

Foraging locations of female New Zealand sea lions (*Phocarctos hookeri*) from a declining colony

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Abstract: Figure of Eight Island is located in the southern end of the Auckland Islands and hosts the smallest breeding colony of New Zealand (NZ) sea lions (*Phocarctos hookeri*). Between 1995/96 and 2005/06, pup production in this colony decreased by 57% (from 144 to 62 pups). In contrast, there was a 30% decrease in pup production in the largest colony in the north-east of the Auckland Islands over the same period. NZ sea lions in the Auckland Islands area are subject to by-catch deaths and resource competition from subantarctic trawl fisheries. The present study investigated where four lactating females from Figure of Eight Island foraged during the austral summer of 2007/08 and compared their foraging areas with female NZ sea lions from the northern Auckland Islands breeding locations (Enderby and Dundas islands) and with fisheries activities. Females foraged south of Adams Island (the southernmost Auckland Island), predominantly at the edge of the Auckland Islands shelf, but those from Figure of Eight Island made shorter foraging trips within more concentrated areas than females from Enderby or Dundas islands. The 59 female NZ sea lions satellite-tracked to date from Figure of Eight, Enderby and Dundas islands foraged over the entire area of the Auckland Islands shelf and many (including three of the four females from Figure of Eight Island) had extensive overlap with subantarctic trawl fisheries. Further research is needed to determine whether the foraging behaviour of females from Figure of Eight Island is linked to their greater decline in pup production.

Keywords: fisheries interactions; foraging ecology; management

Introduction

The New Zealand (NZ) sea lion (*Phocarctos hookeri*) is one of the world's rarest otariids (eared seals) and has a declining population; it is classified as 'Vulnerable' in decline by the International Union for the Conservation of Nature (IUCN 2008) and 'Threatened' under the New Zealand Threat Classification System, as a result of its restricted distribution and number of breeding locations (Hitchmough et al. 2007). NZ sea lions breed on Auckland and Campbell/Motu Ihupuku islands in the New Zealand subantarctic between latitudes 48°S and 53°S (Gales & Mattlin 1997; Chilvers et al. 2007). Pup production of NZ sea lions at the Auckland Islands (86% of the species) has shown a 30% decline in the last 10 years (Campbell et al. 2006; Chilvers et al. 2007).

Figure of Eight Island, an uninhabited 4-ha island in the north-west arm of Carnley Harbour, Auckland Islands (50° 46'S, 166° 01'E; Fig. 1), hosts the smallest breeding colony of NZ sea lions. This colony annually produces approximately 3% of this threatened species' pups, but showed a 57% decrease in pup production between 1995/96 (144 pups) and 2005/06 (62 pups)

(Chilvers et al. 2007). New Zealand sea lions in the Auckland Islands area are subject to by-catch deaths and possible resource competition from subantarctic trawl fisheries, predominantly those which target arrow squid (*Nototodarus gouldi*) and scampi (*Metanephrops challengeri*) (Chilvers 2008a). Therefore, one hypothesis is that breeding females from the Figure of Eight Island colony may be disproportionately affected by this activity, resulting in the observed decline in pup production at this colony (Chilvers et al. 2007).

The aim of the present research was to identify where lactating females from Figure of Eight Island forage and to determine their overlap with: (1) female NZ sea lions from the other breeding locations, Enderby and Dundas islands, which have been studied previously (Chilvers et al. 2005a, unpubl. data), and (2) fisheries activities. Female NZ sea lions show high site fidelity to foraging locations both within and between years (Chilvers 2008b). Therefore, by gaining an understanding of the foraging habitat and partitioning of resources between the breeding islands, it will be possible to identify where foraging areas of breeding females and the activities of the trawl fishery overlap, and potential management implications of this.

