



# New Zealand sea lions *Phocarctos hookeri* and squid trawl fisheries: bycatch problems and management options

B. Louise Chilvers\*

Marine Conservation Unit, Department of Conservation, PO Box 10420, Wellington 6143, New Zealand

**ABSTRACT:** The New Zealand (NZ) sea lion *Phocarctos hookeri* is one of the world's most rare and highly localized pinnipeds. NZ sea lions only breed on New Zealand's subantarctic islands, with 86 % of breeding occurring on the Auckland Islands (50°S, 166°E). In 1995, the sea surrounding the Auckland Islands out to 12 nautical miles (n miles) was declared a Marine Mammal Sanctuary, primarily to protect the breeding area of this species. Subsequently, in 2003, this area became a concurrent no-take Marine Reserve. Both protection measures ban commercial trawl fishing within this area. Trawling is the predominant anthropogenic impact upon this species, both through direct (mortality as a result of bycatch) and potential indirect (resource competition) effects. However, despite this area-based protection and the fisheries management measures in the surrounding waters, the species, which numbers less than 12 000 ind., has shown a 30 % decline in pup production over the last 8 yr. In this paper, I review the biology, foraging ecology and management of NZ sea lions in relation to the subantarctic arrow squid *Nototodarus sloanii* fishery to explore alternative management options within the framework of current legalisation in New Zealand. Management options need to afford better protection for this declining species, while still allowing profitable commercial fisheries operations for arrow squid in New Zealand waters.

**KEY WORDS:** *Phocarctos hookeri* · New Zealand sea lions · Management · Fisheries interactions · Marine mammal protected area

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## INTRODUCTION

The New Zealand (NZ) sea lion (previously known as Hookers sea lion; *Phocarctos hookeri*) is one of the world's most rare and highly localized pinnipeds. It has been classified as 'Vulnerable' by the International Union for Conservation of Nature, IUCN (Reijnders et al. 1993) and 'Threatened' under the New Zealand threat classification system (Hitchmough 2002). NZ sea lions only breed on New Zealand's subantarctic islands between latitudes of 48 and 53°S (Gales & Mattlin 1997, Chilvers et al. 2007a). Their population size is one of the smallest reported for an otariid, with less than 12 000 ind. (Campbell et al. 2006). Eighty-six per cent of all breeding occurs on the Auckland Islands (50°30'S, 166°E). The only other breeding area is

located on Campbell Island/Motu Ihupuku (52°30'S, 169°E), which is 400 km southeast of the Auckland Islands (Fig. 1, Chilvers et al. 2007a).

In 1995, the New Zealand Department of Conservation declared a Marine Mammal Sanctuary (MMS) in the sea around the Auckland Islands out to 12 nautical miles (n miles) (22 km) to protect this vulnerable species. MMS are areas protected and managed by the New Zealand Marine Mammals Protection Act (1978), whereby fisheries activities are controlled by the Minister of Conservation. In 2003, the MMS area was also designated a concurrent no-take Marine Reserve (MR). The boundaries of the MMS, and hence the MR, were set according to the limits allowed by New Zealand marine protection area legislation, in an attempt to protect the areas where the majority of NZ

\*Email: lchilvers@doc.govt.nz

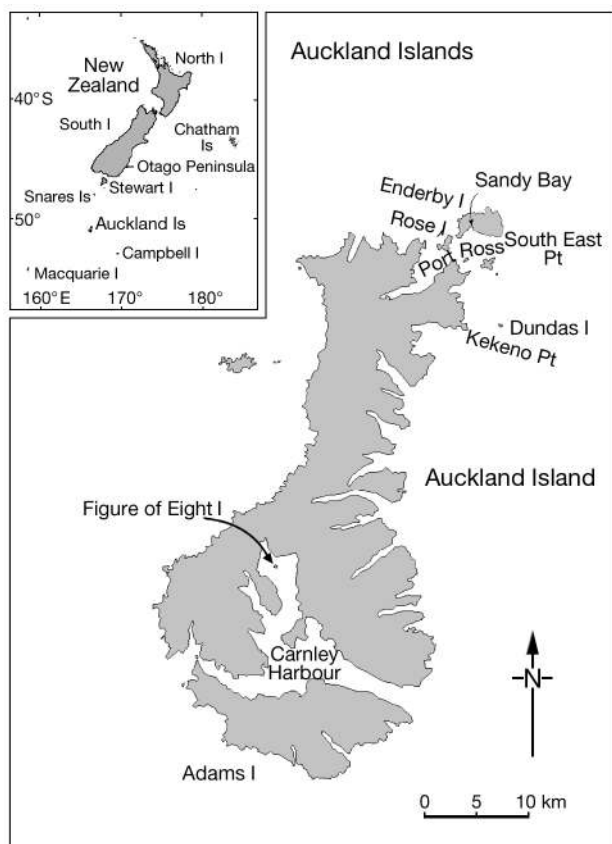


Fig. 1. *Phocartos hookeri*. Auckland Islands showing the main breeding areas for NZ sea lions: Sandy Bay and South East Point, Enderby Island; Dundas Island; and Figure of Eight Island, Carnley Harbour. Inset: New Zealand's subantarctic showing the Auckland Islands and Campbell Island/Motu Ihupuku, where over 99.9% of all NZ sea lion breeding occurs

sea lions breed (Chilvers et al. 2007a). However, despite this area-based protection and the additional fisheries management measures in the surrounding water, the pup production of this species has declined significantly in the last 8 yr. This is thought to be a knock-on effect from a decline in the number of breeding adults (Wilkinson et al. 2006, Chilvers et al. 2007a).

Over the past decade, the interaction between NZ sea lions and the arrow squid *Nototodarus sloanii* trawl fishery, which operates on the Auckland Island shelf between February and May each year, has been investigated (Gales 1995, Gales & Mattlin 1997, Uozumi 1998, Costa & Gales 2000, Wilkinson et al. 2003, Chilvers et al. 2005, 2006). Squid comprise a consistent but variable proportion of the NZ sea lion diet (Childerhouse et al. 2001, L. Meyneir unpubl. data), and their presence coincides with the first 5 mo of lactation for the NZ sea lion (Gales 1995). Since some NZ sea lions and trawlers will be pursuing the same prey, incidental captures of NZ sea lions in squid trawl nets are inevitable (Wilkinson et al.

