Stable isotope signatures of whisker and blood serum confirm foraging strategies for female New Zealand sea lions derived from telemetry

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<th>Journal:</th>
<th>Canadian Journal of Zoology</th>
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<tr>
<td>Manuscript ID</td>
<td>cjz-2016-0299.R1</td>
</tr>
<tr>
<td>Manuscript Type:</td>
<td>Article</td>
</tr>
<tr>
<td>Date Submitted by the Author:</td>
<td>29-Mar-2017</td>
</tr>
<tr>
<td>Complete List of Authors:</td>
<td>Chilvers, B.L.; Massey University, Institute of Veterinary, Animal and Biomedical Sciences</td>
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<td>Keyword:</td>
<td>New Zealand sea lion, Phocarctos hookeri, stable Isotope, diving behaviour, whisker, blood serum</td>
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Stable isotope signatures of whisker and blood serum confirm foraging strategies for female New Zealand sea lions derived from telemetry

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Abstract: Recognizing the individual variability of foraging behaviour of marine predators is important for understanding their role in the marine ecosystem and identifying how species may respond to environmental variability or human impacts. This research examines stable isotope signatures (δC13 and δN15) of blood serum and whiskers from 22 female New Zealand sea lions, *Phocarctos hookeri* (Gray, 1844) to determine if the isotopic composition of serum reflects foraging strategy and; that serum and proximal whisker growth had similar signatures reflecting that the isotopic composition of whiskers reflects foraging strategy diet.

Female NZ sea lions are known to have two distinct foraging strategies (mesopelagic or benthic ecotypes), shown to be habitual within and between years. Females who are known to be mesopelagic foragers have higher overlap and are at greater risk of harmful interactions with fisheries. This research found that the two foraging strategies identified from telemetry are also associated with different δC13 and δN15 isotopic values from blood serum and whiskers. Therefore, stable isotope analysis could be used to determine the proportion of the female population that are likely to be exposed to the detrimental direct and indirect interactions with fisheries.

Key words: New Zealand sea lion, *Phocarctos hookeri*, stable isotope signatures, diving behaviour, diet, benthic, mesopelagic.
Introduction

There is growing evidence that individuals within a population vary considerably in the way they use habitats and resources, and that this variation may differ with age, sex, reproductive status or resource partitioning within a population (Newsome et al. 2010; Silva et al. 2014; Kermaléguen et al. 2015a, 2015b). Documenting the degree of niche or individual specialisation is important in understanding the implications of this diversity for the ecology, evolutionary, and conservation biology of a species (Bolnick et al. 2003). Most commonly, niche specialisation is identified using research on foraging behaviour of individuals, satellite tracking and for marine mammals, diving behaviour. However increasingly, stable isotope analysis is being used to quantify foraging strategies as a less invasive and less costly research method.

Stable isotope analysis has been documented to be well suited for quantifying foraging strategies at both the population and the individual level (Bearhop et al. 2004; Newsome et al. 2010). Stable carbon (δC13) and nitrogen (δN15) isotope ratios of marine predators define the isotopic niche along two dimensions, with δC13 and δN15 values reflecting the predators’ foraging habitat and trophic level, respectively (Newsome et al. 2010). Concurrently, different predator tissues used for stable isotope analysis can also reflect diet and foraging behaviour over different time scales depending on tissue type used and their turnover rate (Crawford et al. 2008). Blood components represent stable isotope patterns of diet over time frames of days to weeks (Crawford et al. 2008). Inert keratinized tissues (i.e. whiskers), records the stable isotope ratio at its time of growth but then remains unchanged once grown, therefore keratinized tissue can represent longitudinal isotopic ratio patterns and consequently
long-term diet and foraging behaviours for individuals (Cherel et al. 2009). Samples of whiskers taken from the proximal end of the whisker represents the most recently laid down tissue, therefore isotopic signatures from the last weeks to months depending on an animal’s whisker growth rate (McHuron et al. 2016).

Stable isotope research has been used to identify trophic position, spatial variation in diet and geographic sources of prey for a variety of pinniped species (e.g. Huckstadt et al. 2007; Porras-Peters et al. 2008). Seasonal, inter-annual and decadal differences in diet have also been detected and related to fluctuations in prey availability and oceanographic conditions (e.g. Hall-Aspland et al. 2005; Drago et al. 2009; Hanson et al. 2009). For many pinnipeds, both Otariid (eared seals) and Phocid (true seals), species specific, sexual and individual foraging strategies and migration patterns have also been described using stable isotopes (Cherel et al. 2007a; Aurioles-Gamboa et al. 2009; Eder et al. 2010; Lowther et al. 2010; Arnould et al. 2011).

