

# Importance of studying foraging site fidelity for spatial conservation measures in a mobile predator

A. A. Augé<sup>1,2\*</sup>, B. L. Chilvers<sup>3</sup>, A. B. Moore<sup>2</sup> & L. S. Davis<sup>1</sup>

<sup>1</sup> Zoology Department, University of Otago, Dunedin, New Zealand

<sup>2</sup> School of Surveying, University of Otago, Dunedin, New Zealand

<sup>3</sup> Aquatic and Threats Unit, Department of Conservation, Wellington, New Zealand

## Keywords

*Phocarcctos hookeri*; New Zealand sea lion; pinniped; marine protected area; foraging range; Otago Peninsula; fisheries; spatial ecology; recolonization.

## Correspondence

Amélie A. Augé, School of Surveying, University of Otago, Dunedin 9016, New Zealand.

Email: amelie.auge@gmail.com

Editor: Karina Acevedo-Whitehouse

Associate Editor: Carmen Bessa-Gomes

\*Current address: ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia.

Received 22 January 2012; accepted 19 April 2013

doi:10.1111/acv.12056

## Introduction

Spatial studies on foraging areas of mobile predators have been used to create and propose spatial conservation measures for threatened species or populations that are affected by anthropogenic activities (e.g. Litzgus *et al.*, 2004; James, Ottensmeyer & Myers, 2005; Ashe, Noren & Williams, 2010; Scott *et al.*, 2012). Protected areas can be implemented to limit interactions between anthropogenic activities and animals or their resources. However, the efficiency of such conservation measures predominantly depends on the proportion of time that animals spend within the protected areas (Woodroffe & Ginsberg, 1998). For mobile predators, foraging areas are a key element of their environment. Individual site fidelity for foraging areas, within and between years, has been reported in a few species of various groups of mobile predators at a range of spatiotemporal scales in reptiles (Sazima & Marques, 2007), in bony fish (Block *et al.*, 2001; Jorgensen *et al.*, 2006), in terrestrial mammals (Kitchen, Gese & Schauster, 2000; Hillen, Kiefer & Veith, 2009), in marine birds (Hamer *et al.*, 2001; Mattern *et al.*, 2007) and in marine mammals including

## Abstract

The efficiency of spatial conservation measures for threatened species depends mostly on the proportion of time that animals spend within the protected areas. We illustrate this with our case study of the population of recolonizing female New Zealand (NZ) sea lions *Phocarcctos hookeri* ( $n = 13$ ) at Otago Peninsula, South Island, NZ. Human interactions at sea, where sea lions forage, are of concern, and spatial management measures have been proposed. Understanding the level of foraging site fidelity of these animals was consequently essential. We used satellite tracking of individuals across three autumns to assess foraging site fidelity and year-round on-land sighting surveys over 2.5 years as proxy to foraging areas outside autumns. Each individual exhibited a high level of autumnal site fidelity for foraging areas between years (64% overlap between 65% Kernel ranges with a 3-km buffer) while using beaches along a 12-km stretch of coastline during  $96 \pm 8\%$  (range 79–100%) of their time onshore. As a proxy for foraging areas outside autumns, these animals exhibited a high level of site fidelity to this stretch of coastline throughout the year. Breeding females were sighted there during 86% of months (range = 73–100%) and non-breeding females during 69% of months (range = 58–90%). The site fidelity of these animals indicates that protected areas would be efficient in this case and highlights the importance of studying foraging site fidelity in mobile predators to design efficient conservation measures.

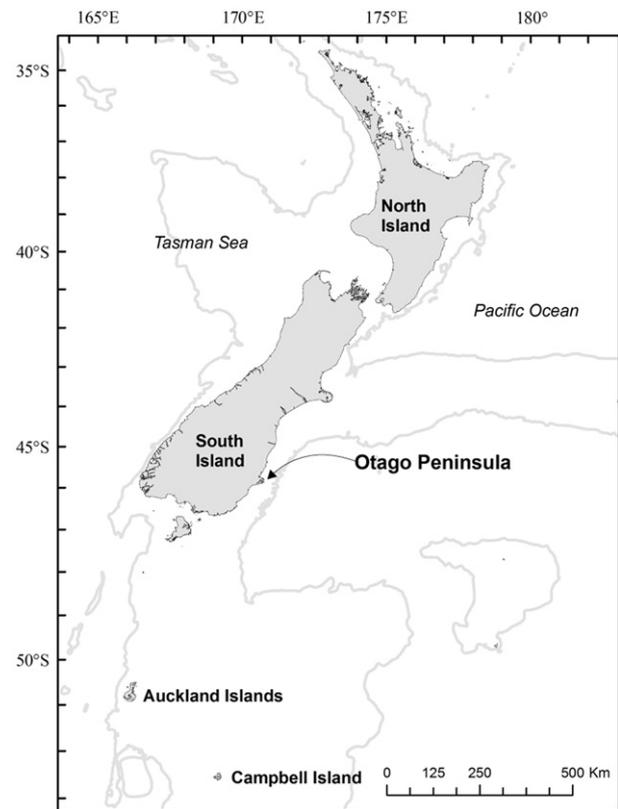
pinnipeds (Stewart & DeLong, 1995; Bradshaw *et al.*, 2004; Chilvers, 2008a; Kelly *et al.*, 2010).

Pinnipeds (commonly referred to as 'seals') are amphibious mammals and may interact with anthropogenic activities on land and at sea. Most pinnipeds, including all eared seals (fur seals and sea lions), breed and rest on land in restricted coastal areas during defined periods each year and also commonly show breeding site fidelity and philopatry (Twiss, Pomeroy & Anderson, 1994; Slade *et al.*, 1998; Bradshaw, Lallas & Thompson, 2000; Pomeroy, Twiss & Redman, 2000; Van Parijs, Janik & Thompson, 2000; Campbell *et al.*, 2008; Chilvers & Wilkinson, 2008; Kelly *et al.*, 2010). Consequently, shaping protected areas on land to reduce the impacts of anthropogenic activities on these species can be straightforward. However, pinnipeds feed exclusively at sea and are highly mobile in this environment. Populations of pinnipeds that spatially interact with fisheries while foraging are susceptible to incidental deaths in fishing gear (bycatch), depredation and resource competition (Wickens *et al.*, 1992; Alonzo, Switzer & Mangel, 2003; Huckstadt & Krautz, 2004).

Marine spatial management areas were found to be efficient options to limit interactions between some marine mobile predators and fisheries (Pichegru *et al.*, 2010; Gormley *et al.*, 2012). This required that animals permanently forage in relatively consistent areas (i.e. exhibit foraging site fidelity). This is an important factor to determine before protected areas can be designed. However, studies of year-round foraging areas in pinnipeds are often not logistically possible as all animals annually moult (prohibiting the use of satellite telemetry tags for more than a few seasons as instruments are attached to the fur) or may disperse making it more difficult to obtain long-term data on the same animals. There has not been, to date, a study on pinnipeds that reported on a multi-year continuous fine-scale foraging areas of specific individuals.

