Assessment of the impacts of seal populations on the seafood industry in South Australia

Simon D Goldsworthy, Frederic Bailleul, Melissa Nursey-Bray, Alice Mackay, Andrew Oxley, Sarah-Lena Reinhold and Peter D Shaughnessy

June 2019

FRDC Project No. 2013/011

© 2019 Fisheries Research and Development Corporation and South Australian Research and Development Institute. All rights reserved.

ISBN: 978-1-876007-16-4

Assessment of the impacts of seal populations on the seafood industry in South Australia.

2013/011

2019

Ownership of Intellectual property rights

Unless otherwise noted, copyright (and any other intellectual property rights, if any) in this publication is owned by the Fisheries Research and Development Corporation and the South Australian Research and Development Institute. This work is copyright. Apart from any use as permitted under the *Copyright Act* 1968 (Cth), no part may be reproduced by any process, electronic or otherwise, without the specific written permission of the copyright owner. Neither may information be stored electronically in any form whatsoever without such permission.

This publication (and any information sourced from it) should be attributed to Goldsworthy, S.D., Bailleul, F., Nursey-Bray, M., Mackay, A., Oxley, A., Reinhold, S-L., and Shaughnessy, P.D. South Australian Research and Development Institute (Aquatic Sciences), 2019, *Assessment of the impacts of seal populations on the seafood industry in South Australia,* Adelaide, June.

Creative Commons licence

All material in this publication is licensed under a Creative Commons Attribution 3.0 Australia Licence, save for content supplied by third parties, logos and the Commonwealth Coat of Arms.

Creative Commons Attribution 3.0 Australia Licence is a standard form licence agreement that allows you to copy, distribute, transmit and adapt this publication provided you attribute the work. A summary of the licence terms is available from creativecommons.org/licenses/by/3.0/au/deed.en. The full licence terms are available from creativecommons.org/licenses/by/3.0/au/legalcode.

Inquiries regarding the licence and any use of this document should be sent to: frdc@frdc.com.au

Disclaimer

The authors warrant that they have taken all reasonable care in producing this report. The report has been through the SARDI internal review process, and has been formally approved for release by the Research Director, Aquatic Sciences. Although all reasonable efforts have been made to ensure quality, SARDI does not warrant that the information in this report is free from errors or omissions. SARDI and its employees do not warrant or make any representation regarding the use, or results of the use, of the information contained herein as regards to its correctness, accuracy, reliability and currency or otherwise. SARDI and its employees expressly disclaim all liability or responsibility to any person using the information or advice. Use of the information and data contained in this report is at the user's sole risk. If users rely on the information they are responsible for ensuring by independent verification its accuracy, currency or completeness.

The authors do not warrant that the information in this document is free from errors or omissions. The authors do not accept any form of liability, be it contractual, tortious, or otherwise, for the contents of this document or for any consequences arising from its use or any reliance placed upon it. The information, opinions and advice contained in this document may not relate, or be relevant, to a readers particular circumstances. Opinions expressed by the authors are the individual opinions expressed by those persons and are not necessarily those of the publisher, research provider or the FRDC.

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

Researcher Contact Details

Name: Simon D. Goldsworthy
Address: SARD Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024
Phone: 08 8429 0268
Fax: 08 8207 5415
Email: simon.goldsworthy@sa.gov.au

FRDC Contact Details

Address: 25 Geils Court
Deakin ACT 2600
Phone: 02 6285 0400
Fax: 02 6285 0499
Email: frdc@frdc.com.au
Web: www.frdc.com.au

In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

Contents

Tables

Figures

Acknowledgments

We acknowledge the significant support for the development of this project provided by the Australian Southern Bluefin Tuna Industry Association, and especially thank Brian Jeffriess and Claire Webber for their ongoing support. We also thank Sean Sloan and Kate Rodda (PIRSA Fisheries and Aquaculture) and Martine Kinloch (DEW) for their assistance with project development. We thank the FRDC for funding, and Chris Izzo and Skye Barrett (FRDC) for project support.

