

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Feeding ecology of the New Zealand sea lion
(*Phocarctos hookeri*)

A thesis presented in partial fulfilment of
the requirements for the degree of

Doctor of Philosophy

in

Zoology

At Massey University,
Palmerston North, New Zealand

Laureline Meynier

2009

Abstract

Feeding ecology of the New Zealand sea lion
(*Phocarctos hookeri*)

The New Zealand (NZ) sea lion *Phocarctos hookeri* is the only pinniped endemic to NZ with a population of approximately 12,000 individuals. Its breeding range is currently restricted to NZ sub-Antarctic islands, and it has failed to recolonise its pristine distribution around the NZ main islands despite its protection since 1881. The current hypothesis is that the population growth of this pinniped is limited by the distribution of suitable prey on the Auckland Islands (50°30'S, 166°E) shelf, and by the direct and indirect pressure exerted by the arrow squid *Nototodarus sloani* fishery. However, this hypothesis has not been fully tested to date as there has been limited information on the diet of the NZ sea lion and their potential prey. The objective of this thesis is to analyse the diet of NZ sea lions over several years with particular emphasis on the most reproductively important segment of the population: lactating females.

This thesis provides the first quantification by percentage mass of the diet of NZ sea lion using a combination of stomach content analysis, qualitative fatty acid (FA) analysis, and quantitative FA signature analysis (QFASA). Stomach contents and blubber FAs were analysed from 121 individuals incidentally caught (by-caught) in the southern arrow squid fishery from the years 1997 to 2006. The blubber FAs of 78 free-ranging lactating females captured at Enderby Island, Auckland Islands, were also examined during January and February of 2000 to 2005.

Data obtained from both stomach analysis and QFASA indicate that arrow squid, rattails Macrouridae, hoki *Macruronus novaezelandiae* and red cod *Pseudophycis bachus* are key prey species for NZ sea lions in the Auckland Islands region. Because these prey species live mostly at depths greater than 200 m, lactating females must undertake long foraging trips and dive regularly to greater depths than other sea lion species. Data from QFASA indicates that this foraging pattern is conducted over an extended period through the summer and autumn. The daily food requirement of a lactating female was estimated by a simple energetic model to be greater than 20% of its body mass. During years of low arrow squid recruitment such as 1999 and 2001, the

amounts of squid required by the NZ sea lion population may have been similar to the amount harvested by the fishery, suggesting that resource competition is likely to occur between the arrow squid fishery and NZ sea lions in years of low squid abundance.

Half of the fishing activity of the southern squid fishery occurs in the north of the Auckland Islands shelf where NZ sea lions forage, leading to incidental captures every year. This research emphasises that management of the NZ sea lion must not only consider the direct interactions with the arrow squid fishery, but also the likelihood of food resource competition between the fishery and NZ sea lions.

Acknowledgements

First of all, I would like to thank Dr Pádraig Duignan, my main supervisor from 2004 to 2006, for giving me the opportunity to conduct a PhD on the New Zealand sea lion at the Institute of Veterinary, Animal, and Biomedical Sciences (IVABS), and A/Prof. Patrick Morel for accepting the main supervision of my project since 2006. I also address my thanks to my co-supervisors Dr. Louise Chilvers (Department of Conservation), A/Prof. Duncan Mackenzie (Institute of Food, Nutrition, and Human Health IFNHH, Massey University) and Dr. Alastair MacGibbon (Fonterra Research Centre, Palmerston North) for all the time and effort they put into this project and the feedback they provided on the numerous drafts. I am especially grateful to Louise Chilvers for her strong support and motivation, and for giving me the opportunity to go to the Auckland Islands. Big thanks to Patrick Morel who was able to adapt his expertise from pigs to New Zealand sea lions with great enthusiasm. I reserve a special gratitude to Dr. Wendi Roe who provided strong support morally and financially in the second half of my PhD. Thanks to my three examiners Dr. Murray Potter, Dr. Simon Childerhouse and Prof. Mark Hindell, for reviewing my PhD thesis.

This project was sponsored by the Massey University Research Fund, the Lewis Fitch Research Fund, the Postgraduate Research Fund of the IVABS, the Whale and Dolphin Adoption Project, and the Conservation Services Programme of the Department of Conservation through levies on the commercial Fishing Industry. I am grateful to the graduate research school which funded me personally through the Massey University Doctoral scholarship for three years. My travel expenses to international conferences were partly funded by the IVABS.