Satellite tracking tags, the main technology used to study at-sea movements of pinnipeds are typically only attached for a few weeks to a few months (Robinson *et al.*, 2002; Austin *et al.*, 2006; Baylis, Page & Goldsworthy, 2008; Freitas *et al.*, 2009; Geschke & Chilvers, 2009). Nevertheless, long-term studies of terrestrial habitat use are feasible by ground searches and individual identification through flipper tags (Chilvers, Wilkinson & McKenzie, 2010), microchips, brands (Raum-Suryan *et al.*, 2002; Wilkinson *et al.*, 2011), photographic methods (McConkey, 1999; Karlsson *et al.*, 2005) or radio tracking (smaller devices that may have the potential to be fitted under the skin; Lander *et al.*, 2005). Womble & Sigler (2006) showed that seasonal changes in the use of terrestrial sites by Steller sea lions *Eumetopias jubatus* corresponded to seasonal availability of suitable prey, hence to foraging areas. If foraging areas of individuals can be studied over multiple years for a few months, synchronously with the corresponding land use of these individuals, land site use during the rest of the year may consequently be used as a proxy for and allow investigating the level of foraging site fidelity year round.

Otago Peninsula, South Island, New Zealand (NZ; Fig. 1), is the location where the first known recolonizing population of NZ sea lions *Phocartos hookeri* is being established outside the three remnant breeding colonies in the sub-Antarctic islands following human extirpation (Childerhouse & Gales, 1998; McConkey *et al.*, 2002). The recolonizing population was initiated by a unique matriarch in 1994 (McConkey *et al.*, 2002) and has slowly increased since with an exponential curve (Lalas & Bradshaw, 2003). As the recolonization progresses and sea lion number increases, it is predicted that bycatch and competition issues will arise in the foraging grounds of the Otago female NZ sea lions, and spatial conservation measures (e.g. protected areas such as marine reserves and gear-restricted areas) may be the best options to manage these interactions (Augé, Moore & Chilvers, 2012c). However, it is important to understand if the animals in the Otago sea lion population show annual site fidelity for defined foraging grounds before decisions can be made on the best approach. Chilvers (2008a) showed that female NZ sea lions at one of the remnant breeding colonies exhibit seasonal broad site fidelity for foraging areas during midsummer up to 4 years apart. However, no data exist



**Figure 1** Location of the study site, Otago Peninsula, on the east coast of the South Island, New Zealand. Grey lines indicate 1000 m bathymetry contours.

outside of this short period for this population and hence females may migrate or use different foraging areas during other months. Consequently we made the assumptions that Otago female NZ sea lions would also show broad foraging site fidelity for foraging areas, but we wanted to understand foraging site fidelity outside of the satellite tracking period, restricted because of logistical reasons.

Here we present the study of multi-year continuous foraging and land site use of known individual female NZ sea lions around Otago Peninsula using a combination of satellite tracking, radio-telemetry and systematic ground surveys during 3 consecutive years. A total of 13 different animals (all females) were satellite tracked over the 3 years. However because of logistical constraints and the reproductive status of the animals, we only satellite-tracked six of these animals during 2 different years. First, we investigated the foraging areas of the same females during autumn, 1 or 2 years apart, using satellite-tracking data. Logistical and ethical constraints restricted satellite tracking to this season. This gave the level of in-between years autumnal foraging site fidelity. Second, we investigated the land sites that were used by these same females during autumn using the onshore satellite tracking data. The land sites used during this season were used to infer the relationship between foraging areas and land site use, and to assess the use of land sites as a

proxy for foraging areas in this species. Third we investigated the year-round land site use of all these individually identifiable females using systematic weekly ground surveys to determine the level of site fidelity for the Otago Peninsula. We finally discussed year-round foraging site fidelity of the Otago female NZ sea lions and how this relates to management of anthropogenic threats through spatial conservation measures.

## Materials and methods

### Autumnal foraging site fidelity between years

During April and May from 2008 to 2010, a sample of six female NZ sea lions from Otago Peninsula were each satellite-tracked during 2 different years – a first time in 2008 or 2009 and a second time in 2010 (Table 1). Due to logistics, we were unable to study each individual of the population in this section. Each animal was equipped with an Argos satellite tracking tag (SPLASH tag, Wildlife Computers, Redmond, WA, USA) using the same method as described in Augé *et al.* (2011).

The Argos data obtained from the satellite tracking tags were processed following the same filter as described in Augé *et al.* (2011). In each year, an individual's foraging range was calculated using fixed Kernel density maps (single smoothing factor: 1 km) of foraging locations and measured as either her core (65% Kernel contour) or total (95% Kernel contour) foraging range using ArcGIS (ESRI, Redlands, CA, USA). Each foraging trip was also analysed separately to measure the consistency in five foraging characteristics (time at sea, minimum route, distance to shore, water depth and percentage of time at sea). The minimum route was the minimum distance that a female travelled during the foraging trip from the point of departure on land to the next

location where she came onshore (calculated using Hawth's analysis tool; Beyer, 2004). The maximum distance from shore was the maximum straight line distance between land and the farthest location of a trip. The maximum water depth corresponded to the bathymetry over which the female foraged during a trip.

Site fidelity for foraging areas between years (1 or 2 years apart) was investigated by calculating percentages of overlap between core and total foraging ranges between the 2 years. These percentages of overlap were also recalculated with a 3-km buffer around the core foraging range to detect how much of the non-overlapping area corresponded to the edges of the foraging ranges. The buffer distance around the total foraging range of a female during 1 year that covered all of this animal's foraging range during the second year was also determined for each female. Each trip characteristic was then compared between 2008 or 2009 (first year) and 2010 (second year) to determine inter-annual or individual differences using linear models (LM, function *lm* of the package *stats*) with two fixed effects [year and individual identifier (ID)] and their interaction in R 2.10.0 (R Development Core Team, 2009). If ID and year had an effect on these models, LMs with one fixed factor (ID) were conducted for each female.

### Understanding relationships between foraging and land use: autumnal land site fidelity between years

The satellite-tracking data presented in the preceding section of this study and in Augé *et al.* (2011) were used to determine fidelity to land sites on or around Otago Peninsula during autumn at the individual level. In total, 13 juvenile and adult female NZ sea lions (aged 2–16, all known-to-be alive individuals of the population born in or before 2008) were satellite-tracked across the 3-year period 2008–2010 at the Otago Peninsula. Onshore Argos satellite

**Table 1** Details of study animals, deployment of satellite tags, core and total foraging ranges (in km<sup>2</sup>, based on the 65% and 95% Kernel ranges, KR, respectively) used by individual female New Zealand sea lions around Otago Peninsula, South Island, New Zealand, in autumns 2008 or 2009 and in 2010 with percentages of overlap between the 2 years