The New Zealand (NZ) sea lion *Phocarctos hookeri* (Gray, 1844) is NZ’s only endemic pinniped and is listed as ‘Endangered’ by the International Union for the Conservation of Nature (Chilvers 2015). Over 99% of all pups are born in only two areas in the NZ subantarctic; Auckland Islands (50°30′S, 166°E) and Campbell Island (52°33′S, 169°09′E; Fig. 1). The majority of the species breed at the Auckland Islands with 69% of pup production occurring there (Maloney et al. 2012). The Auckland Island NZ sea lions have had a 48% decline in pup production since 1998 (Chilvers and Meyer 2017). Fisheries by-catch is the largest documented anthropogenic impact on NZ sea lions (Robertson and Chilvers 2011) and is considered to be one of the reasons for the decline at the Auckland Islands (Chilvers 2012; Meyer et al. 2015). Adult female sea lion biased by-catch is known to occur as the majority of fishing effort occurs after males have migrated away from the breeding area.
(Robertson et al. 2006, Geschke and Chilvers 2009). This bias appears to be showing in the estimated survival rates of adult NZ sea lions at the Auckland Islands with female sea lions, 3 years old and over, having lower survival estimates than their male counterparts (Chilvers and Mackenzie 2010; Meyer et al. 2015). It is rare for adult female otariids to have lower survival estimates than their male counterparts and indicates impacts that are causing sex bias mortality, such as the fisheries deaths seen for the NZ sea lions species (Pendleton et al. 2006; Hernandez-Camacho et al. 2008).

Lactating female NZ sea lions forage over the entire Auckland Island shelf (Chilvers et al. 2008a, 2008b; Chilvers and Wilkinson 2009; Chilvers et al. 2011). They are restricted in their area and duration of foraging by their need to return to dependent pups ashore for 9 to 10 months a year (Gales 1995). They dive almost continuously when at sea, and their diving behaviour is at or close to their physiological limits (Gales and Mattlin 1997; Chilvers et al. 2006; Chilvers and Wilkinson 2009). Individual females show either benthic (foraging on the sea floor) or mesopelagic (foraging at various, but usually deep, depths in the water column) diving behaviours (Chilvers and Wilkinson 2009), with individuals showing strong fidelity to these foraging areas and strategies within and between breeding seasons (here defined as December–February each year; Chilvers et al. 2005, 2006; Chilvers 2008a, 2008b; Chilvers and Wilkinson 2009). This consistent fidelity occurs even with differences in prey distribution and environmental conditions between years (Chilvers 2008a, 2008b) and has been indicated in differences in diet through qualitative and quantitative fatty acid analysis (Meynier et al. 2014).

The overlap between commercial fisheries around the Auckland Islands and foraging female NZ sea lions is predominantly between the mesopelagic foraging animals and the arrow squid fishery (*Nototodarus gouldi*, (McCoy, 1888), Chilvers 2008a; Chilvers and
Wilkinson 2009). The degree of overlap between the commercial fishing activities and the foraging effort of marine mammals determines the likely rate of spatial encounters between them, and is the key component in the evaluation of the extent of competition between marine mammals and fisheries (Matthiopoulos et al. 2008). Understanding what proportion of the female NZ sea lions in the Auckland Island population that forage mesopelagically (which has the greatest overlap and therefore likely interaction rate with fisheries), will allow a better understanding of what proportion of the population are most exposed to the impacts of fisheries interactions.

The aim of this study is to assess whether stable isotope analyses of blood serum and whiskers could be used to identify foraging strategy (mesopelagic or benthic ecotypes) for female NZ sea lions when compared with their recorded foraging behaviour from time depth recorder (TDR) telemetry. The basic underlying principles for this research were: 1) that the isotopic composition of blood serum reflected foraging strategy ecotype and therefore diet; and 2) blood serum and immediate (proximal) whisker growth had similar signatures reflecting that the isotopic composition of whiskers reflects diet at the time of their growth, because keratin is metabolically inert after synthesis (Rubenstein and Hobson 2004).

