



# Whisker stable isotope analysis used for proactive management of recolonising New Zealand sea lion population

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**ABSTRACT:** New Zealand sea lions *Phocarctos hookeri* have experienced a 46% decline in pup production in the last 25 yr, driven by female deaths in trawl fisheries around the Auckland Islands. The only colony for this species recorded away from the subantarctics and this fishing impact is on Stewart Island. Despite the Stewart Island colony only being 1% of the species, it is significant, as it is currently the only stable population and is located in an area away from most on-land human impacts, although not away from potential fisheries pressures. To ensure this colony's persistence, more information is needed on these sea lions' diet, foraging behaviour, and local fisheries interactions for management that promotes their protection. The present research investigates the long-term foraging behaviour, and infers the diet, of female New Zealand sea lions on Stewart Island using their known foraging behaviour and linking this to their proximal and full-length whisker stable isotope values. Previous foraging studies found that these animals have small foraging areas with consistent mesopelagic diving behaviours. These behaviours, linked with their whisker stable isotope values, show consistency in foraging behaviour and inferred diet across their entire adult life. Currently, there are no known commercial fisheries bycatch issues for sea lions around Stewart Island. However, precautionary measures ensuring fisheries pressure does not increase and management to safeguard that deepwater trawling and finfish aquaculture remain absent would be proactive steps that should be undertaken for the protection of this new colony and for this Endangered species as a whole.

**KEY WORDS:** *Phocarctos hookeri* · Fisheries interactions · Diet · Foraging · Stable isotope

## 1. INTRODUCTION

New Zealand sea lions *Phocarctos hookeri* once bred on mainland New Zealand and its offshore subantarctic islands (Fig. 1). However, Polynesian harvest and European sealing during the 19<sup>th</sup> and 20<sup>th</sup> centuries drove them to extinction around mainland New Zealand, leaving breeding populations only on subantarctic islands (Collins et al. 2014). Since 1998, the remnants of the species in the subantarctics have declined significantly, with the New Zealand sea lion listed as Endangered by the IUCN in 2015 (Chilvers 2015). The species decline has been led by a signifi-

cant decrease at the Auckland Islands, the largest breeding area, driven by female deaths in the localised trawl fishery (Robertson & Chilvers 2011, Meyer et al. 2015). The 2022–2023 year showed the continuation of this significant decline at the Auckland Islands with only (mean  $\pm$  SE) 1278  $\pm$  23 pups born, down from 3021  $\pm$  35 pups in 1998, a 58% decrease in pup production at the Auckland Islands and a 46% decline for the species overall (Chilvers & Dobbins 2021, Manno & Young 2023).

Very small numbers of female New Zealand sea lions have been recolonising mainland New Zealand around the Otago Peninsula and lower southeastern

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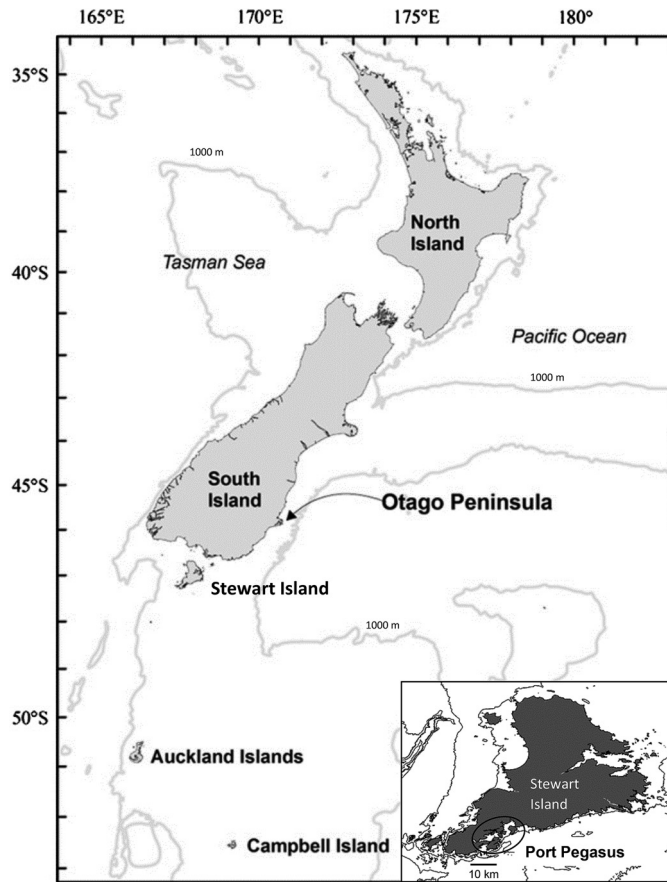


Fig. 1. New Zealand sea lion *Phocarcus hookeri* breeding areas: Auckland Islands, Campbell Island, Stewart Island, and Otago Peninsula. Inset: Stewart Island, showing Port Pegasus circled

South Island area since 1993 (Fig. 1, McConkey et al. 2002). All of the recolonising females had been tagged as pups on the Auckland Islands. These females, daughters, granddaughters, great-granddaughters, and great-great-granddaughters now breed on the New Zealand mainland, with a combined 21 New Zealand sea lion pups born in the lower east coast of South Island in 2020 (Chilvers & Dobbins 2021). At a similar time, if not before, females also appeared to be pupping at Port Pegasus, Stewart Island; however, breeding was not confirmed there until 2011, when 16 pups were found and tagged in the Port Pegasus area (Chilvers & Dobbins 2021, Fig. 1).

Little is known about the New Zealand sea lion population on Stewart Island due to their sparse distribution, cryptic nature, and continuously moving habitat behaviours in an area of New Zealand that is very remote, heavily forested, and unpopulated by humans. Even though breeding was only confirmed in 2011, the population was recorded as being an officially recognised breeding population in 2018. In

2018, the population was recorded as having 35+ pups born annually in 5 consecutive years within the Port Pegasus area, Stewart Island (Fig. 1, definition of an official breeding colony from New Zealand's Department of Conservation [<https://www.doc.govt.nz/nature/native-animals/marine-mammals/seals/new-zealand-sea-lion/new-zealand-sea-lion-rapoka-threat-management-plan/>], Chilvers & Dobbins 2021). Since 2011, all pups found in Port Pegasus in a 10 d period during March each year have been tagged and their presence and dispersal behaviour followed through resighting (Chilvers & Dobbins 2021). There has not been enough time or resighting information for the Stewart Island tagging data set to allow for the estimation of any survival or reproductive parameters for this population, as the resighting rate is very low due to the location of the populations. It does, however, appear that the population in the area is small but stable (Chilvers & Dobbins 2021). Together with the lower South Island–Otago population, these 2 populations combined still only represent 2% of the New Zealand sea lion species. Given these populations are not declining (unlike the sub-antarctic populations), it is an area of significance for New Zealand sea lions. More information is needed to ensure their management encourages persistence, protection, and growth of these 2 populations on New Zealand's mainland islands.

Small populations with restricted distribution, for any species, make them vulnerable to localised extinction-causing events such as high hunting pressure, fisheries bycatch, and/or epizootic diseases. In pinnipeds (seals, sea lions, and walruses), global bycatch is recorded in 100 000's, with bycatch having significant demographic effects on populations, as seen in the Auckland Islands population of New Zealand sea lions (Read et al. 2006, Meyer et al. 2015, Chilvers & Meyer 2017). Additional to the concern of bycatch on the 2 mainland populations of New Zealand sea lions, there are records of harassment and shooting causing serious injury or death, pup deaths from dog attacks, hit-and-run deaths by cars, and lethal interactions occurring around finfish aquaculture (Chilvers & Dobbins 2021). Much of this human harassment is thought to be due to the perception that seals threaten or compete with recreational and commercial fisheries and aquaculture for resources and/or prey, which appears to be leading to harassment, shootings, and disturbances (Kovacs et al. 2012).