ID	Year	Age (year)	Tag on	Number of days	Number of trips	Number of locations	% of overlap 65% KR	with 3 km buffer around 65% KR	% overlap between 95% KR	% of 65% KR included in 95% KR of the other year
F0350	2008	14	8 April	26	19	175	24	32	32	67
	2010	16	12 April	30	29	310				42
F2578	2009	7	31 March	42	37	207	63	76	59	98
	2010	8	13 April	35	24	217				73
F2580	2009	7	1 April	40	46	171	34	91	48	97
	2010	8	12 April	38	27	174				65
F2582	2008	5	8 April	43	41	315	36	74	46	84
	2010	7	12 April	35	28	252				80
F2587	2009	4	30 March	31	30	147	29	56	38	84
	2010	5	12 April	34	27	224				36
F2594	2009	3	30 March	32	27	140	32	53	29	98
	2010	4	12 April	35	25	232				99
Means							37.0 ± 15.3	63.7 ± 20.9	42 ± 11.2	77.0 ± 21.5

Means are presented ± standard deviations.

locations only, as indicated by the wet–dry switch data of the tag, were kept for this analysis (i.e. the locations where the animals came onshore). A beach was attributed to each onshore period (sandy beach is the preferred habitat of female NZ sea lions coming ashore; Augé *et al.*, 2012a) using these onshore satellite locations. The length of each onshore period and proportions of time onshore that each individual spent at the different beaches were calculated for each autumn, for periods 3–6 weeks during April and May 2008 ( $n = 4$ ), 2009 ( $n = 7$ ) and 2010 ( $n = 8$ ). The annual average percentages of time females spent at each beach for each of the 3 study years were compared to determine the autumnal level of land site fidelity of female NZ sea lions on Otago Peninsula. This result was then integrated with foraging site fidelity results to determine the possibility to use land sites as proxy for foraging areas outside autumn.

### Proxy to foraging site fidelity: outside autumn land site fidelity across 2.5 years

In order to determine the fidelity of the female NZ sea lions to the Otago Peninsula area year-round, a 2.5-year continuous survey of presence of the same females ( $n = 13$ ) was conducted from January 2008 to June 2010 (all these females were individually identifiable from flipper tags or permanent body marks). During the study period, at least weekly ground surveys were conducted at six beaches on the Otago Peninsula and three nearby beaches (indicated by stars in Fig. 3) to locate females using systematic searches. To the dataset of weekly locations of females, we added sightings from trusted sources: NZ Sea Lion Trust members (6% of all sightings) and Department of Conservation staff (4% of all sightings).

The number of months during which each female NZ sea lion was sighted and the maximum number of consecutive months individuals were not seen at or near the Otago Peninsula were calculated. Means are given  $\pm$  standard deviations.

## Results

### Individual autumnal foraging site fidelity

There were distinct spatial overlaps in foraging areas of female NZ sea lions 1 or 2 years apart (Fig. 2). These overlaps increased by 27% when a 3-km buffer was used around the 65% Kernel ranges indicating that most of the non-overlapping areas were found at the edges of the foraging areas (Table 1). On average,  $63.7 \pm 20.9\%$  of the core foraging range buffered by 3 km was comprised in the core foraging range in the other year;  $77 \pm 21.5\%$  of these core foraging ranges were included in the total foraging ranges of the other year. Buffers between only 13 and 24 km around the total foraging range of each female during 1 year sufficed to cover all of the total foraging ranges of the other year for all females (i.e. 100% overlap of foraging areas).

The characteristics of foraging trips were all consistent between the 2 years for all females, except in one case where

an individual exhibited foraging trips significantly farther from shore in 2010 than in 2008 (Table 2). The overall percentage of time that each female spent at sea was also similar between the 2 years, with a maximal difference of 7% (Table 2).

### Relationships between foraging and land site fidelity in autumn

Based on the satellite tracking data, the 13 female NZ sea lions that were studied from 2008 to 2010 visited five beaches (mean  $5.4 \pm 1.9$ , range 2–9) during each autumn, with on average for each animal  $96 \pm 8\%$  (range 79–100%) of time onshore spent exclusively at one or several of the five beaches, indicated by the black stars in Fig. 3, along a 12-km stretch of coastline. In total, 20 beaches were used by female NZ sea lions during autumns 2008–2010 on the Otago Peninsula and the surrounding coastline, bounded by Karitane Beach in the north and Kuri Bush Beach in the south (Fig. 3). No beaches were used that were at higher or lower latitudes than the extreme northern and southern foraging locations (Fig. 3). Consequently the land sites used during autumn by female NZ sea lions bounded the latitudinal spread of foraging areas and could be used as a proxy for latitudinal distribution of foraging areas.

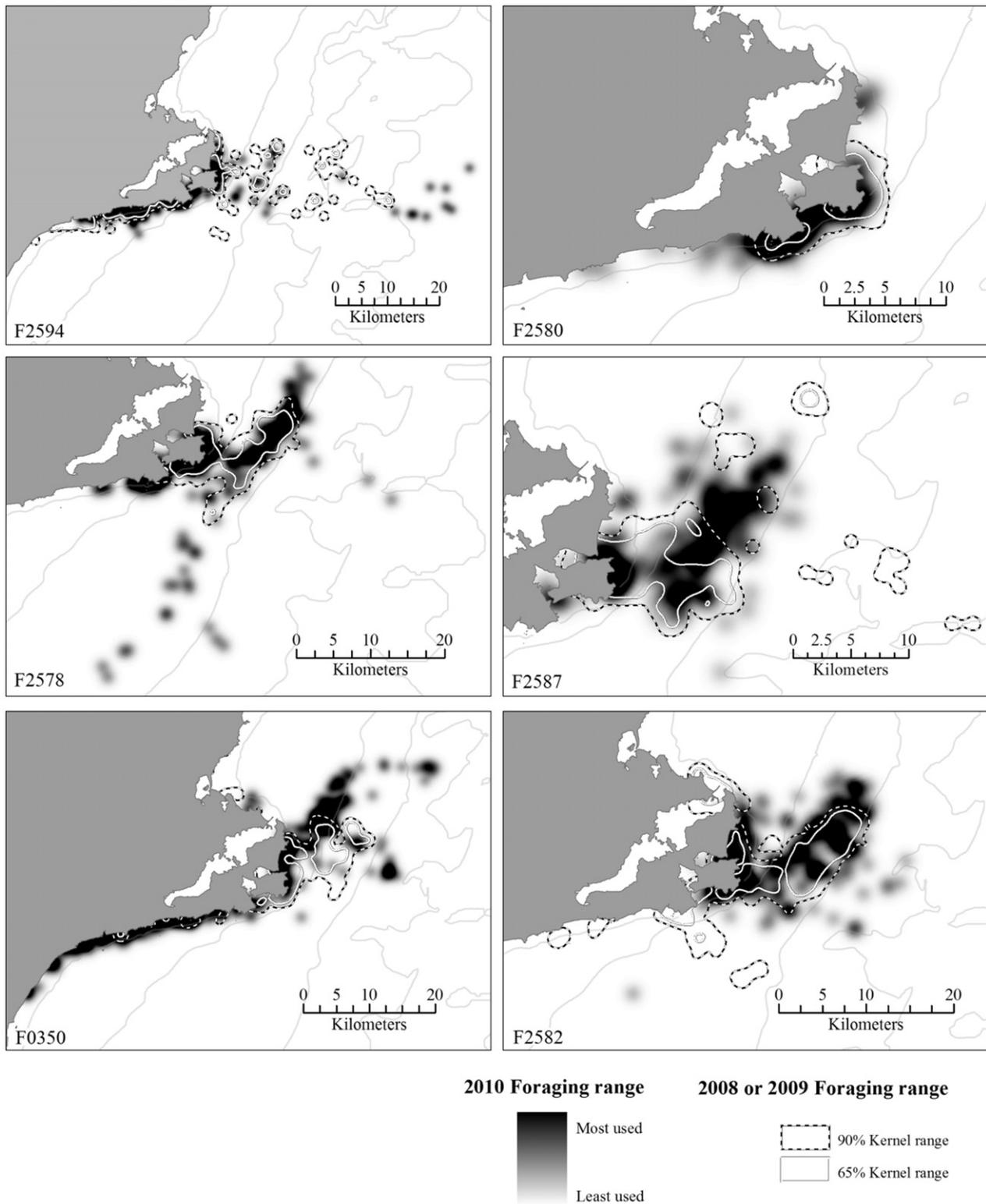
### Land site fidelity as a proxy to foraging site fidelity throughout the year outside autumn