2003). The impact of this fisheries-related mortality on the NZ sea lion population remains unclear; however, several models suggest that this level of take may limit the capacity for NZ sea lions to increase in number and, under some scenarios, may result in population decline (Doonan & Cawthorn 1984, Woodley & Lavigne 1993), other models suggest that there would be little impact (Breen et al. 2003). The New Zealand Government currently manages the sea lion/fishery interaction through the 2 marine protected areas (MPAs—MMS and MR in the sea surrounding the Auckland Islands out to 12 n miles), which are closed to all fishing, and by setting a limit for the number of NZ sea lions the squid fishery may kill incidentally within the management area each year before the fishery is closed for the season. This limit has varied between 32 and 115 sea lions since 1992 (Table 1).

The present study describes the biology and foraging ecology of NZ sea lions, the productivity of the Auckland Island area, and examines the relationship between NZ sea lions and the arrow squid fishery to explore alternative management options within the framework of New Zealand's governance. Management options need to balance species protection and the maintenance of profitable commercial arrow squid operations within New Zealand waters.

## NZ SEA LION BIOLOGY

NZ sea lions are polygamous colonial breeders and have a highly synchronized breeding season. At the Auckland Islands, mean pupping date is 26/27 December each year, with 69% of all pups born 1 wk either side of this date (Chilvers et al. 2007b). Lactation lasts approximately 10 mo (Gales 1995), during which females split their time between foraging at sea and spending time ashore feeding their dependent pup (Chilvers et al. 2005). The absolute growth rate per day for the first 60 d of a pup's life is 151 g d<sup>-1</sup> (Chilvers et al. 2007b). This growth rate is lower than that reported for Steller *Eumetopias jubatus*, Californian *Zalophus californianus* or southern *Otaria flavescens* sea lions (Higgins et al. 1988, Boness et al. 1991, Cappozzo et al. 1991, Schulz & Bowen 2004). This lower pup growth rate may be linked with NZ sea lions' unusually low mean milk lipid content during early lactation, the lowest reported in any otariid species (14%, Riet-Sapirza 2007). Mean milk protein and ash are consistent with other species (protein 10.8%, ash 0.5% of total milk mass, Riet-Sapirza 2007). Reasons for a low milk fat content during early lactation have not been fully elucidated; however, low energy values of NZ sea lions' major prey species (octopus *Octopus* spp.), squid *Nototodarus sloanii*, rattail *Coelorhynchus* spp., juvenile

Table 1. *Phocartos hookeri*. Annual percentage observer coverage, numbers of NZ sea lions captured on observed fishing vessels, number of observed tows, number of total tows within SQU6T (for location see Fig. 3), estimated total number of NZ sea lions captured within a fishing season and fisheries closure date for the arrow squid SQU6T fishery between 1992 and 2007. Data obtained from: A. Martin, Ministry of Fisheries pers. comm., Baird (1996, 1999, 2005a,b), Baird & Doonan (2005), Smith & Baird (2005). MALFIRM: maximum allowable level of fishing-related mortality; FRML: fisheries-related mortality limit; (–) fishery continued until the end of the season, i.e. was not closed due to sea lion bycatch

Season	% observer coverage	Number of NZ sea lion captures on observed boats (# female and male captures)	Observed tows	Total tows	Estimated total NZ sea lion mortalities	Sea lion MALFIRM or FRML limit	Fishery closure data
1992	10	8 (3F, 5M)	218	2153	82	32	–
1993	29	5 (3F, 2M)	197	656	17	63	–
1994	10	4 (2F, 2M)	433	4677	32	63	–
1995	8	8 (4F, 4M)	286	4000	109	69	–
1996	13	13 (10F, 3M)	555	4460	105	73	4 May
1997	20	29 (9F, 20M)	731	3708	123	79	28 Mar
1998	23	15 (4F, 11M)	337	1442	62	63	27 Mar
1999	37	5 (4F, 1M)	156	401	14	64	–
2000	35	25 (11F, 13M)	438	1208	71	65	8 Mar
2001	100	38 (22F, 16M)	576	582	67	75	<sup>a</sup>
2002	33	22 (16F, 6M)	563	1647	84	79	13 Apr
2003	23	10 (6F, 4M)	420	1466	39	70	<sup>b</sup>
2004	31	16 (14F, 2M)	792	2595	118	62	<sup>c</sup>
2005	29	9 (6F, 3M)	805	2693	115	115	17 Apr <sup>d</sup>
2006	28	11 (10F, 1M)	688	2459	110	96	–
2007	41	8 (6F, 2M)	540	1318	56	91	–
Total		226 (130F, 95M)	7735	35465	1204		

<sup>a</sup>The fishery was not officially closed in 2000-01. Industry voluntarily withdrew the majority of vessels on 7 March 2001  
<sup>b</sup>SQU6T fishery was closed on 29 March 2003. However, a High Court Ruling in April 03 allowed fishing to continue  
<sup>c</sup>SQU6T fishery was closed on 22 March 2004. However, a Court of Appeal ruling in April 04 allowed fishing to continue  
<sup>d</sup>Fishers voluntarily withdrew from the SQU6T fishery upon reaching the 115 animal FRML on 17 April 2005

red cod *Pseudophycis bachus* and opalfish *Hemero-coetes* spp.) all with energy values less than 4 kJ g<sup>-1</sup>, (Brasted 1991, Goodman-Lowe et al. 1999, Rosen & Trites 2000, Childerhouse et al. 2001, L. Meynier unpubl. data) and competition for resource through fisheries interactions are both possible factors.

Recent research has shown that female NZ sea lions at the Auckland Islands appear to have a low reproductive ability compared to other sea lions, with an average reproductive rate of 60% (B. L. Chilvers et al. unpubl. data). Steller sea lions have reported reproductive rates of between 60 and 75% (Pitcher & Calkins 1981, Calkins & Pitcher 1982, Boyd 1992, York 1994), Californian sea lions 77% (Melin 2002) and Australian sea lions *Neophoca cinerea*, 71% (Higgins & Gass 1993).