Methods

Study site, captures and instrumentation

Satellite data were collected from four lactating NZ sea lions from Figure of Eight Island, Carnley Harbour, Auckland Islands, from January to April (the NZ sea lion breeding season) 2008. Female NZ sea lions seen suckling a pup were captured using a specially designed hoop net and were physically restrained by two handlers. They were then anaesthetised, using isoflurane delivered with oxygen to a mask via a field-portable vaporiser, a methodology that has been routinely applied to pinnipeds including over 1000 NZ sea lions (Gales & Mattlin 1998; Childerhouse et al. 2004; Chilvers et al. 2005a). Satellite-linked platform transmitting terminals (PTTs) (Telonics 300 mW ST6, potted in epoxy, 130 × 35 × 15 mm, 175 g, Telonics Mesa, Arizona, USA) were attached to a piece of neoprene material (Gales & Mattlin 1997), which was then glued to the female's dorsal hair on her upper back using two-part epoxy glue. Once the instrument was secure (8–10 min after glue application), the flow of anaesthetic was stopped and the animal was allowed to recover and return to her pup. Following restraint, each animal was observed until it was fully conscious and had returned to the group or location where it had been captured. Satellite tags were programmed to work continuously, but were fitted with salt-water and wet-dry switches to ensure that transmission only occurred when animals were at sea.

Locations

At-sea locations were obtained with reference to three satellites and were assigned to six classes by Argos (CLS, Toulouse, France) on the basis of their accuracy. Locations were filtered using the iterative forward/backward speed-averaging filter that removes locations requiring swimming speeds greater than 2 m s⁻¹ and would require an unrealistic rate of travel (McConnell et al. 1992; Crocker et al. 2001; Chilvers et al. 2005a; Chilvers 2008b). Since NZ sea lions dive almost continuously while at sea (Gales & Mattlin 1997; Chilvers et al. 2006), all trips and filtered satellite locations were assumed to be part of a foraging trip and thus to represent foraging locations.

Filtered locations were used to estimate distance from Figure of Eight Island and distance travelled. Total distances travelled were calculated from all filtered locations and are given to the nearest 1 km. Kernel density plots of home ranges (kernel range (KR); Worton 1989) for 50% and 65% of all locations per animal were determined using the Animal Movement Extension of ARCVIEW (Hooge et al. 2000). KR figures were calculated using smoothing factors calculated via least-square cross-validation (Seaman & Powell 1996). These KR plots show the foraging range and thus the areas where foraging occurred (Chilvers et al. 2005a).

All trip variables derived from location data were analysed using Microsoft Office Excel 2003, SPSS 2004 and ARCVIEW© 1998 (ESRI Inc., Redlands, California, USA). Variation between individuals and in trip variables between breeding islands were analysed using one-way ANOVA and post-hoc Tukey's b tests. All fisheries operational location data and NZ sea lion by-catch data were supplied by the Information Management Group of the Ministry of Fisheries, New Zealand. Fisheries data represent all start/stop locations for trawls undertaken between 2001 and 2007. Kernel ranges representing 50% and 95% of all trawler activity were determined to show areas of highest activity. These ranges were calculated as for the foraging KR areas.

Results

The four females from Figure of Eight Island yielded 1677 filtered locations, with equipment deployed or active for 14–45 days per female. Fifty complete foraging trips, each lasting 2–5 days, were identified. The number of days over which equipment was deployed, foraging trip distances, kernel range (KR) sizes and mean straight line distances from the colony to the centre of foraging areas for each female are shown in Table 1.

The four females foraged at variable distances from Figure of Eight Island, with the maximum distance (mean ± SE) from the colony averaging 45 ± 4.5 km (range = 35–55 km) and total trip distance averaging 214 ± 17.9 km (range = 177–259 km). Kernel range (KR) sizes also showed high variability between individuals, with mean areas of 118 ± 35.6 km² for 50% KR and 207 ± 57.8 km² for 65% KR (Table 1). All females had concentrated foraging areas (50% KR = ~200 km²) (Table 1). Females travelled a mean distance of 25 ± 6.2 km from the colony to the centre of their 50% KR.

Examination of areas used during foraging trips showed that breeding females from Figure of Eight Island forage principally south of Adams Island (Fig. 1) at the edge of the Auckland Islands shelf (Fig. 2a).