Ground surveys took place over 30 consecutive months (January 2008 to June 2010) during which female NZ sea lions' presence on the Otago Peninsula was assessed at the beaches indicated with stars on Fig. 3. On average, females that gave birth to at least one pup during the study period were found during  $86.1 \pm 9.9\%$  of the months (range 73–100%). Results exclude the data for one individual, not seen from February 2009 to the end of this study (considered dead). Females that never bred during this period (all juveniles aged 3 years or less) were found during  $69.0 \pm 13.3\%$  of the months (range 58–90%), but there was no significant difference with breeding females (LM,  $F = 1.30$ , degrees of freedom = 1,  $P = 0.28$ ). The mean number of consecutive months with no sighting of an individual female was  $2.0 \pm 1.0$  months (range 0–4 months).

## Discussion

### Foraging site fidelity in female NZ sea lions and other pinnipeds

Our results showed strong foraging site fidelity and consistent foraging characteristics between years in individual female NZ sea lions around Otago Peninsula and a multi-year continuous site fidelity of all female NZ sea lions for the area of the Otago Peninsula with no seasonal migration. The land sites used during autumn by female NZ sea lions



**Figure 2** Fine-scale spatial overlap in foraging ranges of breeding female New Zealand sea lions around Otago Peninsula between autumns 2008 and 2010 (the two bottom maps) and autumns 2009 and 2010 (all others).

**Table 2** Between-year consistency of the characteristics of foraging trips of female New Zealand sea lions around the Otago Peninsula

ID	Year	Time at sea (hour)	Route (km)	Distance (km)	Maximal water depth (m)	% time at sea	Individual model for distance <sup>b</sup>
F0350	2008	14.2 ± 6.1	29.5 ± 17.3	3.2 ± 3.4	39.5 ± 30.7	40	$F = 5.16$
	2010	10.8 ± 3.6	47.1 ± 26.4	9.2 ± 7.1	50.5 ± 42.1	41	$P = 0.03$
F2578	2009	11.9 ± 3.1	24.9 ± 11.1	6.0 ± 4.6	60.8 ± 31.7	50	n.s.
	2010	13.8 ± 6.0	30.8 ± 14.0	8.9 ± 7.1	69.6 ± 34.6	45	
F2580	2009	8.1 ± 5.4	12.3 ± 7.7	1.0 ± 0.6	20.3 ± 13.8	40	n.s.
	2010	10.8 ± 4.4	19.0 ± 10.1	1.0 ± 0.7	21.1 ± 11.5	47	
F2582	2008	11.5 ± 4.1	28.8 ± 12.2	7.2 ± 4.9	58.5 ± 33.6	47	n.s.
	2010	11.8 ± 4.7	36.7 ± 10.5	9.7 ± 5.7	89.5 ± 49.1	45	
F2587	2009	8.7 ± 4.0	21.3 ± 17.2	7.8 ± 7.5	55.4 ± 40.6	38	n.s.
	2010	9.2 ± 5.1	32.4 ± 17.6	9.3 ± 4.6	74.1 ± 33.7	38	
F2594	2009	11.7 ± 6.4	26.5 ± 23.4	5.2 ± 9.1	98.4 ± 216.8	45	n.s.
	2010	14.7 ± 6.4	39.5 ± 33.9	7.4 ± 18.2	111.8 ± 281	50	
Model <sup>a</sup>	Year	n.s.	n.s.	$F = 6.83$	n.s.		
				$P < 0.01$			
	ID	$F = 6.01$	$F = 8.35$	$F = 8.82$	$F = 3.82$		
		$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$		
	Year × ID	n.s.	n.s.	n.s.	n.s.		

<sup>a</sup>Linear models with two fixed factors (year and ID) and their interaction, d.f. = 11.

<sup>b</sup>Linear model for each female when the full model showed significance of both year and ID, d.f. = 1. n.s. indicates  $P$ -values > 0.05. d.f., degrees of freedom; ID, individual identifier; n.s., not significant.