All research activities undertaken on wildlife were approved by the PIRSA Animal Ethics Committee (approval No. 32-12), and under a SA Department for the Environment and Water Licence to Undertake Scientific Research (Permit No. A24684). We thank Frank Kutsche and Sarah Laurence (DEW Permits), and the PIRSA Animal Ethics Committee for their assistance.

With respect to the support of field operations, we would like to thank Tim Anderson (Helifarm), Tony Jones (Protect Marine), and regional DEW staff, especially Dirk Holman, Damien Miley, and Anthony Maguire. We thank Michael Sheldon (SA Water) for assistance with access to Tauwitcherie Barrage. We would like to acknowledge the support and resourcing of boats, vehicles and field staff provided by Kangaroo Island Natural Resource Management. In particular thanks to Kym Lashmar and Alicia McArdle for their assistance in accessing a number of remote sites around Kangaroo Island.

With respect to DNA metabarcoding work, we would like to thank staff from the South Australian Museum (S Donnellan, L Wheaton, A Crowther and R Foster), SARDI Aquatic Sciences (G Hooper, M Steer, P Rogers, T Fowler, M Lloyd, L Andreachio and O Burnell), Flinders University (C Huveneers), and CSIRO (A Graham and S Appleyard) for the provision of reference tissues. We also gratefully thank S Catalano (Molecular Sciences, SARDI Aquatics) for laboratory support; A Camarinha-Silva (Institute of Animal Science, Animal Nutrition Group, University of Hohenheim, Germany) for providing direction and helpful comment with the NGS assays; and Dr M Wos-Oxley (Flinders University) for assistance with sequence data analysis. We also wish to acknowledge the Australian Genome Research Facility - AGRF and their staff (L McGrath, P Gooding, S Tyagi and N Kasinadhuni) for providing exceptional support in the sequencing and bioinformatics processing of our customised NGS assays.

We thank Cathy Bulman (CSIRO Marine and Atmospheric Research), Jeroen Steenbeek and Marta Coll (Institute of Marine Science, ICM–CSIC, Barcelona, Spain) for assistance with ecological model development. We thank Jason Tanner (SARDI), Jason Earl (SARDI) and Skye Barrett (FRDC) for reviewing the draft final report.

Abbreviations

ABC - Australian Broadcasting Commission
ABTC – Australian Biological Tissue Collection
AFS – Australian fur seal
AGRF – Australian Genome Research Facility
AM - adult male
ANOSIM - Analysis of Similarity
ASL – Australian sea lion
ASBTIA - Australian Southern Bluefin Tuna Industry Association
avTD – average taxonomic distinctness
B - Biomass
BA - Biomass Accumulation
BC - Breeding colony
Bio - Biomass contribution
bp – Base pair
C3 - spacer – three-carbon chain spacer
CBF – Charter Boat Fishery
COI – Cytochrome c oxidase subunit I gene
COI-5P – Cytochrome c oxidase subunit I gene 5 prime region
CTF – Commonwealth Trawl Fishery
CytB – Cytochrome B gene
DDF - Deposit Detritivore feeding
DEWNR - Department of Environment, Water and Natural Resources
DEW Department of Environment and Water
DNA - Deoxyribonucleic acid
DOM - Dissolved organic matter
DPO – Dual Priming Oligonucleotide
DPO Dual Priming Oligonucleotide
ECO - Ecotourism
EE - Ecotrophic efficiency
EGAB - Eastern Great Australian Bight
EwE - Ecopath with Ecosim
FO - Frequency of occurrence
FRDC – Fisheries Research and Development Corporation
GAB - Great Australian Bight
GABTF – Great Australian Bight Trawl Fishery
GPS – Global Positioning Systems
GSV - Gulf St Vincent
HO - Haul out sites
HP - Hard-part
IRI - Index of Relative Importance
Juv - Juvenile
KGW - King George Whiting
LC – Lakes and Coorong Fishery
LNFS – Long-nosed fur seal
M - male
MFA – Marine Fishing Areas
MSF – Marine Scale Fishery
mt - Mitochondrial
mt16S – Mitochondrial 16S ribosomal RNA gene
MW – Molecular Weight marker
NA – Numerical abundance, minimum number of individuals
N - Frequency by Number
NGS – Next Generation Sequencing