**Materials and methods**

The research was undertaken at Sandy Bay, Enderby Island, Auckland Islands (Fig. 1) during the austral summers of 2009/10, 2010/11 and 2011/12 (hereafter referred to as 2010, 2011 and 2012). Twenty-two lactating female NZ sea lions were captured using a specially designed hoop net and were physically restrained by two handlers. They were then anaesthetised, using isoflurane delivered with oxygen to a mask via a field-portable vaporiser (Gales and Mattlin...
A SPLASH tag (10 cm × 4 cm × 4 cm; Wildlife Computers, Redmond, Washington, USA) that is equipped with a satellite-linked platform transmitting terminals (PTTS) and a time–depth recorder (TDR) were attached to a piece of neoprene material (Gales and Mattlin 1997), which was then glued to the female’s dorsal hair on her upper back using two-part epoxy glue. Once the instrument was secure (8–10 min after glue application), the flow of anaesthetic was stopped and the animal was allowed to recover and return to her pup. Following restraint, each animal was observed until it was fully conscious and had returned to the group or location where it had been captured. Satellite tags were programmed to work continuously, but were fitted with salt-water and wet–dry switches to ensure that transmission only occurred when animals were at sea. TDRs were set to record depth of the individual every 5 s while submerged.

While restrained the outer most left whisker of each animals was collected from all individuals and 5ml of blood collected from the brachial vein into BD vacutainer ® venous blood collection tube from 11 of the 22 females. Anticoagulants were not used to avoid altering isotope levels (Drago et al. 2009). Whiskers were cut as close to the face as possible (to remove the root would have required surgical biopsy as they are so imbedded and this was considered too invasive) and stored in individual plastic bags until cleaned just before analysis. Blood samples were kept cool (4-8°C) for several hours before being centrifuged (3 to 5 mins) and were separated into serum and red cell fractions. Only the serum fractions were retained, pipetted into 2ml cryiovials and stored frozen in liquid nitrogen until return to mainland New Zealand. On return serum was stored in a -80°C freezer until analysis in the laboratory.

Foraging behaviour
Diving data were analysed using Multitrace (Jensen Software Systems) to produce summary statistics for each dive. Zero offset drift in the depth values for each tag was corrected manually within Multitrace. Dives < 6 m in depth were considered to be non-foraging dives primarily associated with travel and were not analysed (Gales and Mattlin 1997; Chilvers et al. 2006). Bottom time was defined as the time the sea lion spent at depths >85% of the maximum depth for that dive (Gales and Mattlin 1997). Data were analysed for each animal.

Dive profiles were classified as benthic and mesopelagic using a similar concept to Tremblay and Cherel’s (2000) intra-depth zone (IDZ). IDZ provides an index of the percentages of dives, within a dive bout, that are within or outside of a given (user defined) depth range. Given that lactating NZ sea lions have an average dive depth of 129 m and maximum dives up to 700 m (Chilvers et al. 2006), the percentage of dives within a dive bout which were within 50 m of the mean depth of the dive bout were compared with the percentage greater than 50 m of the mean dive depth. Benthic foragers in pinnipeds are characterised by consistent predominantly uniform maximum depth of a series of dives, and the lack or low percentage of significantly shallower or deeper dives within a dive bout (as seen from IDZ analysis; Hindell et al. 1991; Werner and Campagna 1995; Gales and Mattlin 1997). Conversely, mesopelagic foragers will have a significantly higher percentage of shallower or deeper dives greater than ±50 m of the mean dive depth within a single dive bout (Chilvers and Wilkinson 2009). A dive bout was defined as a group of dives separated by short surface intervals (<10 min), ending when a prolonged surface interval or period ashore occurred (surface interval > 10 min). This definition is based on NZ sea lion surface interval data showing that 90% of all surface intervals between dives are <4 min, and 97% are <10 min. A surface interval up to 10 min in duration is common after long, deep dives (>300 m; Chilvers and Wilkinson 2009); however, surface intervals >10 min are uncommon (3%), and
usually follow a series of shallow dives, indicating a separation of dives into dive bouts rather than animals resting between deep dives.

