (n = 267 sightings) were recorded on all line transects, except for the furthest south-west transect from Stewart I (and Trio Is) colony in Current Basin and inner Admiralty Bay (Fig. 2). Daily locations of foraging king shags at sea varied between consecutive days and by season (Fig. 3a, b).

Most sightings of king shags were in the outer Admiralty Bay between the Stewart I and Trio colonies. Sightings comprised of foraging individuals at sea (n = 131), in flight (n = 65), roosting on land at colonies (n = 63) and resting on mussel floats (n = 6) or foraging at sea within 200 m of the farm boundary (n = 2 sightings). No king shags were recorded between mussel farm lines. However, 2 sightings of king shags resting on mussel floats, were recorded from the mussel farm at the south-west bay of inner Admiralty Bay (MF15, Fig. 4).

The occurrence of shags sighted within 1 km of any transect line was quantified by the proportion of grids with a density > 0 birds/km^2. Foraging king shags (on sea surface) were recorded at a higher rate and density during the non-breeding season (n = 90 sightings, average density of 0.11 birds/km^2) and dispersed over a wider area (53.8% of available grids) compared to the breeding season (n = 43 sightings, 0.04 birds/km^2, 36.4% of available grids). The highest density of king shags was 0.36-0.59 sightings/survey grid (excluding colony-land sightings) off Reef Point, Clay Point and midway between Stewart I and Trio colonies and within 1 km of the Stewart I colony (Fig. 5). Water depths were generally between 30 and 45 m in these areas. No shags were recorded in Current Basin during the winter breeding season.

King shags were recorded at sea all hours of the day (0500-1900 hours) when surveys were undertaken. Most sightings (84%) were recorded between 1000 and 1600 hours when 66% of surveys were started.

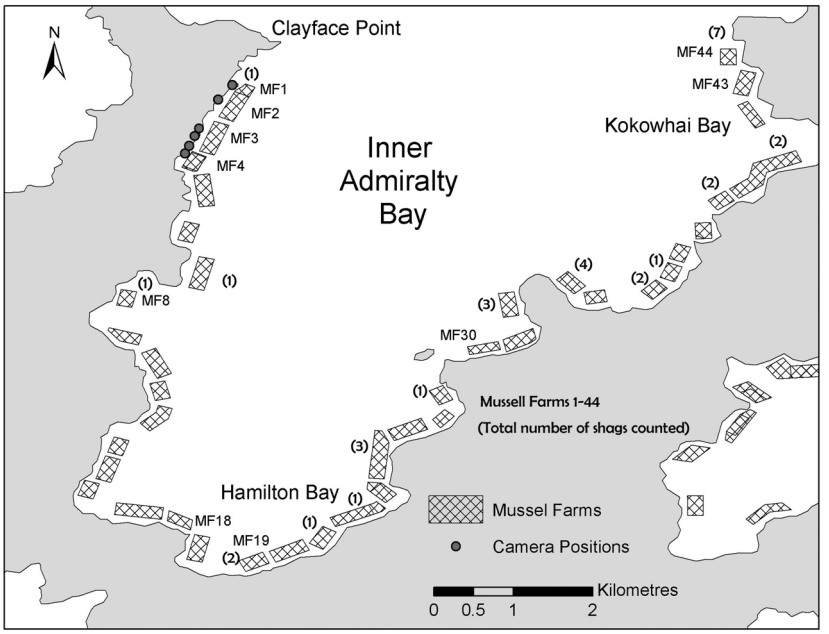

Fig. 5. Locations of mussel farms, camera positions and the total number of king shags (in parentheses) counted from the coastal boat survey through mussel farms 1-44 along the Inner Admiralty Bay coastline.

Boat-based coastal mussel farm observations-Inner Admiralty

Overall, king shags were observed on 16/44 farms within Inner Admiralty Bay, totaling 34 individuals from 13 surveys (birds present on 29/572 farms visited). The highest daily survey total was 6 birds on 4 farms (MF 32, 35, 42, 44) on 18 Jan 2007 (survey time 9:38-10:47 hours). All birds except one were resting/roosting. One bird was observed swimming on the surface, possibly to evade the survey vessel. None were observed foraging by surface diving. Birds disturbed by the survey vessel (n = 3) were observed flying ahead, and returning to farms when the survey vessel passed to the next farm.

Ninety percent of king shag sightings were on farms (numbers 19-44) along the south-east coast of inner Admiralty Bay between Elsie Bay and Kokowhai Bay (Fig. 4). All these farms were situated along a coast with a north-west aspect. Farm 44, Kokowhai Bay, had the highest total of king shags recorded (n = 7). No king shags were observed roosting on land adjacent to the farms.