nt – Nucleotide
OTU – Operational Taxonomic Unit
P/B - Production/biomass
PCoA - Principal Coordinate Analysis
PCR – Polymerase Chain Reaction
PERMANOVA - Permutational Multivariate Analysis of Variance
PF – Prawn Fishery
PIRSA - Primary Industries and Regions South Australia
POM - Particulate organic matter
PTT - Platform Transmitting Terminal
PVC - percentage volume contours
Q/B - Consumption/biomass
REC – Recreational Fishery
rRNA – ribosomal RNA gene
SA - South Australia
SAFRAB - South Australian Fisheries Research Advisory Board
SAM - subadult male
SARDI - South Australian Research and Development Institute
SASF – South Australian Sardine Fishery
SBT – Southern Bluefin Tuna Fishery
SBT - Southern Bluefin Tuna
SCKI – South Coats Kangaroo Island
SG - Spencer Gulf
SIMPER - Similarity percentage analysis
TD – taxonomic distinctness
UD - Utilisation Distribution
UNI - Efficiency of Universal
varTD – variation in taxonomic distinctness
YTK - Yellowtail Kingfish
Z – total mortality
ZF - Zooplankton feeding

Executive Summary

What the report is about

This report provides the most comprehensive assessment of the impact of seals on the seafood industry in South Australia (SA), where management of both the real and perceived impacts of seals has become a very complex socio-ecological economic issue. It uses a range of diverse methods to understand and assess the nature and extent of impacts from seals on marine industries and coastal communities, including: perception surveys, dietary studies, satellite tracking of seals, spatial distribution models and ecological modelling. Critically, the study evaluates the extent of economic and ecological impacts of seals, and addresses stakeholder concerns that the recovery of fur seal populations could have negative impacts on commercial fish production or cause an imbalance in coastal ecosystems. Results of the study should assist industry and government direct support to sectors where seal interactions are having real economic impacts, and address many stakeholder and community misconceptions about the impacts of seals.

Background

South Australia is an important region for seal biodiversity, containing most (>80%) of the nation's Long-nosed Fur Seal (LNFS) and Australian Sea Lion (ASL) populations. The sealing era in the early 1800s almost resulted in the extirpation of seals from coastal Australian waters, and for most of the 150 years that followed, seal populations remained at very low levels. It was during this period that Australia's contemporary fishing and aquaculture industries developed. However, the last three decades have seen a major recovery of fur seal populations, and concomitant with this recovery, direct interactions between seals and some fisheries and finfish aquaculture operations have increased, as have the perceptions about their impacts on fish stocks and the broader marine environment. As large bodied, conspicuous marine predators, seals are viewed by many marine stakeholders as direct competitors that could have negative economic impacts on their livelihoods, with many demanding active management of their populations.

This project set out to significantly improve our understanding of the nature and extent of seal interactions with South Australian marine industries (aquaculture, commercial and recreational fisheries, and ecotourism), by using a range of diverse methodologies and approaches.

Aims/objectives

The objectives of the project were to: 1) assess marine stakeholder perceptions about the impacts of seals on their livelihood and on the broader marine ecosystem; 2) estimate the economic impact of seals on the finfish aquaculture industry; 3) estimate the importance of commercial and recreational fish and finfish aquaculture species in diets of seals; 4) assess the movement patterns of seals in regions where finfish aquaculture and fisheries have significant seal interactions; 5) estimate the spatial distribution of foraging and consumption effort of seals and the overlap with key fisheries; and 6) estimate the impacts of consumption of marine resources by seals on commercial fish production, other species of value to the ecotourism industry, and the broader marine ecosystem.

Methodology

Social perception surveys of marine stakeholders were used to assess the perceived impacts of seals on their livelihood, and on the broader marine ecosystem, and to provide an estimate of the economic impact of seals on the finfish aquaculture industry.

Two main dietary studies were undertaken to improve our understanding of the diet of seals in SA waters. The first, developed and utilised new molecular metabarcoding tools applied to prey DNA extracted from seal faecal samples. The second utilised traditional faecal hard-part analyses to examine the diet of LNFS across different coastal regions in SA, and for a subset of samples, compared the application of hard part and DNA metabarcoding methods.