To understand the interactions between fisheries and any pinniped population, an understanding of the pinnipeds' diet, foraging behaviour, and foraging areas is needed as well as knowledge of the consistency

of diet and use of foraging areas (Butterworth et al. 1988, Goldsworthy et al. 2003, Weise & Harvey 2008). The diet of New Zealand sea lions has been well researched for all populations except Stewart Island. This has been undertaken through scat, regurgitation, stable isotope, and fatty acid analysis (Milne 1996, Childerhouse et al. 2001, Meynier et al. 2008a, 2009, 2010, 2014, Augé et al. 2012, Stewart-Sinclair 2013, Lalas & Webster 2014, Roberts & Lalas 2015, Chilvers 2017, 2019, 2021). Several of these studies investigated diet for the Auckland Islands population over a longer term using either fatty acid analysis (Meynier et al. 2008a, 2010), a long-term data series of scat sampling (Stewart-Sinclair 2013), or foraging behaviour and whisker stable isotope analyses (Chilvers 2019). Similarly, the foraging behaviour of female New Zealand sea lions at the Auckland, Campbell, and Stewart islands and the Otago Peninsula has been researched (i.e. Chilvers et al. 2005, 2006, Chilvers & Wilkinson 2009, Augé et al. 2011a,b, 2014, Leung et al. 2012, 2014, Chilvers 2018, R. Mattlin unpubl.). For Enderby Island in the Auckland Islands group, females have clear life-long linkages between diet and foraging behaviour, shown through both fatty acid analysis and stable isotope analysis of their whiskers (Meynier et al. 2014, Chilvers 2019).

For marine predators, stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope ratios reflect their isotopic diet and foraging niche along 2 dimensions. Firstly,  $\delta^{13}\text{C}$  reflects the foraging habitat of the predators, and secondly,  $\delta^{15}\text{N}$  values reflect the foraging trophic level of the predators (Newsome et al. 2010). Analysis of blood, blubber, milk, hair, whisker, and teeth reflects diet and foraging behaviour over different timescales (Crawford et al. 2008). For lifetime diet and foraging strategies investigation, inert keratinised tissues (i.e. whiskers) document the stable isotope ratio for individuals at the time of growth; therefore, these values are unchanged once whiskers have grown (Cherel et al. 2009). Proximal whisker samples taken from the end of the whisker near the face represent the most recent tissue and therefore record isotopic values, diet, and foraging strategies for the last weeks to months, depending on whisker growth rates. Therefore, as the whiskers grow, they record the individual's foraging behaviour and diet throughout its life (Cherel et al. 2009, McHuron et al. 2016). For pinnipeds, stable isotope analysis has shown seasonal, inter-annual, and decadal changes in the diet of individuals and relates to shifts in prey distribution, marine conditions variation, and migratory patterns (i.e. Hall-Aspland et al. 2005, Cherel et al. 2009, Drago et al. 2009, Hanson et al. 2009).

For female New Zealand sea lions on Enderby Island in the Auckland Islands group, satellite tracking and dive behaviour research have shown individuals display distinct foraging behaviours. These can be categorised as benthic (sea floor foraging) or mesopelagic (foraging at various depths in the water column, Chilvers & Wilkinson 2009). These strategies have also been identified in diet compositions, by both qualitative and quantitative fatty acid analysis (Meynier et al. 2014), and in blood, proximal and full-length whisker stable isotope values (Chilvers 2017). Chilvers (2017) showed that the isotopic composition of blood serum matched the foraging strategy undertaken by 22 female New Zealand sea lions from Enderby Island (foraging strategy shown through telemetry research) and therefore reflected their diet. Similarly, blood serum and proximal whisker growth have similar values, reflecting that the isotopic composition of whiskers for female New Zealand sea lions reflects their diet at the time of their growth. Chilvers (2019) took the research one step further, showing that the foraging behaviour and diet of individuals were consistent throughout their lifetime, as shown in the analysis of the full length of their whiskers.

Using these proven techniques and examples for New Zealand sea lions, the present research is designed to investigate the long-term foraging behaviour and infer the diet of female New Zealand sea lions at the new Stewart Island colony using their known foraging behaviour (Chilvers 2018) and linking this to their proximal and full-length whisker stable isotope values. Understanding these long-term foraging strategies and the flexibility or rigidity of these strategies will pre-empt any discussions regarding New Zealand sea lion foraging patterns, diet, and overlap with fisheries in the Port Pegasus, Stewart Island, area. Additionally, understanding long-term foraging behaviour is critical to understanding the role of apex predators in aquatic ecosystems and how populations could respond to environmental variability such as climate change (Chilvers 2019).

## 2. MATERIALS AND METHODS

### 2.1. Sampling

The present research was undertaken within Port Pegasus, Stewart Island (47° 21' S, 167° 64' E, Fig. 1), during the austral autumns of May 2012 and March 2013. Eight females were captured each year, with foraging behaviour monitored. Two individuals were monitored across both years, therefore giving a total

of 14 individuals. Female New Zealand sea lions were identified and monitored for 3 h before capture to reduce the possibility of food in their stomachs, which can cause vomiting while anaesthetised. Each female was captured by placing a net over her head, preferably while asleep so that when she awoke, her forward movement drove her further into the tapering restraining net. The net end was constructed as a small reinforced opening that held the sea lion's muzzle, closing the mouth but leaving the nostrils clear (Gales & Mattlin 1998, Costa & Gales 2000). The caught sea lion was physically restrained by 2 to 4 people and anaesthetised using an isoflurane–oxygen mix (2–5%) delivered via a mask using a portable vaporising system (Gales & Mattlin 1998, Chilvers 2018). The time taken from capture to anaesthetisation was approximately 5 min, with each sea lion anaesthetised for up to 20 min. Once fully anaesthetised, the sea lion was weighed ( $200 \pm 0.5$  kg capacity scale) and measured before instruments were attached (see Chilvers 2018 for instruments used, attachment procedures, and analysis of foraging data). Instrument attachment took 8 to 10 min after glue application; then, the most caudal whisker on the left side of each animal's face (Sadou et al. 2014) was cut off and collected. Whiskers were cut as close to the face as possible and stored in individual plastic bags until they were cleaned just before analysis. The flow of anaesthetic and oxygen was then stopped, and the animal was observed until fully recovered. See Chilvers (2017, 2019) for details on the sampling of individuals from the Enderby Island, Auckland Islands, population.

## 2.2. Isotope analysis

Stable isotope analysis was undertaken by the Waikato Stable Isotope Unit, Department of Biological Sciences, University of Waikato, Hamilton, New Zealand. Whiskers were individually cleaned for 5 min in distilled water and soaked for a further 5 min with 96% ethanol, followed by a final cleaning and scraping for 5 min with distilled water (Cherel et al. 2009). A stereomicroscope was used to check whiskers for any remaining tissue or dirt. Any contaminants were removed with a scalpel blade; then, samples were left to air dry overnight. Whiskers were measured and cut into 5 mm consecutive sections starting from the proximal end. Sections were weighed with a microbalance and packed in tin foil capsules, and  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  were determined by a Dumas elemental analyser (Europa Scientific ANCA-SL) interfaced to

an isotope ratio mass spectrometer (Europa Scientific 20-20 Stable Isotope Analyser).