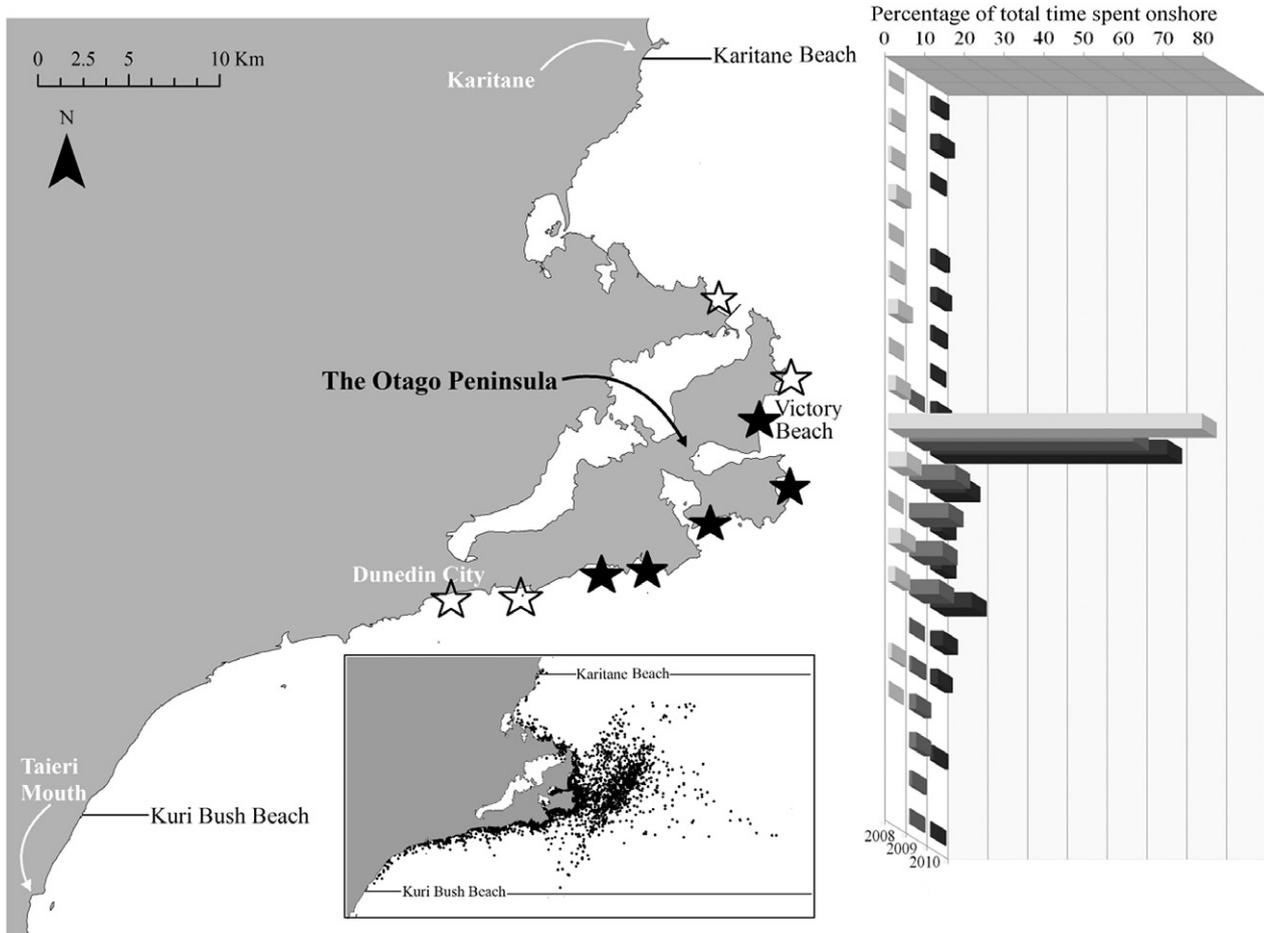
that were satellite-tracked bounded their foraging areas in the north and south. Land sites used by female NZ sea lions consequently appeared to reflect the latitudinal range in foraging areas. For the offshore delimitation of foraging areas, when no satellite tracking data was available, several observations can be made. The continental shelf off the Otago Peninsula (< 180 m depth) is narrow (see Fig. 1). NZ sea lions at the Auckland Islands, as well as most species of sea lions, are known to forage exclusively on the continental shelf (Feldkamp, DeLong & Antonelis, 1989; Merrick & Loughlin, 1997; Campagna *et al.*, 2001; Chilvers *et al.*, 2005; Villegas-Amtmann *et al.*, 2008; Chilvers, 2009). It is consequently likely that the foraging areas of Otago female NZ sea lions are constrained to the east by the edge of the continental shelf and do not extend further offshore outside autumn. Hence, land sites where female NZ sea lions were found throughout the year can be used as a proxy to foraging areas during months where satellite tracking was prohibited because of logistical and ethical reasons. In combining the high foraging site fidelity found in autumn and a continuous presence of all animals on or near the Otago Peninsula outside autumn, we inferred that Otago female NZ sea lions exhibit foraging site fidelity throughout the year.

Victory Beach was the main land site used during all seasons by female NZ sea lions in this study (see Fig. 3). This corresponds to the results presented in McConkey *et al.* (2002) that reported sightings of the same female NZ sea lions as in this study that were already born at Otago from 1991 to 2001 ( $n = 4$ ). The other main beaches used by these animals were also similar between our study and McConkey *et al.* (2002). Consequently over a 20-year period, female NZ sea lions used similar beaches and likely

same overall foraging areas based on our findings in this study. This supports our conclusion that the site fidelity for the Otago Peninsula may possibly be permanent throughout an individual's lifetime. Further research in this area is however needed.

Some male NZ sea lions are known to undertake long seasonal migrations between the mainland and the breeding colonies in the Auckland Islands (Robertson *et al.*, 2006). However, in the context of the small Otago population of NZ sea lions, females currently constitute the most important part of the population for the success of the recolonization. Consequently conservation efforts should first focus on females and later incorporate males if differences in foraging areas exist.

Although our study presents the first account of a multi-year likely long-term and year-round foraging site fidelity in pinnipeds, it is possible to infer, by bringing together existing studies and using the land site proxy approach, that other pinnipeds may also exhibit this foraging site fidelity. Endangered Hawaiian monk seals *Monachus schauinslandi* had less than 10% probability of being sighted at another group of islands than where they were initially marked during a multi-decade-long survey programme, as reported in Baker & Thompson (2007), and foraging behaviour is most likely restricted to areas around particular islands (Craig & Ragen, 1999; Stewart *et al.*, 2006). A genetic study of Australian sea lions *Neophoca cinerea*, one of the least abundant otariid species, found that females display high site fidelity to breeding colonies (Campbell *et al.*, 2008). Gales, Shaughnessy & Dennis (1994) also reported these animals as using the same general land area throughout the year. Using stable isotope analyses, Lowther *et al.* (2011, 2012) reinforced the likely existence of foraging site fidelity



**Figure 3** Mean annual percentages of time onshore that Otago female New Zealand sea lions spent at 20 beaches on the Otago Peninsula and surrounding coastline [from Karitane Beach in the north to Kuri Bush Beach in the south; each row represents a different sandy beach of approximate similar latitude on the coastline; see Augé, (2010) for details on the sites] during autumns 2008 ( $n = 4$ ), 2009 ( $n = 7$ ) and 2010 ( $n = 8$ ). No site outside this area was used by the study animals during these periods. The stars show the beaches that were ground surveyed throughout the year (black stars indicate the five most used beaches by all animals). In inset: black dots showing all foraging locations for the same animals during the same periods (from this study and Augé *et al.*, 2011).

in this species by showing that animals consistently used either onshore or offshore areas across multiple years. Similarly, Wolf, Kauermann & Trillmich (2005) reported a high degree of inter- and intra-annual site fidelity for land sites in the threatened Galapagos sea lion *Zalophus wollebaeki*, although foraging long-term site fidelity is not apparent as foraging areas may depend on age (Villegas-Amtmann *et al.*, 2008). These three species, along with NZ sea lions, have small population estimates, most with reduced breeding ranges and have been impacted by anthropogenic activities (Gales *et al.*, 1994; Childerhouse & Gales, 1998; Baker & Johanos, 2004). Their recovery or persistence requires management because of fishing activities in particular, and foraging site fidelity may play an important role in the success of this management (Friedlander & DeMartini, 2002; Goldsworthy & Page, 2007). It consequently needs to be investigated fully if protected areas become a conservation tool for these species.

**Implications of site fidelity for mobile predators: case study of NZ sea lions at the Otago Peninsula**

The primary foraging habitat of female NZ sea lions at Otago is characterized by shallow rocky reefs and bryozoans thickets (Augé *et al.*, 2011). The foraging site fidelity described here highlights the dependence of these animals for these two habitats in a relatively small marine area. Bottom trawling is known to damage benthic habitat (Jones, 1992; Shephard, Brophy & Reid, 2010) and is used off the Otago Peninsula in the bryozoans area (Ministry of Fisheries, Warehou database, unpubl. data). Bladder kelp *Macrocystis pyrifera*, the main kelp species on shallow rocky reefs at Otago (Fyfe *et al.*, 1999), was recently introduced in the NZ Quota-Management System as a commercial species. Its exploitation may alter and physically disturb foraging sea lions. The main fish species in the diet of female

NZ sea lions (barracouta *Thyrstites atun* and jack mackerel *Trachurus sp.*; Augé *et al.*, 2012b) are two of the top five commercial fisheries in NZ waters (Ministry of Fisheries, 2010). Consequently there is resource overlap between fisheries and Otago NZ sea lions. Competition may occur and alter the quality of the restricted marine habitat for female NZ sea lions. Foraging site fidelity consequently entails or increases several threats that could damage the restricted primary foraging habitat of this population and jeopardize recolonization by this species.