There have been significant gaps in knowledge about the movement behaviour and interactions between male LNFS and fisheries and aquaculture activities. As such, a satellite telemetry study of male LNFS was undertaken to evaluate their foraging patterns and determine the extent to which individual foraging effort was associated with important finfish aquaculture locations and regions important to fisheries. These data were integrated with existing satellite tracking data and demographic consumption models to estimate the spatial distribution of foraging and consumption effort of LNFS and ASL off SA. The extent of overlap with the spatial distribution of catch in the major SA fisheries was also evaluated.

Dietary data were synthesised with historical data to provide an estimate of the overall diet of LNFS, Australian fur seals (AFS) and ASL, as well as to estimate age-class and regional differences in the diet of LNFS. These dietary syntheses were integrated into ecological models developed for Spencer Gulf (SG) and Gulf St Vincent (GSV), two coastal regions critical to the State's seafood industries. These models incorporated multiple stanzas (age-classes) for key commercially targeted species and LNFS, and were used to evaluate the importance of consumption by seals relative to other marine predators and to evaluate the sensitivity of key marine taxa to changes in LNFS and ASL biomass. Scenarios were run in each of these models to assess the potential impacts of changing biomasses of seals on the biomasses of key commercially fished species and other taxa.

Results/key findings

The social perception surveys confirmed that concerns about the impacts of recovering populations of seals on seafood industries, marine communities and coastal ecosystems of South Australia have clearly intensified in recent years, becoming a very complex socio-ecological economic issue.

The most significant direct interactions were between seals and the finfish aquaculture industry off Port Lincoln, and gillnet fishers in the Lakes and Coorong Fishery. Whereas both seal species (ASL and LNFS) were viewed as having an impact on finfish aquaculture operations, for most other marine stakeholders their primary concerns were with LNFS.

Many finfish aquaculture stakeholders judged that the economic impact of seals on their operations, from loss of, and damage to fish stock and their subsequent sale, damage to nets and other infrastructure, and loss of feed, ranged between 1 and 5% a year, with a third of operators estimating the overall cost of seal interactions to be $100,000 per year.

The commercial fishing sector in the Lakes and Coorong region is experiencing acute and immediate stress and economic impact relative to other stakeholders, with some respondents estimating losses of up to 50% or more in their profit and catch in the last five years, due to interactions with LNFS. Concerns about the impacts from seal interactions were often relayed in very emotive terms, with many stakeholders believing that the economic impact of seals was major and potentially catastrophic.

In contrast, marine tourism industry respondents viewed interactions with seals as having a very positive economic impact, in some cases saving businesses in difficult economic times (e.g., for shark cage dive operators when sharks are absent from licensed areas).

The broader ecosystem impacts of seals were believed to be potentially catastrophic by many respondents. Key concerns were the impacts of increasing population of LNFS on fish production, creating imbalance of ecosystems and the killing of birdlife. Many respondents attributed declines in Little Penguin populations to predation by fur seals and the recovery of their populations. Many seafood industry respondents believed that populations of LNFS were overabundant and active management of numbers was needed to mitigate their economic and ecological impacts. The most favoured management option was culling.

The study has confirmed that with respect to LNFS, interactions are largely restricted to the subadult male age-class, a portion of which comes into coastal waters in autumn with numbers peaking in winter months. Analyses of the spatial overlap in seal consumption and fishery catch indicated that for both ASL and LNFS, there was a tendency for there to be a spatial mismatch between areas of intensive seal foraging and commercial catch. This is particularly noticeable in the upper gulfs which are regions of low consumption by seals, but high fishing effort.

Tracking studies provided new data on the movement of male LNFS in coastal waters. GPS tags fitted to male LNFS hauled-out at Donington Reef adjacent to tuna aquaculture cages in SG, demonstrated a remarkably tight association between the seals and tuna cages. While tuna cages are stocked, they provide a reliable and readily accessible source of food to many fur seals that commute from nearby haul-out sites. Diet analysis provided support that LNFS are attracted to aquaculture cages in part to directly feed on either live, sick or dead tuna or Yellow Tailed Kingfish, or on baitfish feed. However, the predominance of mackerel and trevally in the diet suggested they may also be attracted to aquaculture cages to forage on other species attracted to aquaculture operations.