Time lapse photography – Inner Admiralty

A total of 3,779 images provided a total 1,514 observations with birds present. King shags were recorded on 19 occasions, on mussel farm buoys (n = 18) and on the sea surface between lines (n = 1). King shags were not present between 0400 to 0700 and 1200 and 1300 hours, with most shags recorded at 1800 hours (n = 5, Fig. 6) pooling all data from 4 farms.

Land based observer method – Inner Admiralty

Three king shags were observed during the land-based watches over 89 hours. They were observed resting on mussel buoys for periods of 46 minutes (17 Dec 2006, 1800 to 2010 hours), and 23 and 19 minutes (22 Jan 2007, 1025 to 1200 hours). The latter 2 records could possibly be the same bird, returning after 30 minutes away (L Boren, *pers obs*.).

King shag colony counts

A dawn count at Stewart I and North Trio colonies on 12 Jan 2007 yielded 38 birds, including 4 subadults and 184 individuals including 10 subadults plus 3 chicks, respectively (Table 1). Counts at the 2 closest breeding colonies out of the Admiralty Bay study area yielded 45 individuals at Sentinel Rock (Chetwode Is) and 44 individuals including 4 subadults at Rahuinui (west D'Urville I) (not corrected for time of survey). The subadult birds at Rahuinui may have fledged in 2005 or 2006. There was no evidence of nests present. The winter Trio Is count on 19 Jun 2007 had 59 occupied nests and 4 chicks were observed.

The Stewart I colony was surveyed weekly, weather permitting. Three unoccupied nests were present when surveys commenced on 19 Apr. Breeding attempts included 6 nests occupied by May 2006, which were swept away in a storm on 23 May. Nest rebuilding commenced by 14 Jun with 7 nests occupied by 6 Sep 2006. Two chicks in separate nests hatched, 1 on 7 Oct 2006 and the other on 15 Oct 2006, but 1 was washed out by stormy seas during the 1st week of Nov and the remaining chick was not recorded after the 11 Dec 2006.

Table 1. King shag colony counts from this study. The total number of birds (adult and subadult) are provided for each colony visited to compare with Bell (2010). Adult counts in parentheses are corrected for time of day after Schukard (2006b).

This study	DOC 2006/7			Bell (2010)	Sep-Dec 2006		
Date	Adults	Chicks	Nests	Date	Adults	Chicks	Nests
Stewart I							
21/10/06 09:14	(25) 18	2	7				
13/11/06 08:46	37	1	0				
11/12/06 07:00	29	1	0[1]	2/12/06	(20) 8	1	1
12/01/07 06:05	38	0	0				
North Trio							
12/01/07 06:33	184	3	14	2/12/06	(220) 76	19	30
19/06/07 13:55	(258) 89	4	59				
Rahuinui I	44				(55) 22		
14/1/07 18:00[2]		0	0	7/10/06		7	8
Sentinel Rock	45				(35) 16		
12/1/07 08:09		0	0	3/10/06		6	8

[1] One new nest was under construction during the Bell survey of Stewart I and washed away 6 days later.
[2]Count by Danny Boulton
North Trio: The 13:55 count has been corrected 2.9x. Nest count of 14+ minimum estimate; count of 59 nests on 19/6/07 based on occupied nests.
Stewart Island: The 9:14 count has been corrected by 1.4x based on 40-75% birds absent between 10:00 and 14:00 (Schuckard 2006). Number of adults, chicks and nests are actual counts, numbers shown in parentheses are corrected for birds missing.

DISCUSSION

Overall, king shags were dispersed over a wider area and at a higher density during the non-breeding summer season. During this period, males and females feed simultaneously, in contrast to shared parental duties during breeding when one bird remains at the nest (Schuckard 1994). Seasonal variation in king shag foraging distribution may also reflect seasonal differences in prey densities and species, which should be considered when designing surveys for foraging birds. The distribution of sightings from boat-based line transect surveys were similar to the Admiralty Bay distribution observed by Schuckard (2006b; based on a composite of data from 1985-2002) with few king shags recorded at the southern end of inner Admiralty Bay or Current Basin. Furthermore, the king shag foraging distribution extends further north from this survey area, encompassing coastal areas adjacent to the mainland and the D'Urville I coast.

The line-transect survey is a repeatable method and counts/densities can be standardised for survey effort within a given area and compared between years, but has limited value in distinguishing where birds have originated and thus distinguishing between birds flying from the Trios, Stewart I and possibly roost sites around D'Urville I. A combination of survey methods using boats, focal observations of foraging king shags and simultaneous observations of their flight paths to and from colonies have provided a valuable insight into the distribution of foraging birds, broad scale habitat preferences, and estimates of foraging ranges (Schuckard 1994, 2006b). However, this approach requires a concerted effort over a wide geographic area. Remote tracking using VHF or satellite telemetry and temperature-depth loggers would complement what information is known and provide more detailed information describing foraging ranges and feeding ecology of individuals.