There has not been any report of bycatch of NZ sea lions in fishing activities around the Otago Peninsula to date. However, three-quarters of fishing activities around the Otago Peninsula, during this study, involved trawling (Ministry of Fisheries, Warehouse database, unpubl. data), the fishing method responsible for significant bycatch of NZ sea lions around the Auckland Islands and NZ fur seals *Arctocephalus fosteri* throughout NZ waters (Chilvers, 2008b; Bremner *et al.*, 2009). The death of even one female may currently have a significant impact on the success of the recolonization of Otago Peninsula by NZ sea lions (Lalas & Bradshaw, 2003). As sea lion numbers increase around Otago Peninsula, the bycatch issue is also likely to arise, as has been the case for NZ fur seals (Gibson, 1995). Our study shows that female NZ sea lions exhibit foraging site fidelity throughout the year and across years. Consequently a study determining the degree of overlap between the foraging areas of female NZ sea lions and fishing areas should efficiently delineate areas of potential direct interactions between this marine mammal and local fisheries (see Augé *et al.*, 2012c).

Although all the risks mentioned earlier may impede successful recolonization by NZ sea lions on the South Island, NZ, the level of foraging site fidelity described in this study shows that spatial conservation measures (i.e. marine protected areas) within a definite relatively small area should allow minimizing all these risks.

## Conclusion

Our study showed a potentially permanent high level of individual foraging site fidelity in an otariid within a small area. This is also likely typical of other species. Foraging site fidelity should be investigated as it may improve setting of spatial conservation measures. Specifically for NZ sea lions of the Otago Peninsula, advantageous implications of our findings are that conservation measures may be set to more effectively manage anthropogenic interactions with sea lions within the small definite area used by these animals. However, this site fidelity renders Otago female sea lions subject to alterations and damages to this same restricted marine area. The dispersal of adult breeding males among all breeding sites of NZ sea lions create a conservation issue for disease transmission especially and may impede species recovery (Robertson *et al.*, 2006). The high level of site fidelity of females revealed in our study generates different, but as critical conservation issues that may additionally limit species recovery by preventing or slowing down successful

recolonization of this species if no conservation measures are taken. The site fidelity of these female NZ sea lions indicates that protected areas would be efficient in this case and highlights the importance of studying foraging site fidelity in mobile predators.

## Acknowledgments

This work was conducted under a permit from the DOC Coastal Otago area office and ethic approvals from the DOC Animal Ethics committee (DOC AEC 174) and the University of Otago Animal Ethics committee (IDAO AEC 72107001). This study was funded in collaboration between DOC Aquatic and Threats Unit, Wellington and the University of Otago, Dunedin. For help in the field with sea lion captures, surveys and/or sightings, we particularly thank Nathan McNally, the DOC Coastal Otago area office (especially Jim Fyfe), the NZ Sea Lion Trust (especially Shaun McConkey, Colin Emslie and Stevi Broni), Matt Taylor, David Winter, Mel Young, Chris Lalas, Hiltrun Ratz, Justin Cowen, Hamish Bowman, Heather Anderson, Jacinda Amey, Ros Cole and the vets (Katya Geschlke, Kerri Morgan, Kate McInnes, Tony Malthus and Andy Maloney). We acknowledge Bruce Robertson for helpful comments on an earlier version of the manuscript and four reviewers for their insightful comments.

## References

- Alonzo, S.H., Switzer, P.V. & Mangel, M. (2003). An ecosystem-based approach to management: using individual behaviour to predict the indirect effects of Antarctic krill fisheries on penguin foraging. *J. Appl. Ecol.* **40**, 692–702.
- Ashe, E., Noren, D.P. & Williams, R. (2010). Animal behaviour and marine protected areas: incorporating behavioural data into the selection of marine protected areas for an endangered killer whale population. *Anim. Conserv.* **13**, 196–203.
- Augé, A.A. (2010). *Foraging ecology of recolonising female New Zealand sea lions around the Otago Peninsula*. PhD thesis, University of Otago, Dunedin, New Zealand.
- Augé, A.A., Chilvers, B.L., Moore, A.B. & Davis, L.S. (2011). Foraging behaviour indicates marginal marine habitat for New Zealand sea lions: remnant versus recolonising populations. *Mar. Ecol. Prog. Ser.* **432**, 247–256.
- Augé, A.A., Chilvers, B.L., Mathieu, R. & Moore, A.B. (2012a). On-land habitat preferences of female New Zealand sea lions at Sandy Bay, Auckland Islands. *Mar. Mammal Sci.* **28**, 620–637.
- Augé, A.A., Lalas, C., Davis, L.S. & Chilvers, B.L. (2012b). Autumn diet of recolonising female New Zealand sea lions based at Otago Peninsula, South Island, New Zealand. *N. Z. J. Mar. Freshwater Res.* **46**, 97–110.