Stomach contents, blubber samples, fish, cephalopods and crustaceans analysed in this project were collected with the help of many people. I have included an acknowledgement paragraph at the end of all research chapters which recognises specific contributions. I wish to thank Pádraig Duignan who supervised most of the necropsies until 2006, and the people who assisted with the necropsies over the past ten years including Mana Stratton, Nadine Gibbs, Monica Bando, Federico Riet-Sapriza

and Gareth Jones. Blubber biopsies at Enderby Island were under the supervision of Ian Wilkinson and Louise Chilvers.

Fish, cephalopods and crustaceans were collected by the National Institute of Water and Atmospheric research (NIWA) during the Tangaroa sub-Antarctic survey, and by the Ministry of Fisheries observers on the arrow squid and scampi fisheries. Special thanks to Nigel Hollands (MFish observer programme), Darren Stevens (NIWA) and Neil Bagley (NIWA) for providing the specimens. I am grateful to Gavin James (NIWA) who lent me some of his reference material at the beginning of my project, and to Matt Dunn (NIWA) who provided some fish from the Chatham Rise for my reference collection.

The development of my laboratory protocol for fatty acid analysis would not have been possible without the help and advice from numerous people. I wish to thank Robert Galois (Ifremer, France), Jennifer Learmonth (University of Aberdeen, UK), Mike Walton (SMRU, UK), Maggie Zou (IFNHH, Massey University), and Mark Reynolds (Fonterra Research Centre) for sharing their laboratory protocol and for their advice concerning the lipid extraction from adipose tissue. For their guidance on how to use the gas chromatograph, I am grateful to Mike Walton, Maggie Zou, Mark Reynolds and Bruce Fraser (chromatography adviser at Shimadzu Corporation). Concerning quantitative fatty acid signature analysis, I address my special thanks to Mike Walton who provided the programme Fascal, and to Dom Tollit (UBC, Canada) who provided the calibration coefficients calculated from Steller sea lions. Ryan Sherriff (Brimble Sherriff Young Limited, NZ) programmed the optimisation model for Massey University.

I appreciated the assistance of Lynn Rogers, Julianna Sebestyen, Junying Ye, and Laura Donaldson in the FA analysis of blubber and fish samples at the IVABS. Thanks to Fliss Jackson and Leiza Turnbull who were responsible for the lyophilisation of tissues, the protein content analysis and the energy content analysis processed at the IFNHH.

My acknowledgements to Jeff Forman, Matt Dunn, Mike Williams, Neil Bagley and Darren Stevens at NIWA who provided valuable inputs to my discussion concerning fish distribution and oceanographic variables in the NZ waters. I also express my

sincere gratitude to Karen Stockin for reviewing my entire thesis and providing helpful corrections, and to Dom Tollit and Mike Walton for providing wise comments on my Chapter 4.

During my four years as a PhD student, I appreciated the kindness and friendship of the people working at the IVABS. I wish to thank particularly Allain Scott and Kevin Stafford for their strong academic support. Allain, you were very helpful at the first stages of my enrolment at Massey University, and in providing a positive and welcoming work environment. The kindness of my office mates has been very important to me morally. Big thanks to Megan and Troy for their welcome when I arrived, Jo for her friendship, and Amanda and Zoe who had to support the last stressful months of my PhD. My gratitude to Karen Stockin who found me a nice office at Albany campus, and to my “temporary” office mates: Sara Whitwells, Shauna Baillie, Gabriel Machovsky Capuska and Manue Martinez. Gabriel and Manue, thanks for the essential training of table football in the necessary breaks of my final writing stage.

I wish to thank my former supervisors Vincent Ridoux and Graham Pierce, who taught me the “art” of stomach analysis on marine mammals, and guided me through my studies before this PhD. Your advice on writing turned out to be very helpful during my PhD.

I am grateful to a remarkable and inspiring man Jacques-Yves Cousteau, who showed millions of children the beauties of the “silent world”. His life has certainly inspired my vocation of becoming a marine biologist.

Last, I shall dedicate this work to my parents who gave me their support to follow my dreams since my childhood, and to my fabulous knight for his encouragement, understanding, and affection.