Brown (2001) reported that whilst the feeding zones identified by Schuckard's (1994) study on Duffers Reef highlighted areas that may be of importance to king shags, the zones cannot be seen as definitive as they have been created from a single 'snap-shot' study. Brown (2001) attempted to define the relative importance of a mussel farm application site at Forsyth Bay to king shags by making 4 repeat surveys between 20 Jan and 10 Mar 2000. Our 2006/7 study incorporated at least 3 repeat surveys every month, which showed that daily locations of foraging king shags at sea can vary considerably on consecutive days and over the season. Occasional surveys over several days are therefore unlikely to adequately represent the entire foraging range or most important areas. As surveys have not systematically covered the entire potential range of this species, their important foraging areas (zones with ≥3 foraging king shags within 1 km of each other) are likely to be much more extensive than identified in Davidson *et al*. (1995).

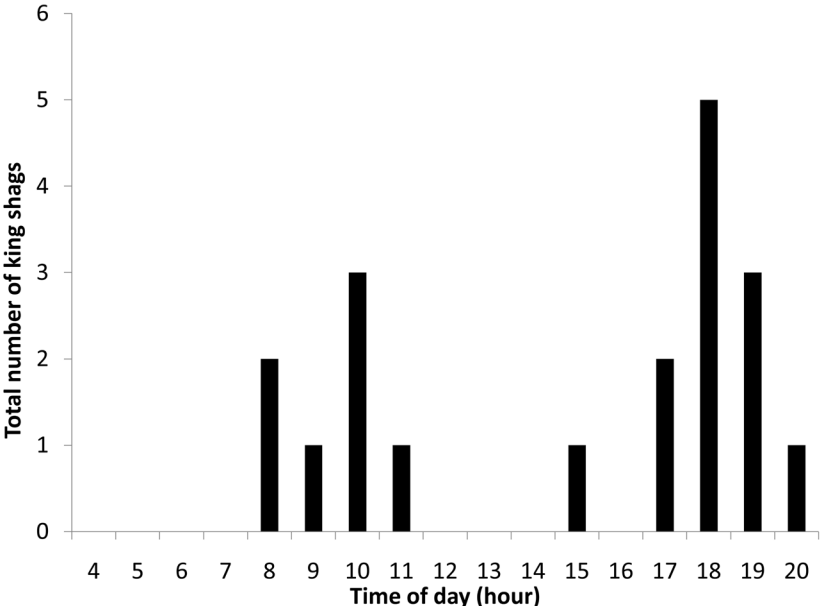

Fig. 6. Abundance king shags at 4 mussel farms during daylight hours from time-lapse cameras.

Brown (2001) re-analysed the foraging ranges from Schuckard (1994) and concluded that the feeding grounds closest to Duffers Reef were not the most important, based on the data available. Differences in diet associated with differences in foraging habitats have been documented for Stewart Island shags (*L. chalconotus*) and Chatham Island shags (*L. onslowi*), the 2 closest relatives to king shags (Lalas, 1983). The mean foraging distance for birds from the Duffers Reef colony was 8.2 km (SD ± 4.1 km, *n* = 219; Schuckard 1994; index of dispersion 2.1) and 9.96 km (no sample size given, SD ± 2.78 km, Schuckard 2006a; index of dispersion 0.8) from the Trio Is colony. Repeat surveys of shag foraging ranges from Duffers Reef and the Trios Is are required to compare foraging ranges over time and provide important information to help explain changes in colony size and productivity and indicate potential changes in the availability of prey and foraging areas.

King shags were recorded on 36% of the farms (*n* = 44) from 13 surveys within inner Admiralty Bay. No individuals were recorded foraging between farm lines from any of the survey methods. The low number of sightings within mussel farms suggests that farms are not important foraging areas for king shags, at least in Admiralty Bay. However, this may vary by site, prey availability and distance from colony/roost. Sightings of king shags foraging within mussel farms (Brown 2001, *n* = 6 sightings; Lalas 2001, *n* = 2 sightings, May 2000 and Jun 2001, respectively) show that mussel farms do not preclude king shags. However, the low number of reported sightings and lack of published data would suggest that king shags do not exclusively use the areas occupied by mussel farms.

Ninety-percent of king shag sightings (*n* = 29) from coastal mussel farm surveys in Admiralty Bay were on farms along the south-east coast between Elsie Bay and Kokowhai Bay, with a north-west aspect; the highest total count of 7 king shags was at Kokowhai Bay. Schuckard (2006a) noted that the geographical location and orientation of the larger colonies are south facing, and feeding areas tend to be to the south (downwind of colony); which may be due to the energetic gains from a prevailing tail wind for the return trip by birds carrying heavy loads of prey (Spear & Ainley 1997).