A number of male LNFS were also fitted with GPS/satellite tags on the north coast of Kangaroo Island and in or on islands adjacent to the Coorong. Movement data from these animals provided further examples of the highly flexible foraging strategies of male fur seals. Several individuals spent time foraging within the estuary and lakes systems of The Coorong and Lower Lakes, before switching to offshore oceanic foraging.

Dietary studies estimated that key commercially fished species made up just 5%, 4%, and 2% of the total prey biomass consumed by LNFS, ASL and Australian fur seals (AFS) in South Australia. Regional differences in the contribution of key commercially fished species were identified in LNFS diet. They were a minor contributor to the diets of LNFS on the West Coast (0.7%), south coast of Kangaroo Island (0.7%) and The Coorong (1.5%); but were more important in SG (6.0%) and were a major part of the diet in GSV (52.2%). Most of this consumption was by male LNFS, and the key commercially fished taxa consumed were Sardine (3% of prey biomass) in Spencer Gulf, and Calamari (24%) and Garfish (17%) in GSV.

Ecosystem models developed for SG and GSV enabled the consumption of prey species by seals and other predators to be assessed, and their relative consumption to be compared. The most significant consumers of finfish and cephalopods were other finfish and cephalopods. Seals consumed only about 1% of all finfish and 2-3% of all cephalopods, and only accounted for around 0.5% of the total consumption of commercially targeted finfish, most (0.4%) of this consumption was by LNFS.

Scenarios of the potential impacts of increasing seal populations on commercially fished species found no evidence that further increases in seal biomass would result in significant impacts on future fish production. Outputs from both the SG and GSV models indicated a less than 1% change in biomass of key commercially targeted finfish, cephalopod and crustacean taxa in response to LNFS biomass increasing from 0.1 to current biomass levels. Under increasing LNFS biomass scenarios (from current up to 10-times current biomass levels), the biomass of key commercially fished taxa tended to increase as the biomass of LNFS increased.

The study found that most key fished species responded non-linearly to changes in seal biomass, indicating that the indirect predation effects of seals on other predators or competitors of commercially fished species were more important than their direct predation on these species. In this way, seals are important in mediating predator-prey interactions that affect the biomass of many taxa, including those targeted by commercial fishers.

Scenario analyses of increasing LNFS biomass in both SG and GSV provided the first quantitative support that recovering LNFS populations may have contributed to declines in Little Penguin populations. However, the impact from other predators, such as sharks, may be underestimated in these models.

Implications for relevant stakeholders

With respect to economic impacts, the study confirmed that direct interactions with seals (e.g. depredation of catch/farmed fish, loss of feed, damage to nets and gear) can cause significant economic impact, but these are largely restricted to two marine sectors: the finfish aquaculture industry in SG, and the gillnet sector of the Lakes and Coorong Fishery. Direct interactions with other SA fisheries are rare or economically insignificant, principally because these represent active gear fisheries that offer seals less opportunity to exploit.

With respect to ecological impacts, the study found no evidence to support claims that seals, and specifically increasing populations of LNFS, are having potentially catastrophic impacts on commercial fish production, or on the integrity and health of the broader marine ecosystem. This mismatch between the perceived and actual impacts of seals on fish production and the broader marine ecosystem represents one of the key findings of this study.

The results have important implications for industry, policy and management and the community. For the seafood industry, outcomes should help direct policy and management priorities to address seal conflict issues. Specifically, the outcomes provide the basis to direct attention and support to sectors where seal interactions have real economic impacts, and should provide some objectivity to address many of the perception issues about the impacts of seals, especially where control of numbers has been argued as a management solution. For the seafood industry, coastal communities and the broader public, results of this study should help allay concerns about the potential impacts of recovering populations of LNFS on commercial fish production and the integrity and health of the marine ecosystem.

Recommendations

With respect to finfish aquaculture interactions, further research and development into reliable and affordable systems to exclude seals from aquaculture pens is needed to reduce the opportunity for seals to impact their operations. In the gillnet sector of the Lakes and Coorong Fishery, there is a need to assess the economic and ecological impacts of LNFS in the Lower Lakes and Coorong region to assist development of policy and management strategies to address seal conflicts in the region. Education to address stakeholder and community misconceptions about the ecological impacts of seals on fish production and coastal ecosystems, and perceptions of overabundance represents a significant challenge, but should be seen as an essential part of addressing future seal conflict issues.