Comparison with females from Dundas and Enderby islands

Significant differences in foraging trip parameters were found between the three breeding islands (Table 1). Females from Figure of Eight Island undertook shorter foraging trips over significantly more concentrated areas (KR) than females from the other islands (Table 1). Only KR sizes from Figure of Eight and Enderby islands were comparable as they were derived from more than one foraging trip (Table 1; Chilvers et al. 2005a). The KR sizes for Dundas Island females were based mainly on a single foraging trip (unpubl. data).

Table 1. Number of days instrumentation was deployed, foraging trip distances, kernel range (KR) sizes and mean straight line distances from colony to centre of foraging trips for four lactating NZ sea lions from Figure of Eight Island, Auckland Islands, 2007/08. Means presented ± SE.

Sea lion identification	No. days deployed	Total no. locations	No. of trips	Trip distance (km)	Max. distance from colony (km)	50% KR (km ²)	65% KR (km ²)	Distance from colony to centre KR (km)
1	24	206	10	177 ± 19.6	40	221	369	25
2	45	601	18	259 ± 12.6	55	101	205	33
3	43	585	16	194 ± 13.6	50	90	147	35
4	14	285	6	224 ± 39.7	35	58	106	8
Figure of Eight means				214 ± 17.9 ^a	45 ± 4.5 ^a	118 ± 35.6	207 ± 57.8	25 ± 6.2 ^a
Enderby means*				423 ± 43.9 ^c	102 ± 7.7 ^b	378 ± 80.5	643 ± 131.1	64 ± 6.5 ^b
Dundas means†				302 ± 21.5 ^b	87 ± 5.3 ^b	691 ± 84.2	1213 ± 139.2	74 ± 5.2 ^b
Statistical differences				$P = 0.01$ $F_{(2,55)} = 4.9^+$	$P = 0.005$ $F_{(2,56)} = 5.7$	n.s.‡	n.s.‡	$P = 0.01$ $F_{(2,55)} = 4.9^+$

^{a,b,c}Tukey's b post-hoc test results.

*From Chilvers et al. (2005a).

†Unpubl. data.

‡KR sizes were only compared between Enderby and Figure of Eight islands (see text for details). n.s. = not significant.

+The number of females included in this test is one less than for max. distance from colony because trip distance and mean distance from colony to centre of KR could not be determined for one of the females from Dundas Island (unpubl. data).

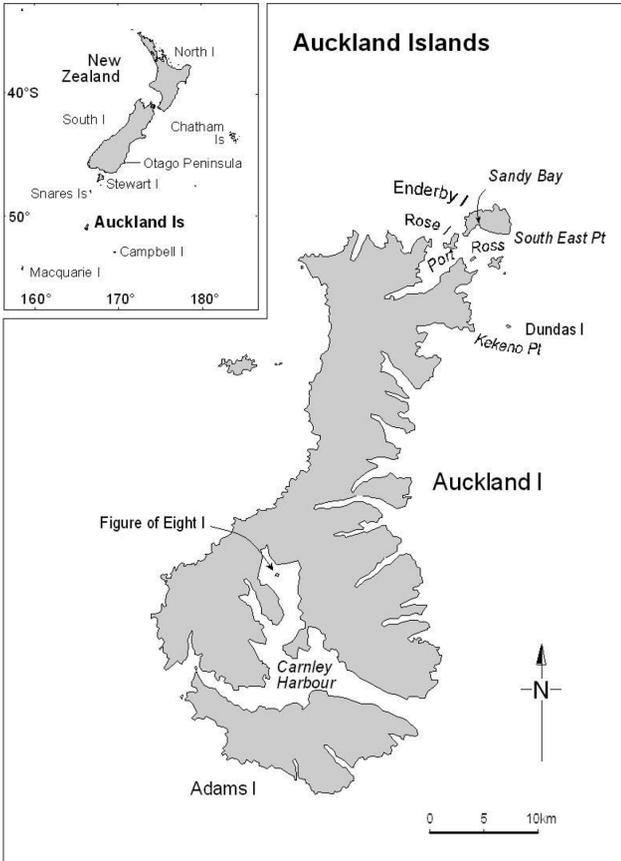


Figure 1. Auckland Islands showing the main breeding islands for NZ sea lions: Enderby, Dundas and Figure of Eight. Inset: New Zealand's subantarctic area.