- Augé, A.A., Moore, A.B. & Chilvers, B.L. (2012c). Predicting interactions between marine mammals and fisheries: defining precautionary management. *Fish. Manag. Ecol.* **19**, 426–433.
- Austin, D., Bowen, W.D., McMillan, J.I. & Iverson, S.J. (2006). Linking movement, diving, and habitat to foraging success in a large marine predator. *Ecology* **87**, 3095–3108.
- Baker, J.D. & Johanos, T.C. (2004). Abundance of the Hawaiian monk seal in the main Hawaiian Islands. *Biol. Conserv.* **116**, 103–110.
- Baker, J.D. & Thompson, P.M. (2007). Temporal and spatial variation in age-specific survival rates of a long-lived mammal, the Hawaiian monk seal. *Proc. Biol. Sci.* **274**, 407–415.
- Baylis, A.M.M., Page, B. & Goldsworthy, S.D. (2008). Colony-specific foraging areas of lactating New Zealand fur seals. *Mar. Ecol. Prog. Ser.* **361**, 279–290.
- Beyer, H.L. (2004). *Hawth's analysis tools for ArcGIS*. Available at <http://www.spatialecology.com>.
- Block, B.A., Dewar, H., Blackwell, S.B., Williams, T.D., Prince, E.D., Farwell, C.J., Boustany, A., Teo, S.L.H., Seitz, A., Walli, A. & Fudge, D. (2001). Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. *Science* **293**, 1310–1314.
- Bradshaw, C.J.A., Hindell, M.A., Sumner, M.D. & Michael, K.J. (2004). Loyalty pays: potential life history consequences of fidelity to marine foraging regions by southern elephant seals. *Anim. Behav.* **68**, 1349–1360.
- Bradshaw, C.J.A., Lalas, C. & Thompson, C.M. (2000). Clustering of colonies in an expanding population of New Zealand fur seals (*Arctocephalus forsteri*). *J. Zool. (Lond.)* **250**, 105–112.
- Bremner, G., Johnstone, P., Bateson, T. & Clarke, P. (2009). Unreported bycatch in the New Zealand west coast South Island hoki fishery. *Mar. Policy* **33**, 504–512.
- Campagna, C., Werner, R., Karesh, W., Marin, M.R., Koontz, F., Cook, R. & Koontz, C. (2001). Movements and locations at sea of South American sea lions (*Otaria flavescens*). *J. Zool. (Lond.)* **257**, 205–220.
- Campbell, R.A., Gales, N.J., Lento, G.M. & Baker, C.S. (2008). Islands in the sea: extreme female natal site fidelity in the Australian sea lion, *Neophoca cinerea*. *Biol. Lett.* **4**, 139–142.
- Childerhouse, S. & Gales, N.J. (1998). The historic and modern distribution and abundance of the New Zealand sea lion. *N.Z. J. Zool.* **25**, 1–16.
- Chilvers, B.L. (2008a). Foraging site fidelity of lactating New Zealand sea lions. *J. Zool. (Lond.)* **276**, 28–36.
- Chilvers, B.L. (2008b). New Zealand sea lions *Phocarctos hookeri* and squid trawl fisheries: bycatch problems and management options. *Endanger. Species Res.* **5**, 193–204.
- Chilvers, B.L. (2009). Foraging locations of female New Zealand sea lions (*Phocarctos hookeri*) from a declining colony. *N.Z. J. Ecol.* **33**, 106–113.
- Chilvers, B.L. & Wilkinson, I.S. (2008). Philopatry and site fidelity of New Zealand sea lions (*Phocarctos hookeri*). *Wildl. Res.* **35**, 463–470.
- Chilvers, B.L., Wilkinson, I.S., Duignan, P.J. & Gemmill, N.J. (2005). Summer foraging areas for lactating New Zealand sea lions. *Mar. Ecol. Prog. Ser.* **304**, 235–247.
- Chilvers, B.L., Wilkinson, I.S. & McKenzie, D.I. (2010). Predicting life-history traits for female New Zealand sea lions, *Phocarctos hookeri*: integrating short-term mark-recapture data and population modelling. *J. Agric. Biol. Environ. Stat.* **15**, 259–278.
- Craig, M.P. & Ragen, T.J. (1999). Body size, survival, and decline of juvenile Hawaiian monk seals, *Monachus schauinslandi*. *Mar. Mammal Sci.* **15**, 786–809.
- Feldkamp, S.D., DeLong, R.L. & Antonelis, G.A. (1989). Diving patterns of Californian sea lions, *Zalophus californianus*. *Can. J. Zool.* **67**, 872–883.
- Freitas, C., Kovacs, K.M., Ims, R.A., Fedak, M.A. & Lydersen, C. (2009). Deep into the ice: over-wintering and habitat selection in male Atlantic walrus. *Mar. Ecol. Prog. Ser.* **375**, 247–261.
- Friedlander, A.M. & DeMartini, E.E. (2002). Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. *Mar. Ecol. Prog. Ser.* **230**, 253–264.
- Fyfe, J., Israel, S.A., Chong, A., Ismail, N., Hurd, C.L. & Probert, K. (1999). Mapping marine habitats in Otago, southern New Zealand. *Geocarto Int.* **14**, 17–28.
- Gales, N.J., Shaughnessy, P.D. & Dennis, T.E. (1994). Distribution, abundance and breeding cycle of the Australian sea lion *Neophoca cinerea*. *J. Zool. (Lond.)* **234**, 353–370.
- Geschke, K. & Chilvers, B.L. (2009). Managing big boys: a case study on remote anaesthesia and satellite tracking of adult male New Zealand sea lions, *Phocarctos hookeri*. *Wildl. Res.* **36**, 666–674.
- Gibson, D.M. (1995). *Incidental catch of New Zealand fur seals (A. fosteri) in trawl fisheries in the New Zealand exclusive economic zone, 1990–93*. New Zealand Fisheries Assessment Research Document 95/00. Wellington, New Zealand: Ministry of Agriculture and Fisheries.
- Goldsworthy, S.D. & Page, B. (2007). A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries. *Biol. Conserv.* **139**, 269–285.
- Gormley, A.M., Slooten, E., Dawson, S., Barker, R.J., Rayment, W., DuFresnes, S. & Brager, S. (2012). First evidence that marine protected areas can work for marine mammals. *J. Appl. Ecol.* **49**, 474–480.
- Hamer, K.C., Phillips, R.A., Hill, J.K., Wanless, S. & Wood, A.G. (2001). Contrasting foraging strategies of gannets *Morus bassanus* at two North Atlantic colonies: foraging trip duration and foraging area fidelity. *Mar. Ecol. Prog. Ser.* **224**, 283–290.