Isotopic analysis

Stable isotope analysis was conducted by Waikato Stable Isotope Unit, Department of Biological Sciences, University of Waikato. Prior to the isotopic analysis, all whiskers were cleaned in a method similar to Cherel et al. (2009). Whiskers were cleaned individually for 5 min with distilled water, then for 5 min with 96% ethanol, followed by a final clean and scraping with distilled water for an additional 5 min. Each whisker was checked under a stereomicroscope for any remaining tissue or dirt; contaminants were removed using a scalpel blade. All samples were then rinsed with distilled water and left to air-dry overnight. Blood serum was thawed, freeze dried and ground into a fine powder. Whisker sections and powdered serum were weighed and packed in tin foil capsules, and carbon and nitrogen isotope ratios were determined by a Dumas elemental analyser (Europa Scientific ANCA-SL) interfaced to a isotope mass spectrometer (Europa Scientific 20-20 Stable Isotope Analyser). Results are presented in the conventional notation relative to a laboratory standard/reference sucrose and urea (the urea had been calibrated relative to atmospheric nitrogen) for δ13C and δ15N, respectively. Quality control samples were run before and after every 12 samples.

Using SPSS (Version 22 for Windows, SPSS), differences between tissue types and mesopelagic and benthic foraging strategy’s were tested by multivariate analysis of variance (MANOVA). Unless otherwise stated, data are presented as means (±1 SE) and results are considered significant at the $p < 0.05$ level.

Results
Foraging behaviour

Data was collected from the dive instruments of 19 of the 22 female NZ sea lions for between 7 and 15 days (mean 11.5 ± 0.5) with 18 772 (mean 985 ± 75) dives logged (the other instruments were either lost or malfunctioned). All females fell qualitatively into one of the two dive profile ecotypes (Fig. 2a and b), 13 defined as a mesopelagic foraging strategy and six with a benthic foraging strategy (Chilvers and Wilkinson 2009; Table 1). Benthic divers averaged 84% of all dives within 50 m of the mean dive bout depth (range = 76 to 88%, Fig. 2a), while mesopelagic divers averaged 25.5% of all dives within 50 m of the mean dive bout depth (range = 15 to 36%; Fig. 2b; Table 1). Table 1 presents mean surface interval, mean and maximum dive depth, mean dive duration and % bottom time dive statistics for the 19 female NZ sea lions. For all of these measurements, females with mesopelagic diving strategies had significantly longer mean surface intervals, deeper mean and maximum dive depths, lower % of time at bottom of their dives and longer mean dive durations (although dive duration was not significant; Table 1).

Stable Isotope Signatures - Blood Serum

Blood was sampled and tested from 11 of the 22 females captured. Isotopic signatures were spread over a small range with δ15N and δ13C values varying from 11.1 to 13.6 ‰ (a 2.5‰ difference) and from -16.4 to -15.1‰ (a 1.3‰ difference; Table 2; Fig. 3). The lowest δ15N values were associated with the lowest δ13C values and were consistently from females that showed a benthic foraging strategy (Table 2). There were significant differences in δ13C and δ15N values between females with benthic or mesopelagic foraging strategies (δ13C benthic -
Stable Isotope Signatures - Whiskers

Whisker isotopic signatures were collected from all 22 females captured with isotope signatures spread over a similar range to the blood serum, $\delta^{15}N$ from 11.0 to 14.3‰ (a 3.3‰ difference) and $\delta^{13}C$ from -16.6 to -15.1‰ (1.5‰; Table 2; Fig. 4). There were significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between females with benthic or mesopelagic foraging strategies ($\delta^{13}C$ benthic $-15.5\%$: mesopelagic $-16.2\%$, $F_{1,20} = 33.9$, $p<0.0001$, $\delta^{15}N$ benthic $11.5\%$: mesopelagic $12.9\%$, $F_{1,20} = 23.8$, $p<0.0001$, Table 2). Overall, the lowest $\delta^{15}N$ values were associated with the lowest $\delta^{13}C$ values and the lowest $\delta^{15}N$ and $\delta^{13}C$ values consistently came from benthic foraging females’ whiskers (Table 2). There were no significant difference between blood serum and whisker values across either foraging type. The whisker stable isotope values from the three females with no foraging data indicated they were either mesopelagic (B0581 and 3857) or benthic (0119) ecotypes (individuals circled in Fig. 4).

Discussion

The aims of this research were to determine if the isotopic composition of blood serum reflected foraging strategy based on individuals diving behaviour and; that blood serum and proximal whisker growth had similar signatures reflecting that the isotopic composition of whiskers reflects foraging strategy diet. Results show that lactating NZ sea lions have clear inter-individual variation in their isotopic niches, with both blood serum and whisker isotopic
values reflecting their telemetry identified mesopelagic or benthic foraging patterns (Fig. 3; Table 1 and 2). There were no significant differences in blood serum and proximal whisker isotopic values for individuals (Table 2) indicating that the proximal whisker growth isotopic signature also reflects the foraging type and diet of individuals (Fig. 4).