Factors contributing to this are that the minimum age of first pupping at the Auckland Islands is 4 yr. Elsewhere, NZ sea lions are known to pup at 3 yr (McConkey et al. 2002). Twenty percent of females that live to age 3, and could therefore be mated to give birth at Age 4, are never expected to breed and of those that do, 22% are never expected to have a pup survive. Of the 80% of females who will breed, 50% will have bred by Age 6. If a female has not bred by Age 8, she is unlikely to breed (B. L. Chilvers et al. unpubl. data).

Over the past 8 yr, NZ sea lions have been affected by 3 epidemics caused by bacterial infections, which resulted in the deaths of 53, 32 and 21% of annual pup production at the Auckland Islands for the 1998, 2002 and 2003 seasons, respectively, and at least 75 adult females during the 1998 epidemic (Baker 1999, Duignan 1999, Wilkinson et al. 2003, 2006). In years without bacterial epidemics, pup mortality at 1 mo at the Auckland Islands ranges between 1 and 15% (Chilvers et al. 2007a). These factors lead to a median predicted lifetime pup production of 5 pups per female (95% CI 0 to 13). If pup mortality during the first month is taken into account, this median falls to 4 pups surviving (95% CI 0–11) (B. L. Chilvers et al. unpubl. data).

NZ sea lion abundance and distribution were drastically reduced during historical subsistence and commercial seal hunting. The size of the historical population is unknown, but fossil records suggest NZ sea lions once bred on both the North and South Islands of New Zealand (Childerhouse & Gales 1998). To date, NZ sea lions have failed to recolonize their former breeding range. Their breeding is currently highly localized within the New Zealand subantarctic, with 86% of pups born at the Auckland Islands (Chilvers et al. 2007a). They mainly breed on 2 islands in the northern Auckland Islands, Enderby Island, where 19% of

pups are born, and Dundas Island, where 64 % of pups are born (Chilvers et al. 2007a). The other 2 breeding areas are Figure of Eight Island in Carnley Harbour, Southern Auckland Islands, and Campbell Island/Motu Ihupuku, where 3 and 14 % of the species' pups are born each year, respectively (Fig. 1). In recent years, up to 6 pups have been born each year on Otago Peninsula, South Island, New Zealand. However, this area is not yet recognized as an established breeding site for NZ sea lions, due to the low numbers of pups being born and high variability between years (McConkey et al. 2002, Chilvers et al. 2007a). Resighting data of NZ sea lions that were born and marked as pups on the northern Auckland Islands suggest that both site fidelity and philopatry are important characteristics of this species, particularly for females (B. L. Chilvers & I. S. Wilkinson unpubl. data). Males (both breeding and non-breeding) disperse to the extremes of the species' range at the end of female oestrous in late January (Robertson et al. 2005), which is consistent with the dispersal/migration behaviour often seen in other male otariids (Robertson et al. 2005). This dispersal pattern means fewer males are present around the Auckland Islands during the fishing season, lowering their chances for interactions with fisheries activities and therefore capture and death.

### NZ SEA LION FORAGING ECOLOGY

Lactating NZ sea lions at the Auckland Islands are central place foragers, foraging from and returning to their pups on land within a restricted time frame (on average 2.7 d, Chilvers et al. 2005). During foraging, lactating females preferentially use the Auckland Islands continental shelf and its edge, north of the Auckland Islands (Fig. 2, Chilvers et al. 2005). Mean return travel distance per trip is  $423 \pm 43$  km (maximum = 1087 km). This is a greater average foraging distance than has been recorded for any other sea lion species (Campagna et al. 2001, Chilvers et al. 2005). Lactating NZ sea lions show high levels of individual variation in foraging location, distance from shore and duration. However, individuals show strong site fidelity to specific foraging areas within a breeding season and across years, despite probable changes in climate or prey distribution and abundance (Chilvers et al. 2005).

While at sea, NZ sea lions dive almost continuously, spending on average 52.7 % of their time submerged (>6 m, Chilvers et al. 2006). Their mean dive depth is  $129.5 \pm 5.3$  m (range 95 to 179 m), and the mean duration of dives is  $4.0 \pm 0.1$  min, with an average of 40 % of all dive times spent in the deepest 85 % of the dive (Chilvers et al. 2006). Although there is a large amount of variation in diving behaviour between individuals,

animals have been shown to dive beyond their calculated aerobic dive limits (cADL) on 68 % of all dives (Chilvers et al. 2006). This is much higher than for most other otariids, for which the cADL is usually exceeded on between 4 and 10 % of dives (Gentry et al. 1986, Feldkamp et al. 1989, Ponganis et al. 1990, Boyd & Croxall 1996). An exception to this is Australian sea lions *Noephoca cinerea*, which exceed their cADLs at similar percentages to NZ sea lions (Costa & Gales 2003). Recent research has shown that individual NZ sea lions have distinct dive profiles, being either benthic divers, which dive consecutively to similar depths presumably foraging on the benthos, or more epipelagic/mesopelagic divers, which have varied dive depths in deeper waters. There is a significant difference in foraging location between individuals with these 2 dive profiles. 'Benthic divers' forage further from the breeding areas, northeast over the Auckland Island shelf, whereas 'mesopelagic divers' forage northwest from the breeding areas along the edge of the shelf where it drops steeply to 3000 m (Fig. 2, B. L. Chilvers & I. S. Wilkinson unpubl. data). Benthic divers exceed their cADLs significantly more often than mesopelagic divers (82 and 51 % of dives, respectively,  $F = 51.9$ ,  $p < 0.0001$ ). Dietary differences between these 2 dive types are currently being investigated. Given the differences in foraging locations of these 2 distinct dive types, it is expected that the mesopelagic divers have the greatest overlap and therefore interaction with fisheries activities, increasing their chances of death from fisheries activities relative to benthic divers. This hypothesis is also currently being investigated.

Diet analysis of NZ sea lions shows that the predominant prey types taken, both in number and mass, around the Auckland Islands are octopus, squid, rat-tail, juvenile red cod and opalfish (Childerhouse et al. 2001, L. Meynier unpubl. data). These data should be interpreted with caution, however, as both studies were biased due to their methodology. Childerhouse et al. (2001) used scat analysis, which is biased towards less digestible prey items and L. Meynier (unpubl. data) used stomach analysis from bycaught animals, which would be expected to be biased toward squid, as the animals were caught while foraging in an area of high squid concentration where trawlers operate.