Sampling was also performed on finfish caught in both areas, the Campbell Plateau (where the Auckland Islands are located, Meynier et al. 2008b) and Port Pegasus. Finfish samples were collected from javelin *Coelorinchus australis* ( $n = 5$ ), opalfish *Hemerochetes monopterygius* ( $n = 5$ ), red cod *Pseudophycis bachus* ( $n=15$ ), blue cod *Paraperchis colias* ( $n = 10$ ), hoki *Macruronus novaezelandiae* ( $n = 5$ ), and triplefin species (Tripterygiidae spp.,  $n = 13$ ). These samples were used to define baseline isoscapes between the 2 regions. Finfish samples were dried to constant weight at  $60^\circ\text{C}$ , weighed to 5 g, packed in tin foil capsules, and analysed as above. All results are presented in the conventional delta ( $\delta$ ) notation calculated as the relative variation of stable isotope ratios expressed as per mille (‰) relative to a laboratory standard reference for sucrose and urea (the urea had been calibrated relative to atmospheric nitrogen) for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively. Quality control samples were run before and after every 12 samples. Precision for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  measurements was 0.1 and 0.2‰, respectively.

## 2.3. Statistics

Using SPSS (version 29 for Windows), differences between whisker samples for each individual's location and foraging strategy were tested using general linear models (GLMs), with post hoc comparisons undertaken using Tukey's *b* tests. Data were checked for normality and homogeneity of variance via Shapiro-Wilk and Levene's tests, respectively. The correlation between  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values along each individual's whisker was tested using Pearson's correlation (*r*). Unless otherwise stated, data are presented as mean  $\pm 1$  SE, and results are considered significant at  $p < 0.05$ .

## 3. RESULTS

### 3.1. Foraging behaviour

Satellite and dive data from the 14 female New Zealand sea lions from Stewart Island are published in Chilvers (2017). In summary, the foraging study showed that lactating females from the Port Pegasus area spent, on average, only 15 h at sea foraging, followed by 13 h on land between foraging trips. They travelled, on average, less than 28 km from shore,

with an average total foraging trip distance of 45 km, concentrating their foraging areas to within, on average, a 38 km<sup>2</sup> home range. Their diving behaviour shows they dive almost continuously while at sea, with 62% of their time at sea spent below 6 m in depth. They have comparatively shallow dives for female New Zealand sea lions, with mean dive depths of 60 m and maximum dives between 250 and 300 m (Chilvers 2017). Dive patterns from females with complete time depth recorder (TDR) profiles showed a variable mesopelagic diving behaviour (Chilvers 2018).

### 3.2. Stable isotope values

Stable isotope values from the proximal and mean sequentially sampled whiskers of 14 female New Zealand sea lions from Stewart Island are shown in Table 1, along with the Pearson's correlation coefficient between the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values along each individual's whisker. There was only 1 known-age female from this study (6064, Table 1). Assuming female New Zealand sea lion whiskers grow continuously at a comparable rate across the life of the individual and are not shed as adults, as seen in other otariids (Hirons et al. 2001, Rea et al. 2015, McHuron et al.

2016), each 5 mm whisker section for 6064 represented 4 mo of her life, based on dividing the female's known age by her whisker length (Table 1). Based on whisker length and age, the mean whisker growth rate for 6064 was 0.06 mm d<sup>-1</sup> (this being a minimum estimate, as this would not take into consideration any wear at the whisker tip). The length of whiskers across the 14 females ranged from 85 to 200 mm, and the number of whisker sections analysed for each individual varied accordingly from 14 to 40 (Table 1).

There was only a small range in both proximal and mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for individuals (Table 1), with  $\delta^{13}\text{C}$  values ranging from -14.1 to -16.1‰ for proximal values (difference 2‰) and -14.6 to -15.6‰ for combined average whisker length values (difference 1‰). The largest individual difference for  $\delta^{13}\text{C}$  was between -15.7 and -14.0‰ (-1.7‰). For  $\delta^{15}\text{N}$ , proximal values ranged between 14.4 and 16.5‰ (difference 2.1‰), and average whisker length values between 14.8 and 16.0‰ (difference 1.2‰). The largest difference within an individual range for  $\delta^{15}\text{N}$  was 3.0‰, being between 14.5 and 17.5‰. In both cases, the largest variation was seen in E793 (Table 1).

There was no correlation associating high  $\delta^{13}\text{C}$  variation along the length of the whisker with high  $\delta^{15}\text{N}$  values for any individual or vice versa. Evidence from foraging data that females are not foraging over

Table 1. Female identification, breeding status, year, weight, length, whisker length and number of sections, proximal stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope values, and mean stable isotope values from the whisker length of 14 female New Zealand sea lions *Phocarctos hookeri* from Stewart Island, New Zealand. Means presented  $\pm$  SE. r: correlation between  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ; SI: stable isotope; meso: mesopelagic dive profile, Enderby Island (Chilvers & Wilkinson 2009, Chilvers 2019); benthic: benthic dive profile, Enderby Island (Chilvers & Wilkinson 2009, Chilvers 2019); n.a.: not available

Female ID	With pup	Year	Weight (kg)	Length (cm)	Whisker length (mm)	No. of 5 mm sections	Proximal $\delta^{15}\text{N}$ whisker sample (‰)	Proximal $\delta^{13}\text{C}$ whisker sample (‰)	Mean $\delta^{15}\text{N}$ for length of whisker (‰)	Mean $\delta^{13}\text{C}$ for length of whisker (‰)	r
6064 <sup>a</sup>	Yes	2012	181	106	105	21	15.8	-15.4	15.9 $\pm$ 0.10	-14.8 $\pm$ 0.09	0.88
E788	Yes	2012	109	181	101	20	15.2	-15.7	15.0 $\pm$ 0.12	-15.6 $\pm$ 0.08	0.58
E789	Yes	2012	140	193	85	14	14.4	-16.1	14.8 $\pm$ 0.09	-15.5 $\pm$ 0.08	0.65
E790	Yes	2012	106	110	101	20	14.9	-15.4	14.9 $\pm$ 0.06	-15.1 $\pm$ 0.05	0.32
E791	Yes	2012	113	191	105	19	15.4	-15.5	15.0 $\pm$ 0.11	-15.5 $\pm$ 0.07	0.75
E792	Yes	2012	n.a.	173	86	17	15.6	-15.4	15.9 $\pm$ 0.11	-14.8 $\pm$ 0.09	0.72
E793	Yes	2012	112	187	140	28	15.4	15.6	15.5 $\pm$ 0.15	-14.9 $\pm$ 0.10	0.93
E794	Yes	2012	120	188	92	16	15.1	-15.4	15.1 $\pm$ 0.15	-15.1 $\pm$ 0.06	0.75
H822	Yes	2013	125	191	125	25	15.9	-14.1	15.7 $\pm$ 0.04	-14.6 $\pm$ 0.05	0.34
H823	No	2013	97	172	135	27	15.0	-15.3	15.7 $\pm$ 0.14	-15.1 $\pm$ 0.06	0.78
H824	Yes	2013	118	188	200	40	14.9	-15.6	15.1 $\pm$ 0.11	-15.1 $\pm$ 0.04	0.48
H825	Yes	2013	129	188	160	32	15.8	-14.9	15.3 $\pm$ 0.11	-14.8 $\pm$ 0.04	0.33
H826	No	2013	89	169	95	19	16.4	-15.1	16.0 $\pm$ 0.10	-14.9 $\pm$ 0.05	0.31
H828	No	2013	120	112	145	29	16.5	-15.0	15.5 $\pm$ 0.07	-15.1 $\pm$ 0.02	0.23
SI ave.							15.4 $\pm$ 0.17	-15.3 $\pm$ 0.12	15.4 $\pm$ 0.11	-15.1 $\pm$ 0.08	
Meso ave.							12.9 $\pm$ 0.13	-15.5 $\pm$ 0.02	13.1 $\pm$ 0.18	-15.3 $\pm$ 0.06	
Benthic ave.							11.5 $\pm$ 0.05	-16.2 $\pm$ 0.02	11.5 $\pm$ 0.08	-16.2 $\pm$ 0.06	