For both blood serum and whisker stable isotope signatures, mesopelagic foragers had significantly higher δ15N and δ13C values than benthic foragers (Table 2; Fig. 3 and 4). It has previously been shown that for marine predators, δ15N values are indicative of trophic position of prey species and δ13C values can be used to infer the geographic origin of prey (e.g. Trull and Armand 2001; Cherel et al. 2007b). The higher δ15N values for mesopelagic foragers indicate that they are likely to be preying on resources or a higher percentage of resources at a higher trophic level than the benthic foragers (i.e. fin fish compared with cephalopods). This difference has been suggested from foraging behavioural studies (Chilvers and Wilkinson 2009) and shown in fatty acid analysis (Meynier et al. 2014). The mesopelagic foraging females predominantly forage in the waters above the western slopes of the Auckland Island shelf (Chilvers and Wilkinson 2009), which matches the prey distribution of hoki (*Macruronus novaezelandiae* (Hector, 1871)), and rattails (*Coelorinchus* spp.), which are the principal demersal fish assemblages at the upper and midslope of the Auckland Islands (Jacob et al. 1998). In contrast, the benthic foraging females forage in the shallower Auckland Island shelf waters north and east of the Auckland Islands (Chilvers and Wilkinson 2009), which match a prey distribution more likely to be dominated by lower tropic level prey items such as octopus (*Enteroctopus zealandicus* (Gould, 1852)).

This research did not sample prey for stable isotope nor attempt to estimate the prey species related to the stable isotope signatures or their potential proportions in each foraging ecotypes diet. NZ sea lions have been shown to consume a wide variety of prey, and the
species is considered to be a generalist predator (Meynier et al. 2009; Meynier et al. 2014). In the present study, mean δ15N values from blood serum ranged from 11.1 to 13.6‰. Isotope fractionation values are not available for NZ sea lions, but prey-to-tissue fractionation values of from 3.1 to 5.2‰ have been reported for serum/plasma δ15N in captive otariid, the Northern fur seals (*Callorhinus ursinus* (Linnaeus, 1758); Kurle 2002). These would equate to mean prey δ15N values of from 8.0 to 10.5‰ and from 5.9 to 8.4‰, respectively. Isotope data on potential prey were not collected in the present study, but were obtained from a previous diet study from the Auckland Island shelf (Meynier and Chilvers unpublished). While not exhaustive, the species assessed are likely to represent the greatest biomass contributions to female NZ sea lions diet (i.e. arrow squid, *Nototodarus sloani* (Gray 1849), octopus, opal fish (*Hemerocoetes monopterygius* (Bloch and Schneider, 1801), red cod, *Pseudophycis bachus* (Bloch and Schneider, 1801) and hoki; Meynier et al. 2009). The δ15N values for these prey were all within 7.5 to 12.9‰, thus suggesting that a 3.1‰ prey-to-tissue fractionation for plasma appears appropriate for NZ sea lions.

Whereas δ15N values are indicative of trophic position, δ13C values can been used to infer the geographic origin of prey. δ13C represents the isotope signature of particulate organic matter (POM) within the trophic levels above it which varies with location (e.g. Trull and Armand 2001; Cherel et al. 2007b). Prey-to-tissue fractionation for serum/plasma δ13C in pinnipeds has been reported to be between 0.2 and 0.8‰ (Kurle 2002; Lesage et al. 2002). For the female NZ sea lions in this research, their blood serum δ13C values were in the small range from –16.4 to –15.1 ‰. The majority of δ13C values from the prey samples listed above were –21.5 to -17.3‰, higher than expected if the pinniped fractionation levels reported were similar. Given lactating female NZ sea lions have only ever been recorded foraging over the Auckland Island shelf (Chilvers 2009; Chilvers et al. 2005, 2011, 2013),
these results suggest that some of their prey originate from outside the region. Of the prey known in NZ sea lions diet: arrow squid are believed to migrate from the Snares shelf to Auckland Island shelf and from deeper waters to the edge of the Auckland Island plateau during spawning (Jackson et al. 2000; Uozumi and O’hara 2003); the most important spawning grounds for red cod are the SE of the South Island of NZ with no known spawning ground for red cod on the Campbell Island Plateau (which includes the Auckland Island shelf; NZ fisheries assessment plenary, http://www.mpi.govt.nz/); similarly the most important spawning grounds for Hoki is the West coast of the South Island, NZ, with no known ground on the Campbell Plateau, supporting that the δ13C results from these species are likely to originate outside the area.