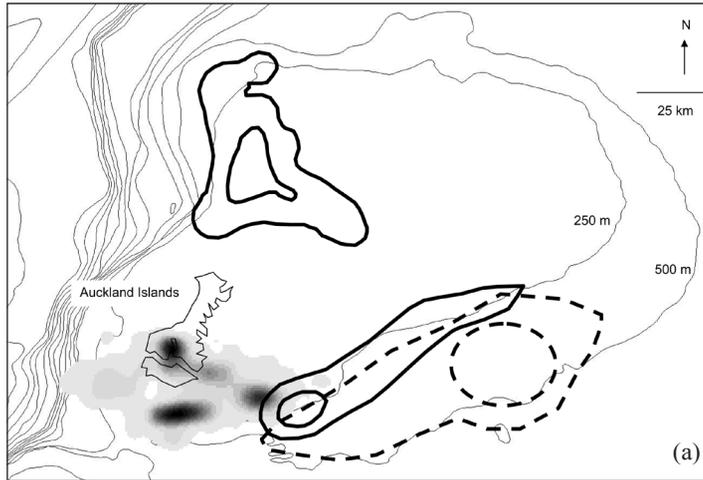
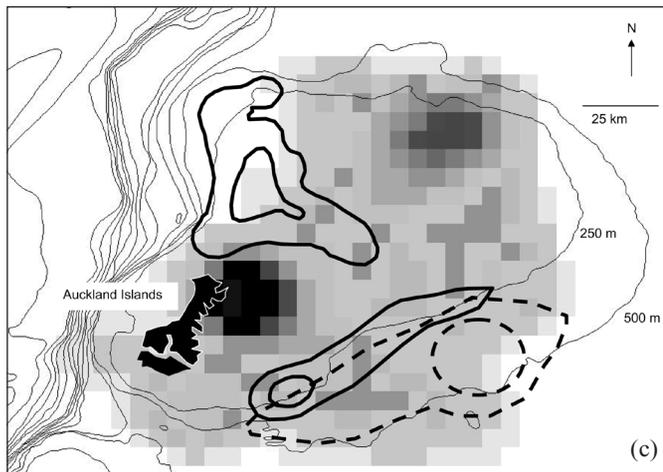
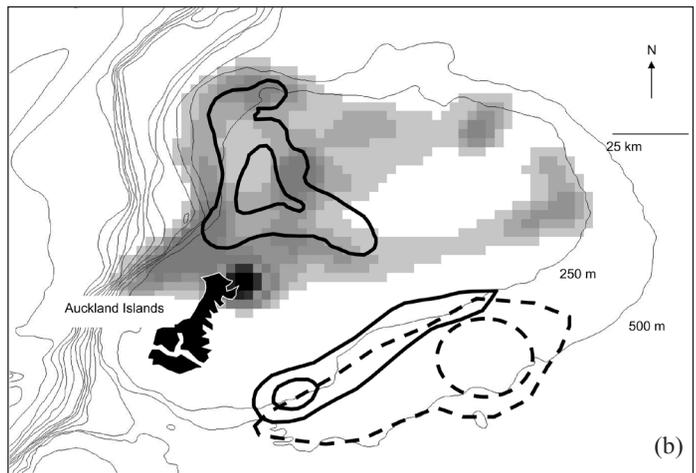


Figure 2. Kernel range of all filtered satellite locations for lactating NZ sea lions from (a) Figure of Eight Island, January and February 2007 and 2008 ($n = 4$); (b) Enderby Island, January and February 2001–2004 ($n = 26$); (c) Dundas Island January and February 2005–2007 ($n = 29$). Intensity of shading of kernel ranges represents percentage of time spent in the area displayed as highest concentration of locations (darkest) to lowest concentration (lightest). Bathymetric contours are shown as thin black lines, with the Auckland Islands Shelf represented by the 500-m bathymetric boundary. Arrow squid *Nototodarus gouldi* trawl fishery effort (50% and 95% kernel ranges 2001–2007) is represented by thick black solid lines, and scampi *Metanephrops challengeri* trawl fishery effort (50% and 95% kernel ranges 2001–2007) is represented by thick black dashed lines.