List of Abbreviations

CC	Calibration coefficient
FA	Fatty acid
FAMES	Fatty acid methyl esters
Im	Immature
K-W	Kruskall Wallis (test)
LF	Lactating female
Ma	Male
MUFA	Monounsaturated fatty acid
M-W	Mann Whitney (test)
NLF	Non-lactating female
NZ	New Zealand
PUFA	Polyunsaturated fatty acid
QFASA	Quantitative fatty acid signature analysis
SAFA	Saturated fatty acid
TAG	Triacylglycerol

Table of Contents

1 Chapter 1	1
General introduction and literature review	1
1.1 General introduction.....	2
1.2 NZ sea lion biology	3
1.2.1 Distribution	3
1.2.2 Abundance and trends	5
1.2.3 Breeding biology and lactation	6
1.2.4 Management of the squid fishery at the Auckland Islands	7
1.2.5 Foraging and feeding behaviour.....	8
1.2.6 Summary of NZ sea lion biology	9
1.3 Methods for dietary studies on marine mammals	10
1.3.1 “Traditional” diet methods: faeces and stomach analyses	12
1.3.2 DNA extraction from scat samples	14
1.3.3 Stable isotopes.....	16
1.3.4 FA signature analysis	20
1.3.5 Summary of dietary methods	27
1.4 Outline of the thesis	27
2 Chapter 2	29
Variability in the diet of New Zealand sea lion at the Auckland Islands, New Zealand	29
2.1 Introduction	31
2.2 Materials and methods	32
2.2.1 Sample collection	32
2.2.2 Stomach analysis	33
2.2.3 Statistical analysis	35
2.3 Results	39
2.3.1 Overall diet.....	39
2.3.2 Dietary variation (digested fraction)	42
2.4 Discussion	43
2.4.1 Limitations of the study	45
2.4.2 Feeding ecology of the NZ sea lion	46
2.4.3 Ontogenic variation in diet.....	47

2.4.4	Geographical variation in diet.....	48
2.4.5	Interactions with fisheries	49
2.5	Conclusion	50
3	Chapter 3	51
	Temporal and sex differences in the blubber fatty acid profiles of the New Zealand sea lion.....	51
3.1	Introduction.....	53
3.2	Materials and methods	55
3.2.1	Tissue collection	55
3.2.2	Laboratory methods	55
3.2.3	Statistical methods	56
3.3	Results.....	57
3.3.1	Composition of the sample set.....	57
3.3.2	Overall blubber FA composition.....	58
3.3.3	Temporal and sex differences in FA profiles.....	62
3.4	Discussion	63
3.4.1	Limitations of the study	64
3.4.2	Variation in FA profiles among sex categories.....	65
3.4.3	Year variation in FA profiles	67
3.5	Conclusion	68
4	Chapter 4	69
	Proximate composition, energy content, and fatty acid composition of marine species from the Campbell plateau, New Zealand	69
4.1	Introduction.....	71
4.2	Materials and methods	73
4.2.1	Sample collection.....	73
4.2.2	Proximate analysis	74
4.2.3	FA analysis.....	74
4.2.4	Statistical methods	75
4.3	Results.....	76
4.3.1	Proximate composition	76
4.3.2	FA composition.....	78
4.4	Discussion	82
4.4.1	Proximate composition and energy density	82

4.4.2	FA composition in relation to diet	83
4.5	Conclusion	85
5	Chapter 5	87
	Quantitative fatty acid signature analysis on New Zealand sea lions: sensitivity analysis & diet estimates	87
5.1	Introduction	89
5.2	Materials and methods	91
5.2.1	Sample collection	91
5.2.2	Lipid analysis	91
5.2.3	QFASA model.....	91
5.2.4	Sensitivity analysis of QFASA	93
5.3	Results	95
5.3.1	Sensitivity analysis of QFASA	95
5.3.2	Diet estimates of by-caught NZ sea lions using QFASA.....	100
5.4	Discussion	102
5.4.1	Sensitivity of QFASA	104
5.4.2	Overall diet estimate and feeding ecology.....	106
5.4.3	Diet estimates of males and females	107
5.4.4	Between-year variation in the diet estimates	108
5.5	Conclusion	109
6	Chapter 6	111
	Foraging diversity in lactating New Zealand sea lions: insight from qualitative and quantitative fatty acid signature analysis	111
6.1	Introduction	113
6.2	Materials and methods	115
6.2.1	Sample collection	115
6.2.2	Lipid analysis	116
6.2.3	Statistical analysis	117
6.2.4	QFASA model.....	118
6.3	Results	118
6.3.1	FA composition of biopsied lactating sea lions and variation	120
6.3.2	Biopsied lactating sea lions <i>versus</i> by-caught female sea lions.....	123
6.3.3	Diet estimates of NZ sea lions using QFASA.....	123
6.4	Discussion	126