For over 8 yr, lactating female NZ sea lions at the Auckland Islands have been shown to be diving and foraging at their physiological limits (Gales & Mattlin 1997, Chilvers et al. 2005, 2006). It is not yet clear why lactating NZ sea lions have adopted a physiologically extreme foraging behaviour. It may be due to factors such as range restriction caused by past harvests, environmental change, prey choice, current human impacts or the stress and energy requirements during early lactation, or to some other as yet unidentified factor. How-

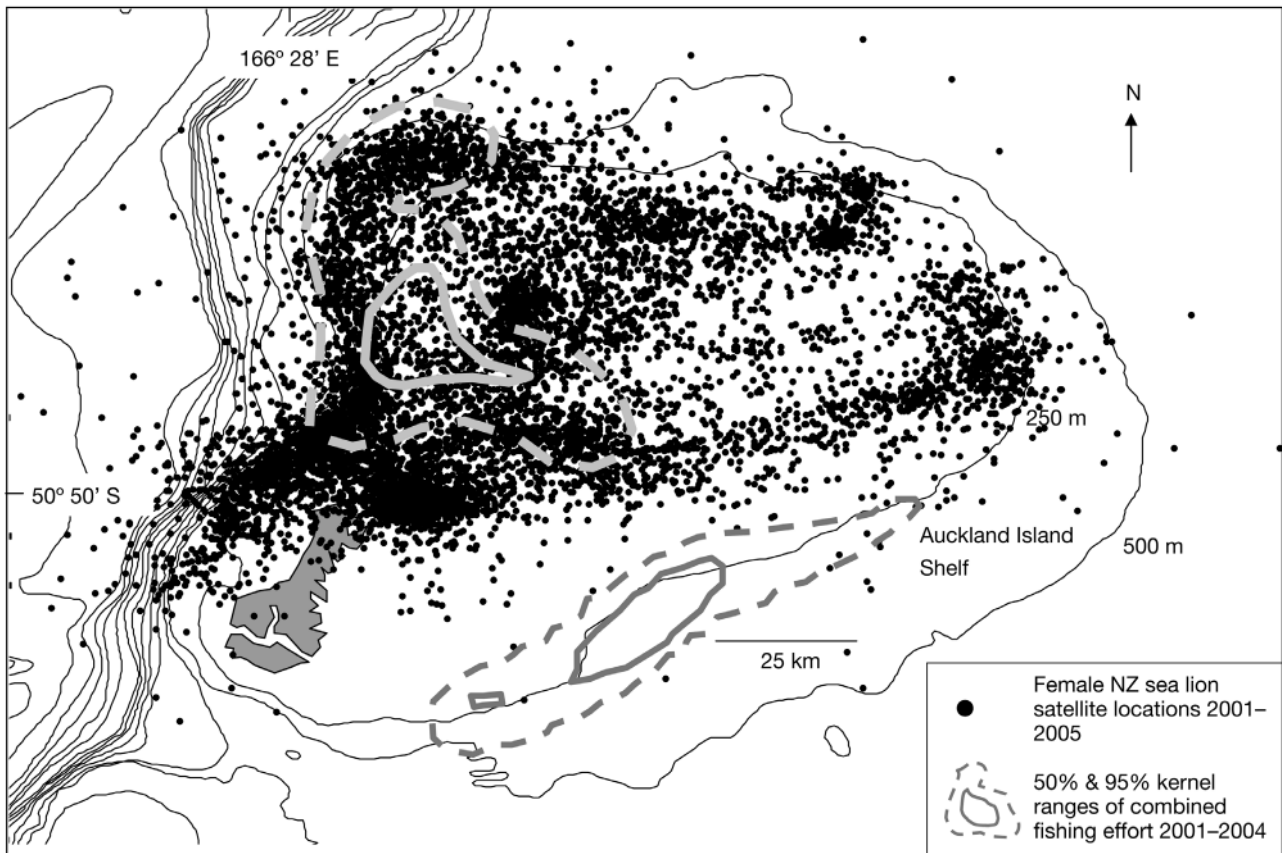


Fig. 2. *Phocartos hookeri*. Distribution of foraging locations for 26 lactating female sea lions and overlap with squid trawl fisheries effort (50 and 95 % kernel ranges represented as solid and dashed grey lines, respectively) from the austral summers of 2001 to 2005. Auckland Islands are represented in grey. Bathymetric contours are shown as thin black lines. The Auckland Island Shelf is represented by the 500 m bathymetric boundary (Chilvers et al. 2005)

ever, the fact that lactating females do operate at this physiological level, and have been for at least a decade, makes them highly susceptible to external impacts such as direct and indirect fisheries impacts and other local environmental changes. This is because they have limited ability to increase foraging effort, such as dive duration, as they are already foraging at their physiological limits. Despite area-based protection, female foraging locations also overlap temporally and spatially with the operation of the subantarctic arrow squid trawl fishery (Gales 1995, Gales & Mattlin 1997, Uozumi 1998, Costa & Gales 2000, Wilkinson et al. 2003, Chilvers et al. 2005, 2006). Suboptimal foraging conditions will increase foraging costs and hinder pup provisioning for a mother attempting to minimize the return time to her pup, thus affecting species viability (Boyd et al. 1994, 1997, 1998).

### THE ARROW SQUID FISHERY

The arrow squid fishery is one of the largest commercial fisheries in New Zealand. Its importance has increased in recent years, predominantly because of the decreasing catch limits for other New Zealand

Table 2. *Nototodarus sloanii*. Arrow squid harvests (t), New Zealand fisheries waters, 2001-02 to 2005-06. SQU6T total allowable commercial catch (TACC) is 32 369 t annually. New Zealand total SQU TACC (for location of the quota management areas see Fig. 3) is 127 322 t annually (Source: New Zealand Ministry of Fisheries)

Fishing year	Total NZ Squid catch (SQU1J, SQU1T and SQU6T)	SQU6T catch	% total NZ SQU harvest taken from SQU6T	% TACC harvest taken from SQU6T
2001-02	48173	11502	24	9
2002-03	43719	6887	16	5
2003-04	84962	34635	41	27
2004-05	86075	27314	32	21
2005-06	72361	17425	24	14
Average	67058	19553	27	15

deep water fisheries, especially hoki *Macruronus novaezealandiae*. Although catch varies considerably between years (Table 2), in the last 3 calendar years squid exports have comprised between 9 and 13% of the total value of all of New Zealand's seafood exports, and has been the biggest export by volume (New Zealand Ministry of Fisheries, [www.fish.govt.nz](http://www.fish.govt.nz)).