The foraging areas of Figure of Eight Island females did not overlap with those of Enderby Island females (minimum swimming distance between colonies 68 km; Fig. 1); however, they had extensive overlap with the foraging areas of some females from Dundas Island (minimum swimming distance between colonies 58 km; Figs 1, 2a, b & c).

Fishery interactions

Figure 2a shows satellite locations of the four female NZ sea lions from Figure of Eight Island and the squid and scampi fishery trawl start/stop locations from 2001 to 2007. For the squid trawl fishery, two fishing areas predominated: one lay north/north-west of the Auckland Islands (56% of all trawls undertaken) and the second was south-east of the Auckland Islands along the 250-m bathymetry line (44% of all tows undertaken; Chilvers et al. 2005a). For the scampi fishery, all trawls were made in the south-east area of the Auckland Islands shelf, which is also the area where Figure of Eight Island females foraged. The foraging areas of the three lactating female NZ sea lions from Figure of Eight Island that foraged south-east of the Auckland Islands overlapped with fisheries operations (Fig. 2a).

Between 2001 and 2004 the south-east fishing area accounted for 28% of all NZ sea lion mortality by-catch captures by the squid fishery (Chilvers et al. 2005a). Reported captures for the 2001–2007 period ranged from 39 to 118 animals per year (Baird 2005a; b; Baird & Doonan 2005; Smith & Baird 2005; Chilvers 2008a). The scampi fishery was reported to have killed 2–3 sea lions per year as by-catch (Rowe 2008). By-catch data for both fisheries are dependent on observers and the fishery reporting their occurrence; therefore, there may be bias in the data if observer coverage varies significantly between fishing areas, and/or fisheries neglect to report captures.

Discussion

The aim of this research was to investigate whether the foraging behaviour of females from Figure of Eight Island could be a factor in that colony's higher decline in pup production. Results showed that females from Figure of Eight Island made shorter foraging trips within more concentrated areas than those from the northern colony. Of the four Figure of Eight Island females tracked, three foraged in the area where 44% of all trawls and 28% of all sea lion by-catch was taken by the squid fishery between 2001 and 2004, and where all scampi fishing and by-catch occurred (Fig. 2a). Therefore, female NZ sea lions from Figure of Eight Island that forage in areas of overlap with squid and scampi fisheries have likely been subjected to increasing resource competition and a greater likelihood of being killed as by-catch because fisheries activity has increased in the Auckland Islands area over

the last 13 years (Chilvers 2008a). Similar increases in vulnerability might be expected for NZ sea lions from the other breeding islands, but if different proportions of females from each breeding colony forage in fisheries-free areas, this could help explain differences in rates of decline in pup production.

There are several other possible foraging-related explanations for the decline in the Figure of Eight breeding colony compared with the more northern colonies. They include potentially different environmental/climate changes in the southern area of the Auckland Islands compared with the northern area, differences in prey availability and the energy values of prey between the two areas, increased competition with foraging females from other islands, and increasing fisheries pressure.

Lactating NZ sea lions are central-place foragers, their foraging behaviour being restricted by their colonial breeding habit and their need to return regularly to dependent pups ashore (Chilvers et al. 2005a). Central-place foragers that are colonial breeders have a restricted foraging range, often resulting in local prey depletion (Ashmole 1963). Therefore, given the potential for increased competition in a common foraging area, it might be expected that resource partitioning both within and between species that breed within the same area would occur (Bailleul et al. 2005; Page et al. 2005; Breed et al. 2006). Consistent with this expectation, colony-specific foraging areas have been documented for Antarctic fur seals (*Arctocephalus gazella*; Boyd et al. 2002) and Northern fur seals (*Callorhinus ursinus*; Robson et al. 2004).