Behavioural or tracking foraging studies often homogenise the foraging preferences of a species, underrepresenting the intraspecies diversity of foraging ecotypes usually because of their cost and labour intensive nature (Bolnick et al. 2003). Increasingly the foraging specialisation of individuals from within small geographic regions are being identified and recognised for their importance to the species and influences on ecosystems e.g. lactating females from the same breeding colonies, (Villegas-Amtmann et al. 2008; Baylis and Nichols 2009; Baylis et al. 2009). Foraging research has shown this is the case for female NZ sea lions (Chilvers and Wilkinson 2009). The results from this research and Meynier et al. (2014), confirms that these foraging ecotypes are also represented by differing stable isotope signatures and therefore likely prey or proportions of prey in diet. Being able to collect and analyse stable isotope composition and therefore identify likely foraging ecotype from blood or a whisker from a female NZ sea lion is a far faster, less invasive and more cost effective option than undertaking foraging studies, meaning the foraging ecotypes of more individuals could be determined. This is important for female NZ sea lions because fisheries by-catch is
the largest documented anthropogenic impact on NZ sea lions (Robertson and Chilvers 2011; Meyer et al. 2015), and fisheries interactions and therefore by-catch are more likely to occur on mesopelagic foraging females than benthic foraging females (Chilvers and Wilkinson 2009). Understanding the proportion of females that have mesopelagic foraging ecotypes would give a better understanding of what proportion of the population is exposed to the risk of by-catch and resource competition. Along with a greater appreciation of fisheries interactions risk, understanding that populations composed of long-term individual foraging strategy and diet specialists, such as female NZ sea lions, is also thought to indicate limited ecosystem productivity (Tinker et al. 2008). Therefore, these specialised populations are thought to be highly susceptible to, and less able to respond to, environmental changes or anthropogenic impacts such as fisheries resource competition (Costa 1993; Bolnick et al. 2003; Chilvers et al. 2006).

For this research the time frames of the foraging behaviour (representing the 12 to 14 days from time of capture till tag removed) and the serum and whisker isotope values (representing the weeks before capture) did not overlap directly. Given the consistent fidelity to foraging areas and strategies within and between breeding seasons, even with differences in prey distribution and environmental conditions between years of female NZ sea lions (Chilvers et al. 2005, 2006; Chilvers 2008a, 2008b; Chilvers and Wilkinson 2009; Chilvers unpublished data) this difference in time frame was not considered significant, however could be investigated in the future. There are numerous other next steps also warranted in stable isotope research for NZ sea lions including to investigate the stable isotope signatures of prey species with each of these foraging ecotype signatures to help clarify if the differences in signatures between ecotypes is due to differences in prey species or proportions of prey in diets. Concurrently, further studies investigating the stable isotope signature and likely
foraging ecotypes in age and sex classes that are not as easy to undertake foraging research on
(i.e. juveniles and adult males) and therefore identify the possible overlap with fisheries of
these classes. Similar to other otariids (Drago et al. 2010; Lowther et al. 2010), it would also
be useful to identify the links between female foraging ecotypes and pup whisker stable
isotope signatures, as an even easier and more cost effective way of identifying foraging
ecotypes for females and therefore likely fisheries interactions. And lastly, now that it has
been confirmed that the proximal whisker growth isotopic signature reflects the foraging
strategy and diet of individuals for NZ sea lions, research can be undertaken serial sampling
whiskers to confirm the across season, one year to the next - long term and life history
foraging patterns of individuals, as seen for other Otariids (Cherel et al. 2009).

Acknowledgements
I thank Anjana Rajendram from the Waikato Stable Isotope Unit, Department of Biological
Sciences, University of Waikato for undertaking the stable isotope analysis. Data presented in
this paper were collected with funding from the NZ Department of Conservation (DOC), in
parallel with field work undertaken for the DOC Marine Conservation Services Programme
(www.doc.govt.nz/mcs) project POP2007/01. Approval for all work was obtained from the
DOC Animal Ethics Committee (Approvals AEC 200, 2 Nov 2009). Thanks to two
anonymous reviewers, all of whom provided helpful, critical reviews of the manuscript and
last but by no means least an enormous thank you to all the people who have worked in the
field collecting this data.