6.4.1	Limits encountered with FA analysis and QFASA.....	126
6.4.2	Foraging diversity are not reflected in FA profiles.....	127
6.4.3	Differences between biopsied and by-caught females.....	129
6.4.4	Between-year variation in FA profiles and long-term diet.....	130
6.5	Conclusion.....	131
7	Chapter 7	133
	Feeding ecology of the New Zealand sea lion: General discussion	133
	Limits of the dietary methods.....	135
	Feeding ecology.....	137
	Importance of the edges of the Auckland Islands shelf.....	139
	Nutritional stress hypothesis and energetics.....	139
	Interactions with the arrow squid fishery and potential resource competition.....	142
	Future research on NZ sea lions.....	143
	General conclusions.....	145
	Appendix 1	147
	Analysis of fatty acids and gas chromatography: development of the laboratory protocol	147
	Development of a protocol.....	147
	Lipid extraction.....	147
	Fatty acid methylation.....	149
	Gas chromatograph analysis.....	151
	Protocol adopted.....	157
	Lipid extraction.....	157
	Fatty acid methylation.....	158
	Gas chromatograph analysis.....	159
	Appendix 2.....	161
	REFERENCES.....	163

List of Tables

(the first number refers to the chapter's number)

Table 1-1. Pros and cons of the main methods used to examine the diet of marine mammals	11
Table 2-1. Regression equations	36
Table 2-2. Number of stomachs of New Zealand sea lions analysed.....	39
Table 2-3. Composition of the New Zealand sea lion's diet	40
Table 2-4. Length and mass of New Zealand sea lion's prey	42
Table 3-1. Number of New Zealand sea lions analysed by year and sex.....	58
Table 3-2. Fatty acid composition of New Zealand sea lion's blubber.....	59
Table 3-3. General linear model on the principal components	63
Table 4-1. Morphometric data and ecology of marine species analysed	77
Table 4-2. Proximate composition and energy content of marine species analysed.....	78
Table 4-3a. Fatty acid composition of marine fish species from the Auckland Islands Rise.....	79
Table 4-3b. Fatty acid composition of cephalopod and crustacean species from the Auckland Islands Rise.....	80
Table 5-1. Number of New Zealand sea lions analysed by year and sex.....	95
Table 5-2. Kullback-Liebler values for different simulations with quantitative fatty acid signature analysis	98
Table 5-3. Predicted proportions by mass of prey species by quantitative fatty acid signature analysis	101
Table 6-1. Number of lactating New Zealand sea lions analysed per year	118
Table 6-2. By-year fatty acid composition	119
Table 6-3. Predicted proportions by mass of prey species by quantitative fatty acid signature analysis	125

List of Figures

(the first number refers to the chapter's number)

Fig. 1-1. Auckland Islands showing the main breeding areas of New Zealand sea lions	4
Fig. 1-2. Annual pup production of New Zealand sea lions	5
Fig. 1-3. Life cycle of the New Zealand sea lion.....	7
Fig. 1-4. Chemical structure of the linoleic acid.....	21
Fig. 2-1. Location of the captures of New Zealand sea lions	33
Fig. 2-2. Length distributions of prey found in the stomach contents	44
Fig. 3-1. Plot of canonical discriminant functions.....	64
Fig. 4-1. Map of the Campbell plateau	73
Fig. 4-2. Plot of the first three principal components	82
Fig. 5-1. Mean predicted proportions of prey species by quantitative fatty acid signature analysis.....	96
Fig. 5-2. Examples of predicted versus true fatty acid profiles	99
Fig. 5-3. Predicted proportions by mass of prey species of the New Zealand sea lion with different calibration coefficients	100
Fig. 5-4. Mean percentage of prey estimated by quantitative fatty acid signature analysis by sex	101
Fig. 5-5. Between-year percentages of prey estimated by quantitative fatty acid signature analysis	103
Fig. 5-6. Diet estimates of New Zealand sea lions by quantitative fatty acid signature analysis.....	104
Fig. 5-7. Estimated commercial catches of hoki, arrow squid and red cod	109
Fig. 6-1. Foraging locations of lactating New Zealand sea lions	114
Fig. 6-2. Plot of the first two canonical discriminant functions	121
Fig. 6-3. Comparison between FA profiles of benthic divers and those of mesopelagic divers.....	122
Fig. 6-4. Plot of the first two principal components	124
Fig. 6-5. Mean estimated percentages of prey species by year from quantitative fatty acid signature analysis	125