<sup>a</sup>Known age of 7 yr in 2012; therefore 5 mm sections represent approximately 4 mo or 0.06 mm growth d<sup>-1</sup>

a large area, and foraging occurs mostly close to shore (Chilvers 2018), signifies individuals are eating a range of trophic-level species in a relatively restricted location. However, generally, the higher the  $\delta^{15}\text{N}$  values for an individual, the lower the  $\delta^{13}\text{C}$  values for both proximal and overall values (Table 1), indicating higher trophic level prey are generally being foraged further offshore. Table 1 and Fig. 2 show the mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for the entire whisker length from female New Zealand sea lions from Stewart Island. Additionally, Table 1 shows the mean values for mesopelagic and benthic foraging females from Enderby Island, Auckland Islands (Chilvers 2019). Based on telemetry and dive data of the females at Stewart Island (Chilvers 2018), the foraging behaviours of all of the females indicated mesopelagic diving patterns with none showing benthic foraging patterns, which is also indicated in the proximal and full length of the whisker stable isotope values (Fig. 2).

Fig. 3 shows 2 examples of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values across the whisker length of Stewart Island females 6064 and E790. There were no females that show oscillating patterns in stable isotope values along the length of their whiskers, indicating no migration or significant change in geographical foraging locations. The main pattern observed was higher  $\delta^{13}\text{C}$  values at the far end of the whiskers (Fig. 3) when the animals were younger, which then decreased as the

animals aged. Pearson's correlation between the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values along each individual's whisker varied considerably from barely correlated to highly correlated (range of  $r$ : 0.23–0.93). Based on the work for Enderby Island females, this range of correlation indicates support for long-term mesopelagic foraging behaviours for the Stewart Island females. Similar to results for Enderby Island females, whisker length stable isotope results for all Stewart Island females show consistent foraging patterns across their entire whiskers and therefore life.

### 3.3. Comparison with Enderby Island females

The whisker isotopic values from the proximal whisker sample of Stewart Island female New Zealand sea lions showed a smaller range than those of Enderby Island females. For  $\delta^{15}\text{N}$ , Stewart Island females showed a 2.1‰ spread compared to 3.3‰ for Enderby but a larger spread for  $\delta^{13}\text{C}$ , with a 2‰ spread compared to Enderby at 1.5‰ (Table 1, Fig. 2). Over the entire length of the whisker, Stewart Island had a smaller spread than Enderby Island females for both values, with  $\delta^{13}\text{C}$  values ranging from  $-15.6$  to  $-14.6$ ‰ (difference 1‰) compared with Enderby Island females, which ranged from  $-16.6$  to  $-15$ ‰ (1.6‰ difference). For  $\delta^{15}\text{N}$ , average whisker length values for Stewart Island females were 14.8 to 16‰ (difference 1.2‰), while those for Enderby Island females were 11 to 14.7‰ (3.7‰ difference).

There were statistically significant differences in whisker length mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values between females from Stewart Island and benthic and mesopelagic foraging Enderby Island females ( $\delta^{15}\text{N}$   $F_{(2,46)} = 158.1$ ,  $p < 0.001$ ,  $\delta^{13}\text{C}$   $F_{(2,46)} = 67.5$ ,  $p < 0.001$ , Fig. 2). Tukey's  $b$  post hoc tests showed all 3 strategies and locations to be significantly different from each other for mean  $\delta^{15}\text{N}$  values (Enderby Island benthic: 11.5‰, Enderby Island mesopelagic: 13.1‰, Stewart Island: 15.4‰,  $p < 0.001$ ) and  $\delta^{13}\text{C}$  values (benthic:  $-16.2$ ‰, mesopelagic:  $-15.4$ ‰, Stewart Island:  $-15.1$ ‰,  $p < 0.001$ , Table 1). Clear differences in stable isotope values between the 3 strategies and locations can be identified by graphing the mean whisker stable isotope values of individuals (Fig. 2).

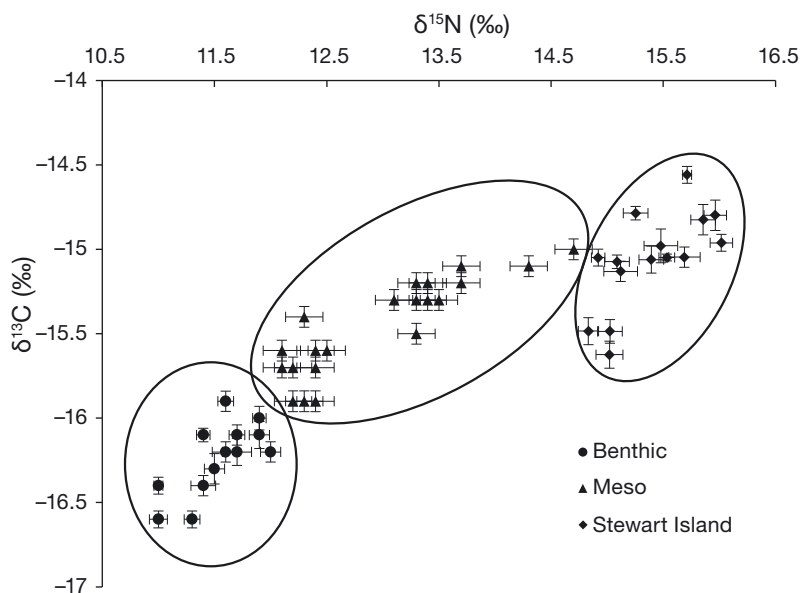


Fig. 2. Female New Zealand sea lion *Phocarctos hookeri* mean stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope values (error bars = SE) for the entire whisker length of females from Stewart Island and mesopelagic and benthic foraging females from Enderby Island, Auckland Islands (Chilvers & Wilkinson 2009, Chilvers 2019)