- Hillen, J., Kiefer, A. & Veith, M. (2009). Foraging site fidelity shapes the spatial organisation of a population of female western barbastelle bats. *Biol. Conserv.* **142**, 817–823.
- Huckstadt, L.A. & Krautz, M.C. (2004). Interaction between southern sea lions and jack mackerel commercial fishery off central Chile: a geostatistical approach. *Mar. Ecol. Prog. Ser.* **282**, 285–294.
- James, M.C., Ottensmeyer, C.A. & Myers, R.A. (2005). Identification of high-use habitat and threats to leatherback sea turtles in northern waters: new directions for conservation. *Ecol. Lett.* **8**, 195–201.
- Jones, J.B. (1992). Environmental impact of trawling on the seabed: a review. *N. Z. J. Mar. Freshwater Res.* **26**, 59–67.
- Jorgensen, S.J., Kaplan, D.M., Klimley, A.P., Morgan, S.G., O'Farrell, M.R. & Botsford, L.W. (2006). Limited movement in blue rockfish *Sebastes mystinus*: internal structure of home range. *Mar. Ecol. Prog. Ser.* **327**, 157–170.
- Karlsson, O., Hiby, L., Lundberg, T., Jussi, M., Jussi, I. & Helander, B. (2005). Photo-identification, site fidelity, and movement of female gray seals (*Halichoerus grypus*) between haul-outs in the Baltic Sea. *Ambio* **34**, 628–634.
- Kelly, B.P., Badajos, O.H., Kunasranta, M., Moran, J.R., Martinez-Bakker, M., Wartzok, D. & Boveng, P. (2010). Seasonal home ranges and fidelity to breeding sites among ringed seals. *Polar Biol.* **33**, 1095–1109.
- Kitchen, A.M., Gese, E.M. & Schauster, E.R. (2000). Long-term spatial stability of coyote (*Canis latrans*) home ranges in southeastern Colorado. *Can. J. Zool.* **78**, 458–464.
- Lalas, C. & Bradshaw, C.J.A. (2003). Expectations for population growth at new breeding locations for the vulnerable New Zealand sea lion using a simulation model. *Biol. Conserv.* **114**, 67–78.
- Lander, M.E., Haulena, M., Gulland, F.M.D. & Harvey, J.T. (2005). Implantation of subcutaneous radio transmitters in the harbor seal (*Phoca vitulina*). *Mar. Mammal Sci.* **21**, 154–161.
- Litzgus, J.D., Mousseau, T.A. & Lannoo, M.J. (2004). Home range and seasonal activity of southern spotted turtles (*Clemmys guttata*): implications for management. *Copeia* **4**, 804–817.
- Lowther, A.D., Harcourt, R.G., Goldsworthy, S.D. & Stow, A. (2012). Population structure of adult female Australian sea lions is driven by fine-scale foraging site fidelity. *Anim. Behav.* **83**, 691–791.
- Lowther, A.D., Harcourt, R.G., Hamer, D.J. & Goldsworthy, S.D. (2011). Creatures of habit: foraging habitat fidelity of adult Australian sea lions. *Mar. Ecol. Prog. Ser.* **443**, 249–263.
- Mattern, T., Ellenberg, U., Houston, D.M. & Davis, L.S. (2007). Consistent foraging routes and benthic foraging behaviour in yellow-eyed penguins. *Mar. Ecol. Prog. Ser.* **343**, 295–306.
- McConkey, S., McConnell, H., Lalas, C., Heinrich, S., Ludmerer, A., McNally, N., Parker, E., Borofsky, C., Schimanski, K. & McIntosh, M. (2002). A northward spread in the breeding distribution of the New Zealand sea lion. *Aust. Mammal.* **24**, 97–106.
- McConkey, S.D. (1999). Photographic identification of the New Zealand sea lion: a new technique. *N. Z. J. Mar. Freshwater Res.* **33**, 63–66.
- Merrick, R.L. & Loughlin, T.R. (1997). Foraging behavior of adult female and young-of-the-year Steller sea lions in Alaskan waters. *Can. J. Zool.* **75**, 776–786.
- Ministry of Fisheries (2010). *QMS species catch*. Available at <http://fs.fish.govt.nz/Page.aspx?pk=6&tk=97&ey=2009>.
- Pichegru, L., Grémillet, D., Crawford, R.J.M. & Ryan, P.G. (2010). Marine no-take zone rapidly benefits endangered penguins. *Biol. Lett.* **6**, 498–501.
- Pomeroy, P.P., Twiss, S.D. & Redman, P. (2000). Philopatry, site fidelity and local kin associations within grey seal breeding colonies. *Ethology* **106**, 899–919.
- Raum-Suryan, K.L., Pitcher, K.W., Calkins, D.G., Sease, J.L. & Loughlin, T.R. (2002). Dispersal, rookery fidelity, and metapopulation structure of Steller sea lions (*Eumetopias jubatus*) in an increasing and a decreasing population in Alaska. *Mar. Mammal Sci.* **18**, 746–764.
- R Development Core Team (2009). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Available at <http://www.R-project.org>.
- Robertson, B.C., Chilvers, B.L., Duignan, P., Wilkinson, J.S. & Gemmel, N.J. (2006). Dispersal of breeding adult male *Phocarcos hookeri*: implications for disease transmission, population management and species recovery. *Biol. Conserv.* **127**, 227–236.
- Robinson, S.A., Goldsworthy, S.G., van den Hoff, J. & Hindell, M.A. (2002). The foraging ecology of two sympatric fur seal species, *Arctocephalus gazella* and *Arctocephalus tropicalis*, at Macquarie Island during the austral summer. *Mar. Freshwater Res.* **53**, 1071–1082.
- Sazima, I. & Marques, O.A.V. (2007). A reliable customer: hunting site fidelity by an actively foraging neotropical colubrid snake. *Herpetol. Bull.* **99**, 36–38.
- Scott, R., Hodgson, D.J., Witt, M.J., Coyne, M.S., Adnyana, W., Blumenthal, J.M., Broderick, A.C., Canbolat, A.F., Catry, P., Ciccione, S., Delcroix, E., Hitipeuw, C., Luschi, P., Pet-Soede, L., Pendoley, K., Richardson, P.B., Rees, A.F. & Godley, B.J. (2012). Global analysis of satellite tracking data shows that adult green turtles are significantly aggregated in marine protected areas. *Glob. Ecol. Biogeogr.* **21**, 1053–1061.
- Shephard, S., Brophy, D. & Reid, D.G. (2010). Can bottom trawling indirectly diminish carrying capacity in a marine ecosystem? *Mar. Biol.* **157**, 2375–2381.
- Slade, R., Moritz, C., Hoelzel, A. & Burton, H.R. (1998). Molecular population genetics of the southern elephant seal *Mirounga leonina*. *Genetics* **149**, 1945–1957.

- Stewart, B.A., Antonelis, G.A., Baker, J.D. & Yochem, P.Y. (2006). Foraging biogeography of the Hawaiian monk seal in the northwestern Hawaiian Islands. *Atoll Res. Bull.* **543**, 131–145.
- Stewart, B.S. & DeLong, R.L. (1995). Double migrations of the northern elephant seal, *Mirounga angustirostris*. *J. Mammal.* **76**, 196–205.
- Twiss, S.D., Pomeroy, P.P. & Anderson, S.S. (1994). Dispersion and site fidelity of breeding male grey seals (*Hali-coerus grypus*) on North Rona, Scotland. *J. Zool. (Lond.)* **233**, 683–693.
- Van Parijs, S.M., Janik, V.M. & Thompson, P.M. (2000). Display area size, tenure length, and site fidelity in the aquatic mating male harbour seal, *Phoca vitulina*. *Can. J. Zool.* **78**, 2209–2217.
- Villegas-Amtmann, S., Costa, D.P., Tremblay, Y., Salazar, S. & Aurioles-Gamboa, D. (2008). Multiple foraging strategies in a marine apex predator, the Galapagos sea lion *Zalophus wollebaeki*. *Mar. Ecol. Prog. Ser.* **363**, 299–309.
- Wickens, P.A., Japp, D.W., Shelton, P.A., Kriel, F., Goosen, P.C., Rose, B., Augustyn, C.J., Bross, C.A.R., Penney, A.J. & Krohn, R.G. (1992). Seals and fisheries in South Africa – competition and conflict. *S. Afr. J. Mar. Sci.* **12**, 773–789.
- Wilkinson, I.S., Chilvers, B.L., Duignan, P.J. & Pistorius, P.A. (2011). An evaluation of hot-iron branding as a permanent marking method for adult New Zealand sea lions, *Phocarcos hookeri*. *Wildl. Res.* **38**, 51–60.
- Wolf, J.B.W., Kauermann, G. & Trillmich, F. (2005). Males in the shade: habitat use and sexual segregation in the Galapagos sea lion (*Zalophus californianus wollebaeki*). *Behav. Ecol. Sociobiol.* **59**, 293–302.
- Womble, J.N. & Sigler, M.F. (2006). Seasonal availability of abundant, energy-rich prey influences the abundance and diet of a marine predator, the Steller sea lion *Eumetopias jubatus*. *Mar. Ecol. Prog. Ser.* **325**, 281–293.
- Woodroffe, R. & Ginsberg, J.R. (1998). Edge effects and the extinction of populations inside protected areas. *Science* **280**, 2126–2128.