Future ecological modelling of seal-fishery interactions would benefit from the inclusion of spatial modules such as Ecospace that enable incorporation of habitat and other spatial distribution factors to improve simulations of taxa interactions. Improved dietary data for many taxa, would improve capacity to evaluate other trophic interactions of interest, such as the impact of seals on Little Penguin populations. There are still many uncertainties about the population dynamics and movement of fur seals into coastal waters, including what portion of the male population moves into coastal waters in winter months, why do they do it, how long they stay for, and do numbers vary annually and if so why? Such information would improve our understanding of why fur seals come into coastal waters, providing marine industries, coastal communities and government important information to better understand and manage sea conflict issues.

Keywords

Seals, Long-nosed Fur Seal, Australian Sea Lion, seal interactions, perception surveys, seal diet, movement behaviour, ecological modelling, Ecopath with Ecosim.

1 Introduction

1.1 Background

Why and how this application was developed:
In most marine systems, marine mammals are major consumers of production from a range of trophic levels, and because of their large body size, they are considered to be important in structuring trophic interactions (e.g. Bowen 1997, Goldsworthy *et al.* 2003). Inevitably this puts them into conflict with human use of marine resources, especially commercial fisheries and aquaculture. Interactions between marine mammals and fisheries are typically described as falling into one of two categories. ‘Operational interactions’ are those that occur between marine mammals and fishing operations. These interactions are documented most frequently because they can be physically observed and in some instances, directly managed (Goldsworthy *et al.* 2010, Hamer and Goldsworthy 2006, Shaughnessy *et al.* 2003). In contrast, ‘trophic interactions’ (also known as ecological, indirect or covert interactions), involve the consumption of resources by marine mammals and may impact on the resources available to human fisheries. They are typically not observed and difficult to assess and manage, and generally receive far less attention (Goldsworthy *et al.* 2003). Nonetheless, the ecological and economic consequences of trophic interactions are usually more significant than operational interactions, and therefore likely to create more complex management challenges (Goldsworthy *et al.* 2003).

The debate over the significance of trophic interactions between marine mammals and fisheries is based on the belief that marine mammals can have significant impacts on prey populations that are also consumed by humans, or alternatively, that over-fishing may be limiting the size, and/or the recovery of some marine mammal populations (Butterworth 1992, Butterworth *et al.* 1988, Goldsworthy *et al.* 2003, Gulland 1987, Wickens *et al.* 1992, Yodzis 2001). Seals typically display flexible foraging strategies that enable them to target seasonally abundant aggregating prey, exploiting several species at one time. Short-term seasonal changes in diet typically correspond to prey movement and life history patterns, whereas long-term annual changes are typically influenced more by regional or large-scale ocean climate shifts (Kirkwood *et al.* 2008, Weise and Harvey 2008). Populations of seals can impact directly on specific prey resources and directly compete with fisheries, although the extent of competition is strongly affected by the degree of spatial and temporal overlap between seal foraging and commercial fishing areas (Butterworth *et al.* 1988, Goldsworthy *et al.* 2003, Weise and Harvey 2008).

Sealing was Australia’s first export industry. Over a short 30-year period (1800-1830s) more than 355,000 skins are recorded to have been shipped through Sydney Harbour (Ling 1999). This is an underestimate of the total number of seals taken as it does not include additional skins shipped directly to overseas markets (mainly China), or spoiled skins or those from unreported harvests. Sealing was unregulated, highly competitive and resulted in sequential depletion, and in many instances elimination of entire breeding populations. As a consequence, all three seal species that breed in southern Australia (Australian Fur Seal AFS, *Arctocephalus pusillus doriferus*; Long-nosed Fur Seal LNFS, *A. forsteri*; Australian Sea Lion ASL, *Neophoca cinerea*) had their populations reduced to a fraction of their original size, and suffered major range contractions, and one species, the southern elephant seal (*Mirounga leonina*), was completley extirpated from the region. Seal numbers remained very low over the next 150 years, due to continued harvests and incidental killing, with closed seasons and or permits being introduced in most States by 1919. Authorised culls were permitted in parts of Australia until the late 1940s (Kirkwood and Goldsworthy 2013). By 1975, all seals in Australia were protected under the Commonwealth *National Parks and Wildlife Act (1975)* in Commonwealth waters and under various legislations in State waters.