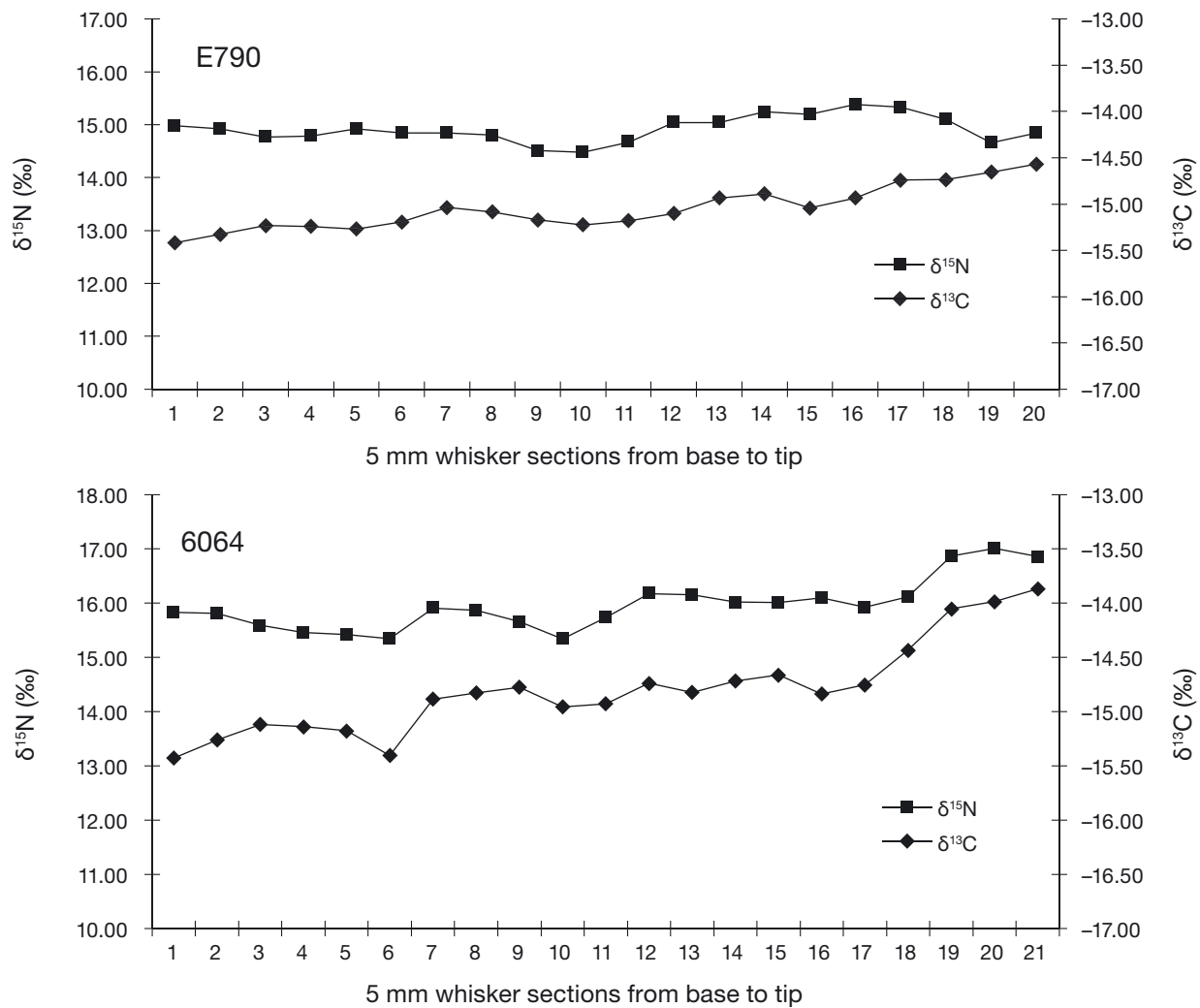


Fig. 3. Stewart Island female New Zealand sea lions *Phocartos hookeri* E790 and 6064 stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope values across the entire whisker length. Sectioning starts from the proximal (base) end of the whisker

### 3.4. Isoscape values

The isotope values from finfish from the Campbell Island Plateau, which represent the potential prey base of the Auckland Islands–Enderby Island females (see Meynier et al. 2008b), showed mean  $\delta^{15}\text{N}$  values of  $10.2 \pm 0.28\text{‰}$  and mean  $\delta^{13}\text{C}$  values of  $-19.5 \pm 0.18\text{‰}$  (Fig. 4). Finfish species from Port Pegasus, Stewart Island, showed mean  $\delta^{15}\text{N}$  values of  $14.5 \pm 0.09\text{‰}$  and mean  $\delta^{13}\text{C}$  values of  $-14.6 \pm 0.26\text{‰}$  (Fig. 4). Higher  $\delta^{13}\text{C}$  values were expected at the lower latitude of Stewart Island (Cherel & Hobson 2007). The differences in isoscape  $\delta^{13}\text{C}$  values, however, do not appear to show in the  $\delta^{13}\text{C}$  values in female whiskers, whereas the lower  $\delta^{15}\text{N}$  values in the Enderby Island isoscape do (Fig. 2).

## 4. DISCUSSION

### 4.1. Stable isotope values and foraging behaviour

The present research was designed to investigate the proximal stable isotope values from the whiskers of female New Zealand sea lions on Stewart Island with their demonstrated foraging behaviour (Chilvers 2018) and then compare this to their full-length whisker stable isotope values, therefore indicating their long-term foraging strategies and inferred diet (Chilvers 2017, 2019). The Stewart Island colony of New Zealand sea lions is a significant colony for this declining Endangered species, despite being only approximately 1% of its total population. It is the first colony to establish on the New Zealand mainland in

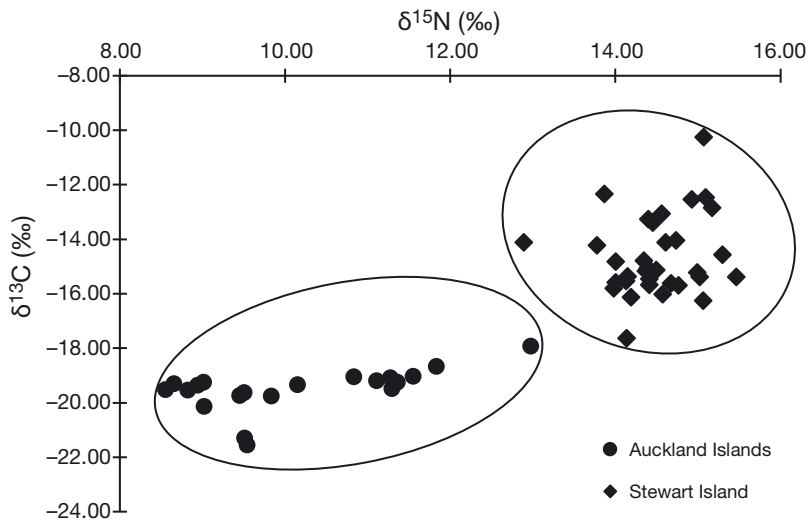


Fig. 4. Stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope values from finfish from the Campbell Island Plateau (Meynier et al. 2008b) and from Port Pegasus, Stewart Island

200 yr. It is recolonising in a remote, only sparsely human-populated area of New Zealand, meaning it has the best chance of establishing and growing without significant terrestrial harassment from humans or dogs or fatal collisions with cars or trains, unlike the Otago population (Chilvers & Dobbins 2021). However, the same should have been able to be said for the even more remote subantarctic populations, where there are no year-round human inhabitants, no dogs, no cars or trains, and no guns allowed. Unfortunately, similar to many pinniped populations, it is not their on-land habitat that is causing their decline but their at-sea foraging range overlap and interactions with fisheries that is causing the significant decline in the Auckland Islands region (Robertson & Chilvers 2011, Meyer et al. 2015). The Auckland Islands population continues to decline at a rate that modelling projected in 2010, which would lead to this population being functionally extinct by 2035 if better management of fisheries interactions is not undertaken (Robertson & Chilvers 2011, Chilvers 2012, Meyer et al. 2015). Given the Stewart Island sea lion population is smaller and more restricted in distribution than the Auckland Islands population, it makes them extremely vulnerable to localised impacts such as is impacting the Auckland Islands. Being able to pre-emptively understand if climate change, environmental variability, or fisheries interactions could impact this small colony now or in the future was the aim of the present research.