References


Figure Legends

**Figure 1.** New Zealand sea lion (*Phocarctos hookeri*, Gray, 1844) breeding and haul-out distribution including New Zealand mainland, Auckland and Campbell Islands and indicating sight of this research Sandy Bay, Enderby Island.

**Figure 2.** Examples of the two distinct dive profiles from female New Zealand sea lions (*Phocarctos hookeri*, Gray, 1844): (A) Benthic (female # 3998) and (B) Mesopelagic (female number 0088). Note the difference in depth scale on each graph.

**Figure 3.** Female New Zealand sea lion (*Phocarctos hookeri*, Gray, 1844) blood serum δ13C and δ15N values collected at Sandy Bay, Enderby Island, Auckland Islands between 2010 and 2012. Values displayed in the distinct foraging ecotypes, Mesopelagic and Benthic foragers.

**Figure 4.** Female New Zealand sea lion (*Phocarctos hookeri*, Gray, 1844) proximal whisker δ13C and δ15N values (mean ± SE) collected at Sandy Bay, Enderby Island, Auckland Islands between 2010 and 2012. Values displayed in the distinct foraging ecotypes, Mesopelagic and Benthic foragers. Individuals circled ○ are the three female whisker values that had no foraging data, 0119 in the Benthic range, 3857 in the middle of the graph, Mesopelagic range, and B0581 higher in the graph in the Mesopelagic range.
Fig. 1
Fig. 3

- Mesopelagic Divers
- Berthic Divers
Fig 4.
Table 1: Summary of diving records, foraging cycle and behaviour of 19 female New Zealand sea lions (*Phocarctos hookeri*, Gray, 1844). Dives are defined as submersions to > 6 m. Means presented ± SE. B = benthic dive profile, M = mesopelagic dive profile

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<th>Mean dive depth (m)</th>
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<td>169 ± 4.5</td>
<td>612</td>
<td>4.0 ± 4.5</td>
<td>26 ± 0.8</td>
</tr>
<tr>
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<td>M</td>
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<td>7.0 ± 18</td>
<td>235 ± 5.1</td>
<td>538</td>
<td>5.0 ± 4.4</td>
<td>22 ± 1.0</td>
</tr>
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<td>M</td>
<td>26</td>
<td>6.7 ± 18</td>
<td>254 ± 3.2</td>
<td>487</td>
<td>5.2 ± 2.3</td>
<td>21 ± 0.7</td>
</tr>
<tr>
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<td>4.2 ± 14</td>
<td>204 ± 3.2</td>
<td>557</td>
<td>4.9 ± 2.7</td>
<td>23 ± 0.7</td>
</tr>
<tr>
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<td>M</td>
<td>29</td>
<td>6.6 ± 24</td>
<td>232 ± 3.6</td>
<td>552</td>
<td>5.5 ± 3.6</td>
<td>17 ± 0.7</td>
</tr>
<tr>
<td>4775</td>
<td>M</td>
<td>33</td>
<td>6.2 ± 27</td>
<td>204 ± 4.2</td>
<td>468</td>
<td>5.4 ± 3.4</td>
<td>35 ± 0.9</td>
</tr>
<tr>
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<td>B</td>
<td>76</td>
<td>3.2 ± 14</td>
<td>131 ± 0.6</td>
<td>221</td>
<td>4.8 ± 1.5</td>
<td>43 ± 0.5</td>
</tr>
<tr>
<td>3885</td>
<td>B</td>
<td>80</td>
<td>2.4 ± 8</td>
<td>142 ± 0.6</td>
<td>200</td>
<td>4.5 ± 1.1</td>
<td>43 ± 0.3</td>
</tr>
<tr>
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<td>87</td>
<td>2.3 ± 9</td>
<td>167 ± 0.7</td>
<td>202</td>
<td>4.9 ± 1.6</td>
<td>39 ± 0.5</td>
</tr>
<tr>
<td>3998</td>
<td>B</td>
<td>88</td>
<td>2.3 ± 9</td>
<td>140 ± 0.6</td>
<td>218</td>
<td>4.4 ± 1.4</td>
<td>38 ± 0.6</td>
</tr>
<tr>
<td>4063</td>
<td>B</td>
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<td>2.8 ± 9</td>
<td>124 ± 0.5</td>
<td>190</td>
<td>4.3 ± 1.1</td>
<td>54 ± 0.3</td>
</tr>
<tr>
<td>4840</td>
<td>B</td>
<td>84</td>
<td>2.6 ± 8</td>
<td>147 ± 0.7</td>
<td>195</td>
<td>3.9 ± 0.7</td>
<td>47 ± 0.3</td>
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</tbody>
</table>

| Mesopelagic means | 25.5 ± 1.8 | 4.9 ± 15 | 192 ± 3.8 | 503 ± 18.8 | 4.9 ± 4.0 | 23 ± 1.0 |
| Benthic means     | 83.8 ± 2.0 | 2.6 ± 9  | 141 ± 0.6 | 204 ± 5.1  | 4.5 ± 1.3 | 44 ± 0.4 |