For both fur seal species in southern Australia, the main period of recovery commenced in the early 1980s (Kirkwood and Goldsworthy 2013). For AFS, pup production increased from about 12,000 across nine breeding colonies in Bass Strait in the late 1980s, to around 22,000 in the late 2000s, with the species now breeding at an additional five colonies, including an expansion of their breeding range to South Australia, with an average growth in pup production of around 6% per annum (Kirkwood *et al.* 2005, Kirkwood and Goldsworthy 2013). Surveys conducted since then have indicated a decline in pup production at many sites (McIntosh *et al.* 2018). Recovery of LNFS has followed a similar pattern, with pup production increasing in South Australia from about 5,600 in 1989-90, to 20,400 in 2013-14, more than a trebling in numbers in 24 years (Shaughnessy *et al.* 2015). Although the overall growth in pup production has been at around 5.5% per year across South Australia, some populations such as Cape Gantheaume on Kangaroo Island have increased at an average of 9% per year, based on annual surveys undertaken for 29 years to 2016/17 (Goldsworthy *et al.* 2017c). There are 29 breeding sites in South Australia, which account for most (>80%) of Australia's population of LNFS (Shaughnessy *et al.* 2015). Populations of LNFS continue to grow and their breeding and non-breeding distributions are expanding. In contrast to the fur seals, ASL populations appear not to have undergone a recovery, at least not over the last 25 years; with declining populations across most of the species range. The South Australian population is estimated to be declining by ~3.5% per year, although the rates of decline are much greater in some regions (e.g. western Eyre Peninsula populations) and most monitored sites appear to be somewhat stable (Goldsworthy *et al.* 2017c, Goldsworthy *et al.* 2015). In contrast to the fur seals where at main breeding sites pup production typically is in the thousands, pup production of ASL only exceeds 100 at five of ~70 known sites (all in South Australia), with the median pup production per breeding site just 19 (Goldsworthy *et al.* 2017c, Goldsworthy *et al.* 2015).

The legacy of the sealing era almost resulted in complete removal of these key high-trophic level predators over a very short time. This undoubtedly altered the state of coastal and shelf marine ecosystems in southern Australia and, due to the major reduction in biomass, seals likely played a minor role in structuring marine ecosystems over the next 150 years or so. As a consequence, the development and growth of most of Australia's commercial and recreational fisheries and aquaculture industries throughout the 20th century occurred during a period of markedly reduced seal populations, and the inevitable recovery of most fur seal stocks is likely to bring about changes to marine ecosystems that will also impact the available biomass of some commercial and recreational fished species (Goldsworthy *et al.* 2003). Given the likely ecological and economic ramifications of such impacts, the limited extent to which trophic interactions between seals and seafood industries are currently understood represents a significant gap in knowledge (Goldsworthy *et al.* 2003). The continued increase in fur seal populations can be anticipated with reasonable confidence. As identified by Goldsworthy *et al.* (2003), the challenge such knowledge presents is how it can be best used to inform short and long-term management of seafood industries, seal populations and the broader marine ecosystem as a whole.