Similar to the Enderby Island, Auckland Islands group female New Zealand sea lions, the small ranges of stable isotope values recorded for the Stew-

art Island females indicate and support the hypothesis that female New Zealand sea lions have a restricted diversity of species in their diet (Meynier et al. 2014) and lack any form of migration or movement away from their breeding areas (Chilvers & Wilkinson 2008). With this pattern shown across the entire length of the whisker, it also indicates their foraging behaviours and prey are unlikely to alter significantly during an individual's lifetime. One pattern observed clearly for some of these females (Fig. 3), which was not seen for Enderby Island females, was the generally higher  $\delta^{13}\text{C}$  values at the far end of their whiskers. This indicates when the animals were younger, they appear to have been foraging closer to shore. The  $\delta^{15}\text{N}$  values

did not show this same trend, indicating the younger animals were foraging in a similar trophic level for prey, however likely closer to shore. Younger animals foraging closer to shore have been seen for New Zealand sea lions in both the Auckland Islands and Otago regions (Augé et al. 2011b, Leung et al. 2013).

From previous research, it is shown that the Stewart Island female New Zealand sea lions do not have the same extreme foraging behaviour as the Auckland Islands females (Chilvers et al. 2005, 2006, 2011, 2020, Chilvers & Wilkinson 2009) and do not appear to be operating at the edge of their physiological capacity. This gives them a potentially greater capacity to buffer changes in the seasonal variability of prey abundance, impacts of climate change, or influences of fisheries prey competition in their foraging home ranges (Robertson & Chilvers 2011, Chilvers 2018). Additionally, their core home ranges are small (38 km<sup>2</sup>), and compared with the home ranges of Enderby Island females being 10 times the area (378 km<sup>2</sup>, Chilvers et al. 2005), the Stewart Island females should have the ability to increase their foraging range in low prey abundance years. The Stewart Island females appear to all be mesopelagic divers, which is a foraging ecotype that has shown to be a more flexible foraging behaviour than benthic divers (Robertson & Chilvers 2011). However, around the Auckland Islands, this foraging ecotype puts them at a higher risk of interactions with trawlers and therefore risk of bycatch (Robertson & Chilvers 2011). For the Stewart Island females, their foraging behaviours have only been documented across 1 to 2 yr using TDR and satellite tracking (Chilvers 2018).



However, the link and consistency of this behaviour and its inferred diet have been shown in the present research with proximal and full-length whisker stable isotope values, indicating these foraging behaviours and related diet occur over the adult life of these females regardless of their breeding status or any environmental fluctuations during that time.

Differences in carbon and nitrogen isotope ratios among colonies may reflect variations in local isotope (isotopic landscapes) from different water masses, as shown by the variation in isotopic values for the finfish between sites (Fig. 4). However, most of the observed variability seen in the present research is more likely due to differences in diet and the distance from shore of foraging locations between the 2 populations (Chilvers et al. 2005, Chilvers 2018) according to the local availability of prey resources.

The aim of the present research was to understand the foraging behaviour and consistency of this behaviour of the female sea lions on Stewart Island to enable proactive management for this colony particularly concerning fisheries interactions, current and future. There are 3 predominant fisheries in the Stewart Island area; 2 use pots as the fishing method for crayfish *Jasus edwardsii* and blue cod, and the third is set netting for shark species. Sea lions have never been recorded as bycatch in any of these fisheries around New Zealand (Abraham et al. 2016); however, Australian sea lions *Neophoca cinerea* have been recorded as bycatch in both fishery types (pots and set nets) in Australia (Campbell et al. 2008, Hamer et al. 2013). Assuming these fisheries continue their current fishing practices and effort in the area, this zero bycatch should continue as the results of the present research indicate that female sea lions are unlikely to change their foraging behaviour or diet. However, if bycatch was shown to occur, similar to much of the rest of the South Island, the extension of restrictions of commercial and recreational set netting put in place for the protection of Hector's dolphins *Cephalorhynchus hectori* could be considered around Stewart Island as a precautionary measure for the protection of this small population of New Zealand sea lions (<https://www.mpi.govt.nz/dmsdocument/40886-MPI-Dolphin-TMP-Factsheet-South-Island-June-2020>). Conversely, known threats and significant problems for New Zealand sea lions are deepwater trawl fisheries and interactions with aquaculture (Abraham et al. 2016, Department of Conservation and Ministry for Primary Industries 2017). There is limited deepwater trawl fishing in the area around Stewart Island, and this fishing method should be managed to ensure this absence continues.

Equally, proposed aquaculture in Port Pegasus (Boffa Miskell 2017, NZIER 2017) would likely result in significant impacts on sea lions. Impacts range from changes in behaviour to harmful interactions for sea lions, as seen for fur seals and sea lions in Big Glory Bay, northern Stewart Island, and other areas of New Zealand and around the world where finfish farms and pinniped territories overlap (Baines & Quigley 2016, Bath et al. 2023). Given the small area these females forage over, all aquaculture should be discouraged from Port Pegasus and from within the foraging area of females as precautionary protection for this new colony and for the species as a whole.

#### 4.2. Future research

An underlying principle for the present research is that otariid whiskers grow continuously at a constant rate and are not shed as adults (Hirons et al. 2001, Rea et al. 2015, McHuron et al. 2016), therefore allowing the reconstruction of an individual's diet and foraging history along its length. Constant growth rates and lack of shedding are fair assumptions for New Zealand sea lions, given every other otariid shows this trait. Based on this and past research, from the known age of females, the mean whisker growth rate for female New Zealand sea lions remains at  $0.03 \text{ mm d}^{-1}$ , with a range from  $0.01$  to  $0.06 \text{ mm d}^{-1}$  (Chilvers 2017, 2019, 2021). As previously recommended, however, research into New Zealand sea lion whisker growth rate and if any shedding occurs would help identify the timespans for the stable isotope values presented here and the validity of these assumptions (Chilvers 2017, 2019).

It would be useful to have direct diet research undertaken for this colony to understand the species, number, and indication of the size of prey that are being taken by the Stewart Island sea lions. Given the remoteness of this colony and how sparsely distributed the individuals are in the colony, this could not easily be undertaken using the normal diet study techniques of analysis of hard parts in regurgitation or faeces (Childerhouse et al. 2001, Augé et al. 2012, Stewart-Sinclair 2013, Lalas & Webster 2014). Instead, it would be recommended that DNA analysis of faeces be undertaken on the small number of samples that could be found in a field trip to have a broader picture of the diet than could be reached using hard parts only on small sample sizes. Additionally, given the possible differences in foraging locations, the  $\delta^{13}\text{C}$  values indicated it would be useful to undertake foraging research via telemetry on younger females

from the colony to understand and identify where their foraging locations may differ from those of the adult females.

A benefit of the present research is that it identified distinct stable isotope signatures between these 2 populations (and as already shown between the Enderby Island foraging types), which could help identify the birth locations of any unidentified bycaught or stranded (dead) New Zealand sea lions if they are not tagged or chipped or have lost their tags. This identification could be undertaken by comparing whisker stable isotope signatures from the dead unidentified individuals with those from the colonies. New Zealand sea lion colonies show no genetic structure to be able to identify individuals to their place of birth genetically (Collins et al. 2017). All females on mainland New Zealand have come from or are parented by individuals that originated from the Auckland Islands; therefore, there is no way to determine the place of birth or origin genetically for this species. To fully utilise this method, stable isotope whisker values should also be collected and analysed from the Otago and Campbell Island populations, so all current known breeding locations could be compared to the unknown individuals.