The arrow squid fishery is divided into 4 quota management areas (QMAs), SQU1J (jig fishing only), and SQU1T, SQU6T and SQU10T (trawl fisheries but can be jigged) (my Fig. 3; Annala 1996). SQU6T is the fishing area directly overlapping with the breeding and foraging areas of NZ sea lions at the Auckland Islands. Between 2001–02 and 2005–06, the SQU6T area contributed between 16 and 41% of the total New Zealand squid harvest, or 5 to 27% of the total allowable commercial catch of squid within New Zealand waters (Table 2). The SQU6T fishery operates annually from 1 February to mid-May over the Auckland Island shelf in depths between 150 and 250 m, using either mid-water or bottom trawling nets with large openings and high

headline nets. Between 2001 and 2004, 56% of all trawl activity in SQU6T was recorded in the area north of the Auckland Islands, resulting in 61% of total squid catch by weight (my Fig. 2; Chilvers et al. 2005). This is also the area where 72% of all incidental bycatch captures of sea lions are reported (Chilvers et al. 2005). The remaining trawling occurs southeast of the Auckland Islands at the edge of the Auckland Island rise, with 28% of NZ sea lion bycatch occurring in this area (Fig. 2).

### NZ SEA LION AND FISHERY INTERACTIONS

The first reported NZ sea lion captures and mortalities were in 1978, when 10 NZ sea lions were killed during 58 research tows in the northern Auckland Island area (Baird 1994). NZ sea lions are fully protected under the Marine Mammals Protection Act 1978. However, incidental captures during fisheries operations are not an offence, provided that captures are reported and handled as directed. Since 1992, government observers have been placed on a proportion of commercial fishing vessels in an effort to determine the numbers and locations of NZ sea lions captured by the SQU6T squid fleet (proportions range from 8 to 100% of the fleet, 1992 to 2007, Table 1). Numbers of captures reported by government observers ( $n = 4$  to 38 NZ sea lions, average  $n = 19$ , Table 1) were then extrapolated across the entire fleet ( $n = 14$  to 123 sea lions, Table 1). Since 2001, sea lion exclusion devices (SLEDs) have been used within the SQU6T fisheries (Fig. 4). A SLED is a separation metal grid fixed inside the trawl net at a 45° angle to the water flow just before the cod-end of the net (cod-end is the collection area at the end of the trawl net that holds the captured target species i.e. squid, Fig. 4). This allows smaller objects, such as squid, to pass through the metal grid into the cod-end, while larger objects, such as sea lions, are directed to the top of the net where there is an escape hatch opening (Fig. 4). Between 2004 and 2007, all fishing vessels used a SLED during SQU6T fishing. However, the number of NZ sea lion captures reported by government observers during this period did not drop significantly from before SLED use ( $n = 8$  to 16 sea lions, average  $n = 11$ , Table 1). The survival of sea lions once they have 'escaped' from trawl nets is also questionable. Trials of SLEDs during 2001 estimated a 91% ejection rate of NZ sea lions through SLEDs to the escape hatch. However, examination by a veterinary pathologist showed that an estimated 55% of animals that went through this ejection process but were then intentionally drowned by cover-nets sewn over the escape hatches suffered traumatic internal and head injuries that would have significantly compromised

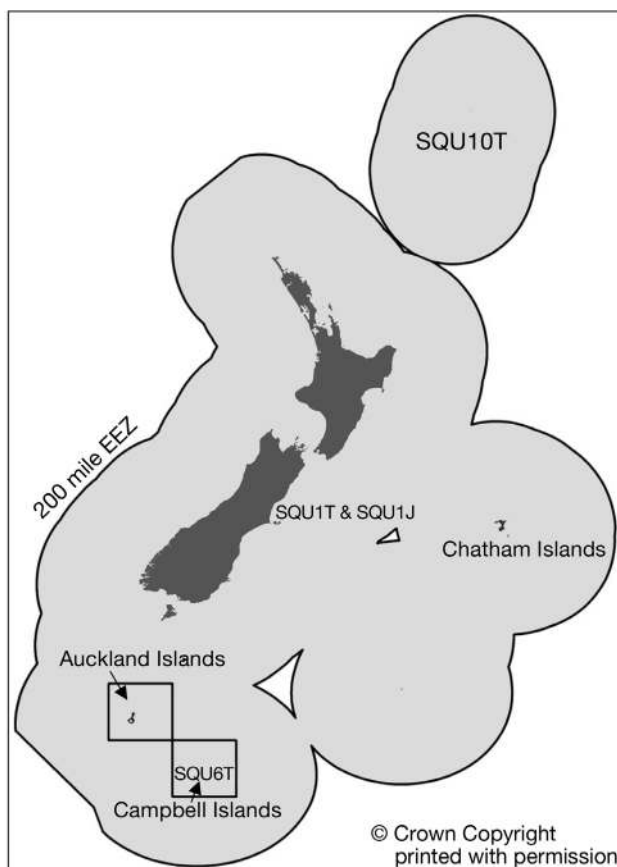


Fig. 3. Quota management areas for New Zealand's squid fisheries. Area SQU6T is represented by the area within the 2 squares surrounding the Auckland and Campbell Islands, Areas SQU1T and SQU1J cover the remainder of the large grey-shaded area. EEZ: Exclusive Economic Zone (Ministry of Fisheries, New Zealand)