In contrast, female NZ sea lions from different islands overlap in their foraging areas. Dundas Island females overlap extensively with Enderby Island females in the north-east area of the Auckland Island shelf (Fig. 2b & c). Figure of Eight Island females overlap with Dundas Island females (Fig. 2a & c), only in a small area south-east of Adams Island, which may indicate more foraging separation than between the two northern breeding areas. Overlap in foraging areas between females breeding on different islands may reflect higher productivity or greater reliability of prey in the areas of overlap. Alternatively, overlap may indicate limited prey availability in other areas forcing individuals from different colonies to forage in the same locations. In support of the limited-prey-availability hypothesis, Bradford-Grieve et al. (2003) have shown that the Auckland Island rise is an iron-limited, low-productivity area, with low levels of phytoplankton biomass and primary production. They estimated that commercial fishing accounted for 32% of the total biomass taken from this low-productivity area, and that top predators, which include NZ sea lions, NZ fur seals, sea birds, and toothed and baleen cetaceans, took only 28%. Also in support of a limited-prey hypothesis, lactating NZ sea lions have been shown to have foraging/diving behaviours that are at their physiological limits, with 68%

of all of their dives being beyond their calculated anaerobic dive limits (ADLs) (Costa & Gales 2000; Chilvers et al. 2006). For most otariids, the frequency with which their theoretical ADL is exceeded is usually between 4 and 10% (Gentry et al. 1986; Feldkamp et al. 1989; Boyd & Croxall 1996).

It is possible that overlap in the foraging ranges (and therefore potential competition) of breeding females from Dundas and Figure of Eight islands has increased over the last 13 years, but this seems unlikely given that Dundas Island pup production and the corresponding breeding population has declined by 30% in the same period that the Figure of Eight Island breeding population has declined. With both breeding islands' pup production decreasing it may be assumed that competition would be reduced. Also, the overlap between Dundas Island and Adams Island is small, with no animals from either of the northern breeding areas utilising Carnley Harbour or south-west of Adams Island. This may indicate that foraging locations of the Figure of Eight females may influence differences in pup production between breeding areas.

Several factors unrelated to foraging could also have brought about the greater decline in NZ sea lion pup production at the Figure of Eight breeding colony than at the northern colony. These include lower genetic variability possibly resulting in reduced reproductive fitness or survival (Chilvers et al. 2007; Chilvers & Wilkinson 2008), increased female mortality resulting from harassment by breeding male sea lions, especially if the sex ratio has altered in favour of males (Chilvers et al. 2005b), and a greater impact of disease (Baker 1999; Wilkinson et al. 2006). These factors need investigation.

Results of the present research and that on the foraging ecology of lactating females from the northern breeding colony (Chilvers et al. 2005a; unpubl. data) show that the entire Auckland Islands shelf and edges are essential foraging ground for lactating NZ sea lions. When considering a declining species such as *Phocarctos hookeri*, protection needs to focus on the most vulnerable proportion of the species (Reeves 2000). For NZ sea lions, the breeding females that produce 86% of the species pup production at the Auckland Islands, and that must forage where fishery activities and by-catch deaths are greatest, are the most vulnerable proportion of the population. To be effective, protection needs to focus on both on-land breeding areas and the essential food resources surrounding them.

Foraging studies have shown that the current 12-nautical-mile (22-km) marine protected area (MPA) surrounding the Auckland Islands did not protect the entire foraging area of any lactating female tracked from Enderby or Dundas islands, or those of three of the four females from Figure of Eight Island (present study; Chilvers et al. 2005a; Chilvers 2008a). Instead, an MPA would need to extend over the entire Auckland Islands shelf as far as the 500-m bathymetric contour (Fig. 2a,

b & c). Such protection could be established through extension of the current marine mammal sanctuary, or through closure of the fishery area through the Fisheries Act (1996). Alternatively, methods used by the squid fishery (which has the highest known by-catch of NZ sea lions and the greatest distribution and fishing effort) could be restricted to jigging over the Auckland Islands shelf. This should result in zero sea lion by-catch, and may reduce resource competition while still allowing fishing within the entire area (Sauer 1995; Arnould et al. 2003; Chilvers 2008a).

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