## 5. CONCLUSIONS

This and previous research shows that the female New Zealand sea lions from Port Pegasus, Stewart Island, are mesopelagic divers foraging over a small foraging area. These foraging behaviours and inferred diet are consistent across their entire adult life based on whisker stable isotope values. This consistency in inferred diet, despite environmental variability and changes in breeding status occurring during the lifetime of these adult females (whisker length), indicates the Stewart Island females may have some ability to increase their foraging area or increase their foraging time in low prey abundance years to continue having the same diet, despite differing environmental and biological pressures. This information and the knowledge of their current diving and foraging locations suggest this population would have a better ability to cope with environmental variability than the population on the Auckland Islands, which is shown to be operating at its physiological limits. The Stewart Island population will continue to be vulnerable to human impacts if or until it significantly increases in size and should be managed proactively using protective measures to minimise human impacts and maximise the population's chance for survival

and growth. There are currently no known fisheries bycatch issues for sea lions around Stewart Island. However, precautionary measures ensuring fisheries pressures do not increase and management to ensure deepwater trawling and finfish aquaculture remain absent from their foraging areas are vital for the protection of this new colony of an Endangered species.

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## LITERATURE CITED

- ✦ Abraham ER, Richard Y, Berkenbusch K, Thompson F (2016) Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 2002–03 to 2012–13. New Zealand Aquatic Environment and Biodiversity Report No. 169. <https://fs.fish.govt.nz/Doc/24049/AEBR-169-Protected-species-catch.pdf.ashx>
- ✦ Augé AA, Chilvers BL, Davis LS, Moore AB (2011a) In the shallow end: diving behaviour of recolonising female New Zealand sea lions (*Phocarctos hookeri*) around the Otago Peninsula. *Can J Zool* 89:1195–1205
- ✦ Augé AA, Chilvers BL, Moore AB, Davis LS (2011b) Foraging behaviour indicates marginal marine habitat for New Zealand sea lions: remnant versus recolonising populations. *Mar Ecol Prog Ser* 432:247–256
- ✦ Augé AA, Lalas C, Davis LS, Chilvers BL (2012) Autumn diet of recolonising female New Zealand sea lions based at Otago Peninsula, South Island, New Zealand. *NZ J Mar Freshw Res* 46:97–110
- ✦ Augé AA, Chilvers BL, Moore AB, Davis LS (2014) Importance of studying foraging site fidelity for spatial conservation measures in a mobile predator. *Anim Conserv* 17: 61–71
- ✦ Baines J, Quigley R (2016) The social and community effects of salmon farming and rearing. <https://www.mpi.govt.nz/dmsdocument/15997-The-Social-and-Community-Effects-of-Salmon-Farming-and-Rearing-Case-Study-of-the-top-of-South-Island>
- ✦ Bath GE, Price CA, Riley KL, Morris JA Jr (2023) A global review of protected species interactions with marine aquaculture. *Aquaculture* 15:1686–1719
- ✦ Boffa Miskell (2017) Port Pegasus/Pikihati salmon farms: natural character, landscape and visual amenity effects assessment. Report prepared by Boffa Miskell for Environment Southland and Ministry for Primary Industries. <https://www.mpi.govt.nz/dmsdocument/22996-Port-Pegasus-Pikihati-Salmon-Farms-Natural-Character-Landscape-and-Visual-Amenity-Effects-Assessment>

- Butterworth DS, Duffy DC, Best PB, Bergh MO (1988) On the scientific basis for reducing the South African fur seal population. *S Afr J Sci* 84:179–188
- ✦ Campbell R, Holley D, Christianopolous D, Gales NG (2008) Mitigation of incidental mortality of Australian sea lions in the west coast rock lobster fishery. *Endang Species Res* 5:345–358
- ✦ Cherel Y, Hobson KA (2007) Geographical variation in carbon stable isotope signatures of marine predators: a tool to investigate their foraging areas in the Southern Ocean. *Mar Ecol Prog Ser* 329:281–287
- ✦ Cherel Y, Kernaleguen L, Richard P, Guinet C (2009) Whisker isotopic signature depicts migration patterns and multiyear intra- and inter-individual foraging strategies in fur seals. *Biol Lett* 5:830–832
- ✦ Childerhouse S, Dix B, Gales N (2001) Diet of New Zealand sea lions at the Auckland Islands. *Wildl Res* 28:291–298
- ✦ Chilvers BL (2012) Population viability analysis of New Zealand sea lions, Auckland Islands, New Zealand's sub-Antarctics: assessing relative impacts and uncertainty. *Polar Biol* 35:1607–1615
- ✦ Chilvers BL (2015) *Phocarctos hookeri*. The IUCN Red List of Threatened Species: e.T17026A1306343. <https://dx.doi.org/10.2305/IUCN.UK.2015-2.RLTS.T17026A1306343.en> (accessed 9 Jun 2023)
- ✦ Chilvers BL (2017) Stable isotope signatures of whisker and blood serum confirm foraging strategies for female New Zealand sea lions derived from telemetry. *Can J Zool* 95: 955–963
- Chilvers BL (2018) Preliminary assessment of the foraging behaviour and population dynamics of a cryptic population of the endangered New Zealand sea lion. *NZ J Ecol* 42:48–57
- ✦ Chilvers BL (2019) Whisker stable isotope values indicate long-term foraging strategies for female New Zealand sea lions. *Endang Species Res* 38:55–66
- ✦ Chilvers BL (2021) Identifying female foraging ecotype and fisheries impacts through pup whisker stable isotopes. *Aquat Conserv* 31:2204–2216
- ✦ Chilvers BL, Dobbins PM (2021) Behavioural plasticity and population connectivity: contributors to the establishment of new pinniped breeding colonies. *Aquat Conserv* 2021:1–12
- ✦ Chilvers BL, Meyer S (2017) Conservation needs for the endangered New Zealand sea lion. *Aquat Conserv* 27: 846–855
- ✦ Chilvers BL, Wilkinson IS (2008) Philopatry and site fidelity of New Zealand sea lions (*Phocarctos hookeri*). *Wildl Res* 35:463–470
- ✦ Chilvers BL, Wilkinson IS (2009) Diverse foraging strategies in lactating New Zealand sea lions. *Mar Ecol Prog Ser* 378:299–308
- ✦ Chilvers BL, Wilkinson IS, Duignan PJ, Gemmell NJ (2005) Summer foraging areas for lactating New Zealand sea lions *Phocarctos hookeri*. *Mar Ecol Prog Ser* 304: 235–247
- ✦ Chilvers BL, Wilkinson IS, Duignan PJ, Gemmell N (2006) Diving to extremes: Are New Zealand sea lions (*Phocarctos hookeri*) pushing their limits in a marginal habitat? *J Zool (Lond)* 269:233–241
- ✦ Chilvers BL, Amey JM, Huckstadt LA, Costa DP (2011) Investigating foraging utilization distribution of female New Zealand sea lions, Auckland Islands. *Polar Biol* 34: 565–574
- ✦ Chilvers BL, Amey JM, Costa DP (2020) Extreme diving of females at the largest colony of New Zealand sea lions, *Phocarctos hookeri*. *Polar Biol* 43:2031–2041
- ✦ Collins CJ, Rawlence NJ, Prost S, Anderson CN, Knapp M, Scofield RP (2014) Extinction and recolonisation of coastal megafauna following human arrival in New Zealand. *Proc R Soc B* 281:2014–2097
- ✦ Collins CJ, Chilvers BL, Osborne A, Taylor M, Robertson BC (2017) Unique and isolated: population structure has implications for management of the endangered New Zealand sea lion. *Conserv Genet* 18:1177–1189
- ✦ Costa DP, Gales NJ (2000) Foraging energetics and diving behavior of lactating New Zealand sea lions, *Phocarctos hookeri*. *J Exp Biol* 203:3655–3665
- ✦ Crawford K, McDonald RA, Bearhop S (2008) Applications of stable isotope techniques to the ecology of mammals. *Mammal Rev* 38:87–107
- ✦ Department of Conservation and Ministry for Primary Industries (2017) New Zealand sea lion/rāpoka Threat Management Plan 2017–2022. <https://www.mpi.govt.nz/dmsdocument/18788-New-Zealand-sea-lion-threat-management-plan>
- ✦ Drago M, Crespo EA, Aguilar A, Cardona L, García N, Dans SL, Goodall N (2009) Historic diet change of the South American sea lion in Patagonia as revealed by isotopic analysis. *Mar Ecol Prog Ser* 384:273–286
- ✦ Gales NJ, Mattlin RH (1998) Fast, safe, field-portable gas anesthesia for otariids. *Mar Mamm Sci* 14:355–361
- Goldsworthy SD, Bulman C, He X, Larcombe J, Littnan C (2003) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In: Gales N, Hindell M, Kirkwood R (eds) *Marine mammals and humans: fisheries, tourism and management*. CSIRO, Melbourne, p 69–99
- ✦ Hall-Aspland SA, Rogers TL, Canfield RB (2005) Stable carbon and nitrogen isotope analysis reveals seasonal variation in the diet of leopard seals. *Mar Ecol Prog Ser* 305: 249–259
- ✦ Hamer DJ, Goldsworthy SD, Costa DP, Fowler SL, Page B, Sumner MD (2013) The endangered Australian sea lion extensively overlaps with and regularly becomes by-catch in demersal shark gillnets in South Australian shelf waters. *Biol Conserv* 157:386–400
- ✦ Hanson NN, Wurster CM, Bird MI, Reid K, Boyd IL (2009) Intrinsic and extrinsic forcing in life histories: patterns of growth and stable isotopes in male Antarctic fur seal teeth. *Mar Ecol Prog Ser* 388:263–272
- ✦ Hirons AC, Schell DM, St. Aubin DJ (2001) Growth rates of vibrissae of harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetobias jubatus*). *Can J Zool* 79:1053–1061
- ✦ Kovacs KM, Aguilar A, Aurioles D, Burkanov V and others (2012) Global threats to pinnipeds. *Mar Mamm Sci* 28: 414–436
- ✦ Lallas C, Webster T (2014) Contrast in the importance of arrow squid as prey of male New Zealand sea lions and New Zealand fur seals at the Snares, subantarctic New Zealand. *Mar Biol* 161:631–643
- ✦ Leung ES, Chilvers BL, Nakagawa S, Moore AB, Robertson BC (2012) Sexual segregation in juvenile New Zealand sea lion foraging ranges: implications for intraspecific competition, population dynamics and conservation. *PLOS ONE* 7:e45389
- ✦ Leung ES, Auge AA, Chilvers BL, Moore AB, Robertson BC (2013) Foraging behaviour of juvenile female New Zealand sea lions (*Phocarctos hookeri*) in contrasting environments. *PLOS ONE* 8:e62728