Most sightings of foraging king shags at sea were between 1000 and 1600 hours. In contrast, most king shags photographed resting on mussel buoys were made at 1800 hours, and presumably were birds resting prior to returning to colonies. No king shags were recorded on mussel buoys at first light from time lapse photography and when present during the day only remained for short periods (up to 46 minutes). This behaviour is indicative of birds using mussel buoys as 'temporary' roost sites for possibly feeding and digesting prey, preening and resting. Mussel farm structures undoubtedly provide safe roosting sites for birds and in some instances are important 'alternative' feeding habitats for some avifauna. However, the importance of mussel farms as foraging sites for king shags or alternative roosting sites to land reported by Brown (2001) was not substantiated by this study. Roycroft *et al.* (2007) found that whilst seabird densities increased within mussel farm areas, diving duration and foraging

success for seabirds did not differ between mussel and control sites. The time-lapse photographic survey of farms provided a cost effective alternative method of sampling seabird occupancy at mussel farms over weeks or months. The method is complimented by the use of focal scans to record seabird behaviours and the return rate of birds.

The colony counts using visual and digital photography from this study provide some context to the survey used to estimate the 2006 population (Bell 2010). Comparing the counts of nests between this study and the population survey, the number of nests counted declined significantly from Oct through to Jan over the main survey period. Nests are temporary structures; nests counted in Oct 2006 at North Trio, Stewart I, Rahuinui I and Sentinel Rock were absent in Jan 2007. Given that nest sites are temporary, and that survey dates vary across years it is possible that historical 'roost sites' such as Hapuku Rock, and more recent roost sites Anatakupu and Penguin Is are all potential breeding sites.

Population counts undertaken late in the breeding season (Sep to Dec) reflect the number of adults and juveniles (subadults and recent fledglings) but do not account for number of breeding attempts. Such data are required to determine productivity and survivorship. Counts from this survey and previous surveys (Nelson 1971) indicate that a small proportion of pairs hatch young in spring and summer months and so winter counts of brown subadults can also represent recruitment from a later breeding cycle. The number of adults present is subject to time of day, with up to 75% of birds foraging away from the colony at mid-day (Schuckard, 1994). However, the relationship between birds vs time of day may not be consistent across colonies or between years. Future population surveys should attempt to visit the breeding colonies on the same day using 4 survey crews. Nest counts can be subjective, difficult to define, particularly in early morning under poor light conditions, and some nests are not readily visible at large colonies (*e.g.*, Trios Is) obscured by birds and ledges. Photographs of colonies at midday when fewer birds are present could be useful to record nest counts and locations and reviewed to confirm the number and age of nestlings/fledglings.

King shags nest in colonies close to productive marine ecosystems and actively forage for demersal fish prey by visual cues. Nests are constructed on relatively inaccessible, exposed ledges on small islands or pinnacles, presumably as an adaption to avoid predators and disturbance but this may also limit the number of nest site opportunities available close to feeding areas. To date mussel farm development in the Marlborough Sounds has been developed along a 'coastal ribbon'. The foraging range and density of king shags was not known before farms were developed, so no direct comparison or impact assessment can be made. Whilst mussel farms are sited away from breeding colonies and appear to have no appreciable direct impact, cumulative effects from habitat modification, alteration of habitat suitability for fish below the farm and wider area, and potential changes in marine species assemblages need to be considered (Keeley *et al*., 2009; Morrisey *et al*., 2006). The zone of effects is largely dependent on the flushing of farms and their proximity to each other. Open water mid-bay aquaculture (shellfish and finfish) potentially poses a greater threat to king shags, in terms of loss of open water habitat from farm structures, and loss of foraging habitat through modification to the water column (*e.g.,* turbidity) and seabed.

Given the lack of knowledge about king shag population dynamics and the potential cumulative effects of aquaculture development on this species and their prey availability, 2 research paths are recommended: (i) to monitor king shag population trends, by undertaking more intensive surveys of breeding attempts, studies of nest site tenacity and movement of birds between colonies; and (ii) undertake fisheries research, to further investigate the king shag diet (prey preferences and foraging profiles), prey habitat requirements and availability (spawning habitat and juvenile recruitment), and repeat surveys to identify important foraging areas for all colonies. Future aquaculture development in the Marlborough Sounds should follow a staged development approach, that incorporates an impact assessment (*e.g.,* Before After Control Impact design) to better understand the carrying capacity of the environment and work toward sustainable management of aquaculture.

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