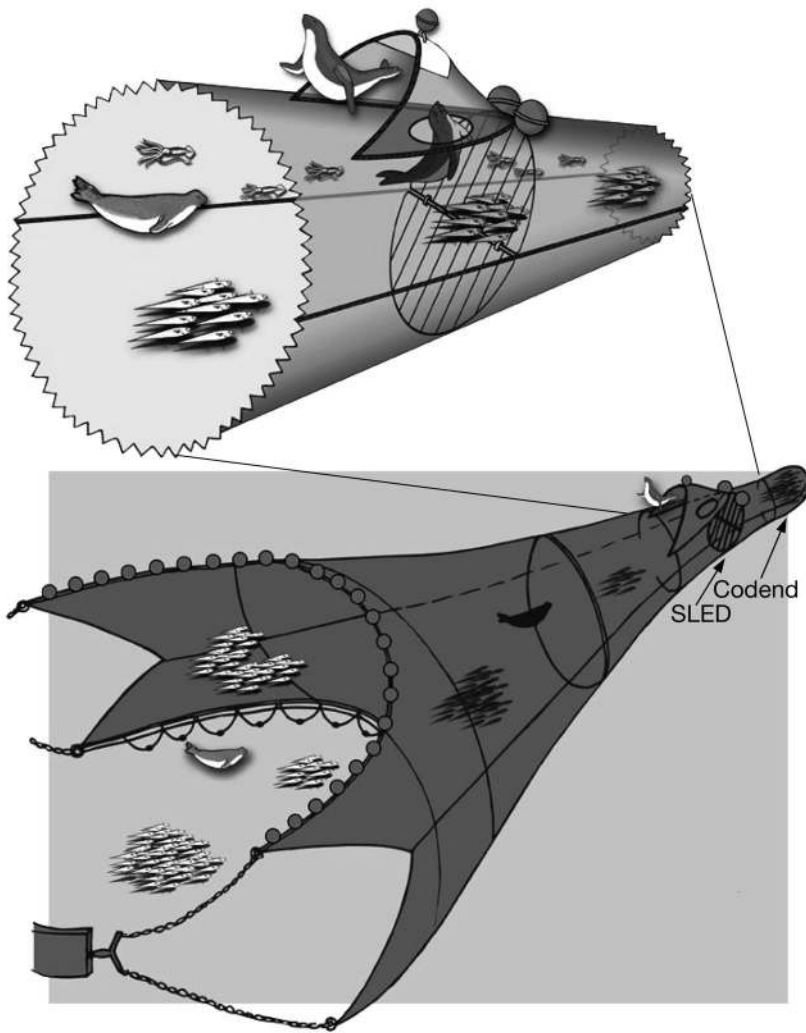


Fig. 4. Diagrammatic representation of a sea lion exclusion device (SLED) showing how and where a SLED fits into a trawl net, just before the cod-end (Ministry of Fisheries, New Zealand)

their chances of survival after escaping from trawl nets (Wilkinson et al. 2003). Therefore, uncertainty about the efficacy of SLEDs remains, and their continued use prevents direct counts of the number of sea lions harmed or killed in the fisheries.

Between 1992 and 2007, 226 sea lions were captured on observed vessels; 58% of these animals were female (Table 1). However, since SLEDs have been used full time in the fishery (2004) the proportion of adult females captured on observed vessels has increased to 82% (Table 1). Given the NZ sea lions' breeding cycle (in which adult females give birth to a pup, are mated and therefore pregnant again within the breeding season—December/January each year) these 82% of captured animals could have a dependent pup ashore and be pregnant, resulting in 3 sea lion deaths when an adult female is captured, rather

than a single death when a male is captured. There are also sea lion mortalities in fisheries other than SQU6T, including SQU1T and fisheries that target other seafood species in the southern ocean, such as scampi *Metaneuphrops challengerii* and southern blue whiting *Micromesistius australis* (Ministry of Fisheries 2006). These deaths are currently not included in any population or management model for the NZ sea lion species.

### CURRENT MANAGEMENT

Under the New Zealand threat classification system (Hitchmough 2002) and in accordance with the Marine Mammals Protection Act 1978, NZ sea lions have to

...be managed to a level of human-induced mortality which would allow the species to achieve non-threatened status as soon as reasonably practicable, and in any event within 20 years.

Given that the most significant human impact on the population is the squid trawl fishery, one of the major aims of management is to reduce fisheries bycatch to the point that it does not prevent or significantly delay recovery of the Auckland Island breeding population, nor reduce the probability of colonization of new breeding locations.

Current management of sea lion and trawl fishery interactions is 2-fold.

Firstly, there is an input control, the 12 n mile MMS and MR surrounding the Auckland Islands, in which no trawling or any other form of fishing are allowed. As seen in Fig. 5, however, this area does not protect the entire foraging area of any lactating NZ sea lion for which foraging data are available (Chilvers et al. 2005). Secondly, there are output-based management controls, i.e. the number of NZ sea lions the trawl fishery may kill incidentally as bycatch within SQU6T before this fishery area is closed for the season (Table 1). The first management model used to set the bycatch limit was called a MALFIRM (maximum allowable level of fishing related mortality), which was derived using the same formula as the potential biological removal (PBR) developed by the US National Marine Fisheries Services (Wade 1998). In 2003, this model was superseded by the fisheries-related mortal-