- Leung ES, Chilvers BL, Nakagawa S, Robertson BC (2014) Size and experience matter: diving behaviour of juvenile New Zealand sea lions (*Phocarctos hookeri*). *Polar Biol* 37:15–26
- Manno KL, Young MJ (2023) New Zealand sea lion/pakake/whakahao field research report Auckland Islands 2022/23. Department of Conservation, Dunedin
- McConkey SD, McConnell H, Lalas C, Heinrich S and others (2002) A northward spread in the breeding distribution of the New Zealand sea lion, *Phocarctos hookeri*. *Aust Mammal* 24:97–106
- McHuron EA, Walcott SM, Zeligs J, Skrovan S, Costa DP, Reichmuth C (2016) Whisker growth dynamics in two North Pacific pinnipeds: implications for determining foraging ecology from stable isotope analysis. *Mar Ecol Prog Ser* 554:213–224
- Meyer S, Robertson BC, Chilvers BL, Krkosek M (2015) Population dynamics reveal conservation priorities of the threatened New Zealand sea lion *Phocarctos hookeri*. *Mar Biol* 162:1587–1596
- Meynier L, Morel PCH, Chilvers BL, Mackenzie DDS, MacGibbon A, Duignan PJ (2008a) Temporal and sex differences in the blubber fatty acid profiles of the New Zealand sea lion *Phocarctos hookeri*. *Mar Ecol Prog Ser* 366:271–279
- Meynier L, Morel PCH, Mackenzie DDS, MacGibbon A, Chilvers BL, Duignan P (2008b) Proximate composition, energy content, and fatty acid composition of marine species from Campbell Plateau, New Zealand. *NZ J Mar Freshw Res* 42:425–437
- Meynier L, Mackenzie DD, Duignan PJ, Chilvers BL, Morel PC (2009) Variability in the diet of New Zealand sea lion (*Phocarctos hookeri*) at the Auckland Islands, New Zealand. *Mar Mamm Sci* 25:302–326
- Meynier L, Morel PCH, Chilvers BL, Mackenzie DDS, Duignan PJ (2010) Quantitative fatty acid signature analysis on New Zealand sea lions: model sensitivity and diet estimates. *J Mammal* 91:1484–1495
- Meynier L, Morel PC, Chilvers BL, Mackenzie DD, Duignan PJ (2014) Foraging diversity in lactating New Zealand sea lions: insights from qualitative and quantitative fatty acid analysis. *Can J Fish Aquat Sci* 71:984–991
- Milne A (1996) The diet of male New Zealand sea lions (*Phocarctos hookeri*) in the Catlins, South Otago, winter 1996. MARI480, Department of Marine Science, University of Otago, Dunedin
- Newsome SD, Clementz MT, Koch PL (2010) Using stable isotope biogeochemistry to study marine mammal ecology. *Mar Mamm Sci* 26:509–572
- NZIER (New Zealand Institute of Economic Research) (2017) Port Pegasus salmon farm indicative business case for new aquaculture in Southland. <https://www.mpi.govt.nz/dmsdocument/23008-Port-Pegasus-Salmon-Farm-Indicative-Business-Case-for-new-aquaculture-in-Southland>
- Rea LD, Christ AM, Hayden AB, Stegall VK (2015) Age-specific vibrissae growth rates: a tool for determining the timing of ecologically important events in Steller sea lions. *Mar Mamm Sci* 31:1213–1233
- Read AJ, Drinker P, Northridge S (2006) Bycatch of marine mammals in US and global fisheries. *Conserv Biol* 20:163–169
- Roberts J, Lalas C (2015) Diet of New Zealand sea lions (*Phocarctos hookeri*) at their southern breeding limits. *Polar Biol* 38:1483–1491
- Robertson BC, Chilvers BL (2011) The population decline of New Zealand sea lions *Phocarctos hookeri*: a review of possible causes. *Mammal Rev* 41:253–275
- Sadou MC, Beltran RS, Reichmuth C (2014) A calibration procedure for measuring pinniped vibrissae using photogrammetry. *Aquat Mamm* 40:213–218
- Stewart-Sinclair P (2013) The role of long-term diet change in the decline of the New Zealand sea lion population. MSc thesis, Massey University, Palmerston North
- Weise MJ, Harvey JT (2008) Temporal variability in ocean climate and California sea lion diet and biomass consumption: implications for fisheries management. *Mar Ecol Prog Ser* 373:157–172

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