Significance

\[ F = 14.4, \quad p = 0.001 \]
\[ F = 7.6, \quad p = 0.01 \]
\[ F = 118, \quad p < 0.0001 \]
\[ F = 29.9, \quad p < 0.0001 \]
Table 2: Age, weight, dive profile type and stable isotope values from blood serum and whiskers of 22 female New Zealand sea lions (*Phocarctos hookeri*, Gray, 1844). Means presented ± SE. B = benthic dive profile, M = mesopelagic dive profile

<table>
<thead>
<tr>
<th>Female Id</th>
<th>Age at capture</th>
<th>Weight</th>
<th>Dive profile type</th>
<th>Average Delta 15N Serum</th>
<th>Average Delta 13C Serum</th>
<th>Average Delta 15N Whisker</th>
<th>Average Delta 13C Whisker</th>
</tr>
</thead>
<tbody>
<tr>
<td>1411</td>
<td>15</td>
<td>129</td>
<td>M</td>
<td>12.1 ± 0.12</td>
<td>-15.6 ± 0.09</td>
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<td></td>
</tr>
<tr>
<td>B0179</td>
<td>11</td>
<td>115</td>
<td>M</td>
<td>13.7 ± 0.07</td>
<td>-15.2 ± 0.03</td>
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</tr>
<tr>
<td>B0581</td>
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<td>116.5</td>
<td>M*</td>
<td>13.4 ± 0.08</td>
<td>-15.2 ± 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0080</td>
<td>11</td>
<td>110.5</td>
<td>M</td>
<td>13.5 ± 0.07</td>
<td>-15.3 ± 0.03</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>11</td>
<td>108.5</td>
<td>M</td>
<td>13.47 ± 0.08</td>
<td>-15.29 ± 0.03</td>
<td>13.3 ± 0.13</td>
<td>-15.5 ± 0.07</td>
</tr>
<tr>
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<td>11</td>
<td>130.0</td>
<td>M</td>
<td>13.5 ± 0.07</td>
<td>-15.3 ± 0.03</td>
<td>12.1 ± 0.16</td>
<td>-15.7 ± 0.10</td>
</tr>
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<td>M</td>
<td>12.5 ± 0.11</td>
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</tr>
<tr>
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<td>11</td>
<td>130.0</td>
<td>M</td>
<td>12.4 ± 0.13</td>
<td>-15.6 ± 0.08</td>
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</tr>
<tr>
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<td>M</td>
<td>14.3 ± 0.09</td>
<td>-15.1 ± 0.04</td>
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<td></td>
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<td>116.0</td>
<td>M</td>
<td>12.28 ± 0.15</td>
<td>-15.60 ± 0.05</td>
<td>13.4 ± 0.15</td>
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<tr>
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<td>12.58 ± 0.05</td>
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<td>12.2 ± 0.14</td>
<td>-15.7 ± 0.04</td>
</tr>
<tr>
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<td>M</td>
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<td>-15.12 ± 0.05</td>
<td>13.7 ± 0.05</td>
<td>-15.1 ± 0.03</td>
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<td>M</td>
<td>12.51 ± 0.14</td>
<td>-15.53 ± 0.04</td>
<td>12.3 ± 0.14</td>
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<tr>
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<td>11.5 ± 0.09</td>
<td>-16.3 ± 0.06</td>
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<tr>
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<td>-15.90 ± 0.07</td>
<td>11.4 ± 0.07</td>
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<td>11.95 ± 0.08</td>
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<td>11.7 ± 0.08</td>
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<tr>
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<td>11.13 ± 0.07</td>
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<tr>
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</tr>
<tr>
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<td>-16.1 ± 0.03</td>
<td>11.5 ± 0.05</td>
<td>-16.2 ± 0.02</td>
</tr>
</tbody>
</table>

* Foraging type predicted from isotope signature