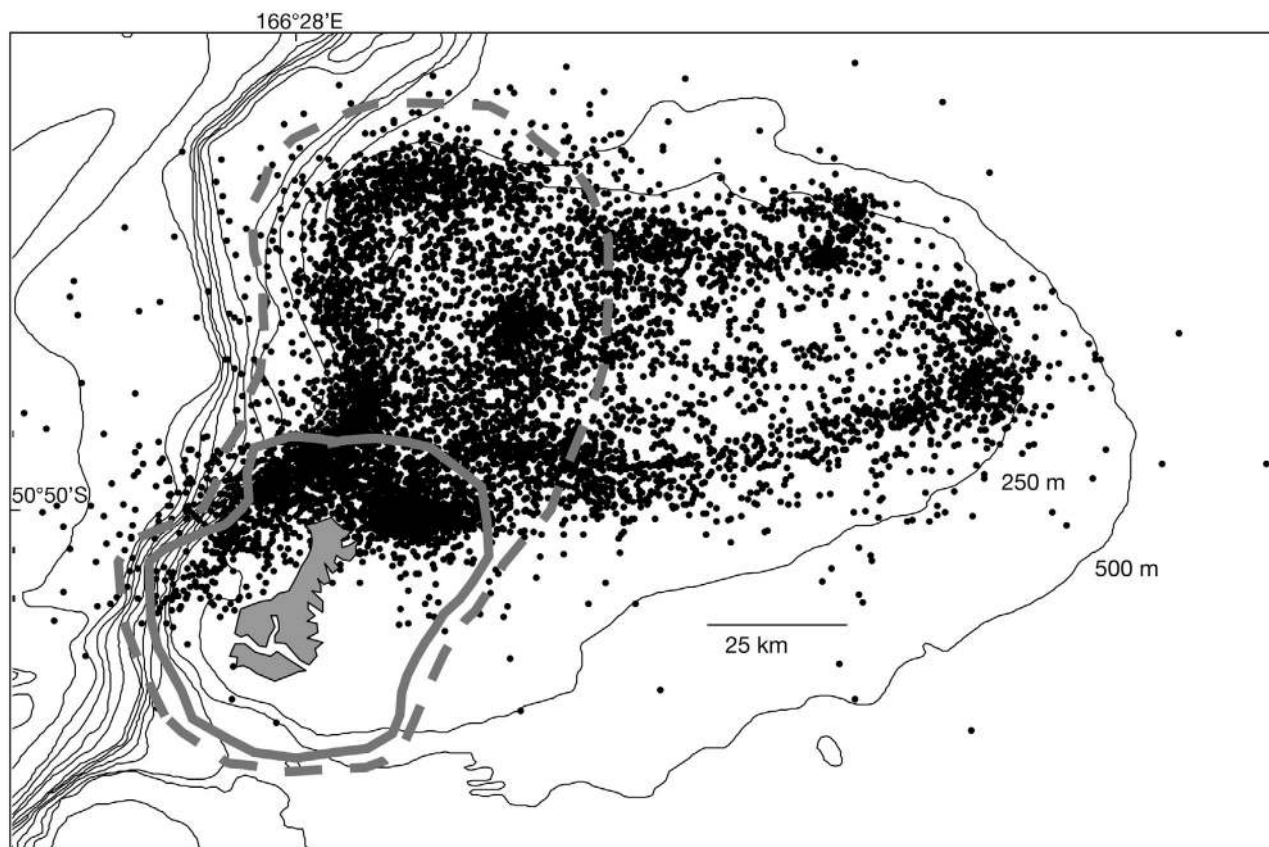


Fig. 5. *Phocartos hookeri*. Distribution of foraging locations for 26 lactating female sea lions and the current 12 n mile Marine Reserve and Marine Mammal Sanctuary (thick solid grey line), showing the limited protection the current MPAs allow over lactating females' foraging areas. An alternative marine protected area (MPA) that would protect the entire foraging areas of 18 of the 26 lactating females in which 72% of all bycatch currently occurs is shown by the dashed grey line. This protected area would still allow over 50% of current fisheries activities to continue. The Auckland Islands are represented in grey

ity limit (FRML), which is currently established using an 'adaptive' rule derived from a Bayesian model (Breen et al. 2003). This management model has been in use for the last 4 fishing years (2003-04 to 2006-07). In the first year of the Bayesian model FRML, the Minister of Fisheries was successfully taken to the Court of Appeal to have the FRML of 62 sea lions set aside and to allow the continuation of fishing up to a bycatch kill limit of 124 sea lions (Squid Fishery Management Company Ltd vs. Minister of Fisheries, 7 April 2004, New Zealand Court of Appeal, CA 39/04). Following this, the FRML was set at 115 in the 2004-05 season and 97 in the 2005-06 season. However, during the 2005-06 season, the FRML was again increased mid-season by the Minister of Fisheries to a bycatch limit of 150 sea lions, although this number was not reached (Table 1). These 'in-season' management changes reflect the difficulty that the current management has in striking a balance between utilization of the squid fishery and the protection of NZ sea lions. These in-season changes were not modelled using the FRML

model; consequently the impact of these extra deaths on the NZ sea lion population is unknown.

In addition to these 2 management controls, mitigation measures have been put in place by the fishing industry in an attempt to mitigate fisheries bycatch of NZ sea lions. These measures include the use of SLEDs and a voluntary code of operating practice that includes: (1) the training of crew members on how to handle and safely release live sea lions to sea; and (2) the completion of bycatch report forms by skippers (Wilkinson et al. 2003).

#### ALTERNATIVE MANAGEMENT OPTIONS

New Zealand sea lions were first classified as 'threatened' in July 1997. For the following 1997/98 season, the pup production estimate for the Auckland Islands was 3021 (Chilvers et al. 2007a). Pup production estimates have been in almost constant decline; the last published pup production figure for the Auckland Islands from the 2005-06 season was 2089, reflecting a

30.8% decrease since the species was declared threatened (Chilvers et al. 2007a). The current management of this species is therefore not likely to meet the requirements set out under the New Zealand Marine Mammals Protection Act 1978. This is despite the MMS and MR protection of the area immediate to the NZ sea lion breeding area, the fisheries output management measures for SQU6T, and the fishing industry's mitigation measures. In this section, I investigate options for additional or alternative management that may achieve a balance between the utilization of the arrow squid fishery and the protection of NZ sea lions.

Under existing New Zealand legislation, there are 4 management options. The first 2 are administered by the Department of Conservation and the second 2 are administered by the Ministry of Fisheries, regulated under the Fisheries Act (1996):

(1) The extension of MPAs (either Marine Reserves; Marine Reserves Act 1971 and/or Marine Mammal Sanctuaries; Marine Mammal Protection Act 1978);

(2) Output control under the Marine Mammal Protection Act (1978) to develop a Population Management Plan (PMP) for NZ sea lions, which would allow the Department of Conservation to set maximum allowable levels of fishing related mortality (MAL-FIRM) for the squid fishery. The current output limit, the FRML, is undertaken by the Ministry of Fisheries under the Fisheries Act (1996);

(3) Input control mechanisms allowed under the Fisheries Act (1996), which allows the prohibition of fishing within set areas and/or prohibition of specific fishing methods;

(4) The adjustment of fisheries quotas within each fisheries management area, i.e. quota could be removed from SQU6T, or removed and reallocated to SQU1T.

### Input control — MPA protection

It is evident from the documented and inferred overlap between NZ sea lions and fisheries that fishing is likely to have in both direct (mortality) and indirect (resource competition) effects. Knowledge of the site fidelity of breeding NZ sea lion females to foraging areas (Chilvers et al. 2005) allows for the development of more scientifically robust and effective MPAs than currently exist, which would result in greater protection for this species. The optimal protection area for a species would encompass that species' year-round distribution (Reeves 2000). However, the year-round distribution of NZ sea lions spans from Macquarie Island (64°S, 150°E) to the New Zealand mainland (Fig. 1). Where it is impractical to protect a species across its full range, the focus must be on the most important

areas for protection, which will be the concentrated breeding areas for polygamous pinnipeds. For example, when there is evidence of depressed breeding success due to local food limitations at breeding sites, the biggest conservation gains would be made by protecting foraging areas to encourage an increase in the breeding population (by enhancing reproductive success or breeding population size) (Hooker & Gerber 2004). In this case, MPAs should be established to protect the important food resources utilized during the breeding season as well as the breeding individuals and sites. This is particularly appropriate for NZ sea lions, where the breeding range is restricted to an area of low productivity that is also commercially harvested (Bradford-Grieve et al. 2003). Foraging studies have shown that the current 12 n mile MPA surrounding the Auckland Islands does not provide protection for the entire foraging area for any lactating female tracked (my Fig. 5; Chilvers et al. 2005). To fully protect all of the known foraging ranges of female NZ sea lions from Enderby Island, an MPA would need to extend to more than 100 km around the Auckland Islands, or the Auckland Island shelf would need to be closed out to the 500 m bathymetric contour. This would result in complete closure of the SQU6T fishery around the Auckland Islands.

Under current legislation, Marine Reserves boundaries, which are no-take areas and therefore would award the greatest protection, cannot be extended beyond 12 n miles from land. However, the 2 other mechanisms of regulation, Marine Mammal Sanctuaries and the Fisheries Act restrictions, could cover larger areas and therefore have the potential to markedly increase protection for foraging sea lions. For example, an MMS or restriction of trawling could be extended out to (1) 100 km; (2) the Auckland Rise edge, 500 m bathymetric contour; or (3) cover an area such as that seen in Fig. 5, which encompasses the entire foraging range of 18 of the 26 satellite-tracked females (69%). Such an area would cover the region in which 72% of all bycatch incidents occur, but would still allow ~50% of current fisheries activities to continue to the south (Fig. 2). Alternatively, the restriction of fishing methods to squid jigging within these areas or over the entire SQU6T area would result in an estimated zero sea lion bycatch and yet still allow fishing up to squid quota within the area (Sauer 1995, Arnould et al. 2003). Trawling is a mid-water and bottom fishing method that directly interacts with diving sea lions. Jigging would eliminate habitat disturbance and associated flow-on effects, such as benthic prey depletion, which are caused by trawling (Watling & Norse 1998, Thrush & Dayton 2002). This type of MPA fisheries management has been implemented and appears to be successful for Steller sea lions in Alaska (Hennen

2006). The establishment of an extended protection area or a change of fishing method would not only increase protection for NZ sea lions, but would also enhance the protection of 52 breeding marine bird species (including 3 threatened penguin species, 5 petrel species, 17 albatross species—many of which are listed as vulnerable—terns, prions and cormorants), as well as New Zealand fur seals, southern elephant seals *Mirounga leonine* and threatened southern right whales *Eubalaena australis*, all of which forage and breed around the Auckland Islands (Sauer 1995, Barton 2002, Whitelaw 2002).

### Output controls—PMP and quotas

A PMP for NZ sea lions (Section 3E under the Marine Mammals Protection Act 1978) would allow the Department of Conservation to set a MALFIRM for the squid fishery. Currently, limits are set by the Ministry of Fisheries in the form of an FRML, which has to ensure the sustainable use of the fishery in its calculation of a bycatch limit. In contrast, the MALFIRM only has to account for the management and threat status of the marine mammal in question. This would undoubtedly lead to a more conservative bycatch limit for NZ sea lions. However, in gazetting a PMP, the Minister of Conservation must get concurrence from the Minister of Fisheries, which would ensure that any MALFIRM was not overly conservative. Such a MALFIRM would allow fewer 'in-season' management changes to occur as a result of court action from the fishing industry, as the MALFIRM does not have to be set, or indeed upheld in a court of law, to allow a balance between utilization of the squid fishery and the protection of NZ sea lions. A reduction in 'in season' MALFIRM alternatives would also allow for better modelling and management predictions of the effects of fishing mortality on the sea lion population.

The second output control option, which would be administered by the Ministry of Fisheries and regulated under the Fisheries Act (1996), would require the adjustment of the total allowable commercial catch limits (TACC) in the fisheries quota management area. The 2 main trawl squid fisheries quota management areas SQU6T and SQU1T have a combined TACC of 77 110 t per year. Between 55 and 94 % of that TACC has been caught in the last 5 yr. The TACC in SQU6T is 32 369 t and in SQU1T 44 741 t. The possibility of transferring quota from SQU6T to SQU1T, to still allow a combined catch of 77 110 t in New Zealand waters but reduce the catch within SQU6T, which is the area immediately adjacent to the Auckland Islands and NZ sea lions' main breeding colonies, could be investigated. This quota reallocation could be done in con-

junction with the area closures suggested above. Thus, closing off the area north of the Auckland Islands (Figs. 2 & 5) and reallocating that quota (approximately half of the 6T quota) to 1T would allow significantly higher protection for NZ sea lions without reducing the economic return of the squid fishery to New Zealand.

### CONCLUSIONS

The conflict between resource use by humans and wildlife conservation is ubiquitous and increasing throughout the world. The marine environment is no exception. However, protection of a species need not necessarily preclude the use of resources. Better utilization of New Zealand's current legislation, including the consideration of MPAs and fisheries regulations that allow for the restriction of fishing or other practices as opposed to complete area closures, should enable concurrent species conservation and resource utilization. In the case of the NZ sea lion, greater protection is required around their only breeding stronghold. This is particularly important given the documented consistent decline in pup production since 1998 (30 % decline), the mass mortality episodic events and anthropogenic impacts on this population. Although it is important to strike a balance between protection and utilization, it is critical that any measures implemented lead to real conservation benefits. This does not appear to currently be the case for NZ sea lions. Therefore, we need to seek alternative management options to enhance protection for NZ sea lions, while still allowing profitable fisheries.

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