In South Australia, as with other southern States, fur seal population size and prey consumption are increasing rapidly and may continue to do so for many decades. For LNFS, considerable research has been undertaken on the foraging ecology of adult females and males. This part of the population tends to feed offshore in outer shelf or oceanic waters and tends not to target commercially fished species (Baylis *et al.* 2008a, 2008b, Page *et al.* 2006). However, juvenile and subadult fur seals appear to forage mostly over shelf waters, and it is this part of the population that consumes the most marine resources and interacts with fisheries and aquaculture activities (Goldsworthy *et al.* 2009a, Goldsworthy *et al.* 2010). Information on their movements and diet are very limited, but they frequently interact with fishing activities, including Coorong net fishers, and they interact with finfish aquaculture causing stock losses and costs associated with mitigation (Goldsworthy *et al.* 2009a, Robinson *et al.* 2008a, Robinson *et al.* 2008b). There is growing concern within the seafood industry about how increasing populations of fur seals will impact the future sustainability and production of key fisheries, and about the growing costs associated with managing and mitigating seal interactions with aquaculture. Furthermore, the rapid growth of fur seal populations in SA has been implicated in declines of Little Penguin (*Eudyptula minor*) colonies that sustain ecotourism operations at Victor Harbor, Penneshaw and Kingscote (Bool *et al.* 2007). Fur seals are also considered by some to be a contributing factor in the decline in the Giant Cuttlefish (*Sepia apama*) population off Point Lowly in northern Spencer Gulf. They have also been suggested to compete for prey resources with ASL, thereby impacting the recovery of their populations (Goldsworthy *et al.* 2009a). In addition, SA has an emerging breeding population of AFS that has established off Kangaroo Island, and has more than doubled in size over the last five years. The implications of further growth in this population for commercial fish production and food-web interactions with LNFS, ASL and other species is uncertain.

Relation to current/recently completed projects:
A major objective of this study was to assess the impacts of consumption by seals, and the implications of further increases in seal populations on the future biomass of commercially and recreationally fished species in South Australia. New dietary information is used to update two previously developed trophic models for the Spencer Gulf (SG) (FRDC Project 2011/205) and GSV (FRDC Project 2013/031) ecosystem. As fish taxa utilised by seafood industries form discrete trophic groups within these models, the extent and

implications of competition with seafood industries for these target species has been explicitly modelled. A key element in assessing the impact of seal populations on seafood industries is to accurately estimate their biomass and consumption, and to estimate future growth in these parameters. Two projects have provided these critical data. Commonwealth funding through the Australian Marine Mammal Centre supported a State-wide survey of LNFS and AFS populations in South Australia in January/February 2014. The last survey of its kind was undertaken 25 years earlier. The South Australian Department for Environment and Water (DEW) has funded three annual surveys of the Cape Gantheaume LNFS population, continuing the annual monitoring that has been conducted at this site over the last 30 years. Both projects provide critical data required to calculate population size, biomass and consumption, as well as ongoing trends (and future projections) in population growth essential to the trophic modelling work proposed.

Industry questionnaires used in this project build upon those developed to assess the extent and implications of seal interactions with finfish farms in 2005 as part of FRDC 2004/201. They provide a means to assess how the nature, extent and industry perceptions of the impacts of seal interactions have changed since then (Goldsworthy *et al.* 2009a).

This study directly addresses FRDC’s Natural Resource Sustainability strategic challenge. It does this by assessing the impact and implications of recovering seal populations on marine ecosystems and fish production, including costs associated with managing and mitigating seal interactions with finfish aquaculture. Such information will help maintain and improve the management and use of aquatic natural resources to ensure their sustainability.

1.2 Need

The 24 years to 2013-14 saw a 3.6 fold increase in the population size of LNFS in SA, which now number over 97,000 individuals (Shaughnessy *et al.* 2015). This recovery may continue for some time, and the level at which populations may stabilise is unknown. New haul-out sites and breeding colonies of the LNFS are establishing across the State, some in close proximity to finfish aquaculture, and major commercial and recreational fishing areas. In addition, an AFS population has recently established in SA and has more than doubled in the last ten years. There is also growing concern from the seafood and ecotourism industries concerned with Little Penguins and Giant Cuttlefish, and from the community that fur seals are overabundant and that their populations and impacts need to be managed. As a consequence of this broad industry and public concern, this project was listed as one of the priority areas for investment by the SARAC.

Most of the seals that interact with fisheries, aquaculture and ecotourism in SA are juveniles and subadult males that restrict their feeding to shelf waters; however the diet and foraging behaviour of this part of the population is poorly understood. Little is also understood about the potential competitive interactions between the three species of seals that may be limiting the recovery of the threatened ASL. This project investigates the diets and foraging distributions of seals in SA’s gulf and shelf waters to assess the importance of commercial fish and finfish aquaculture species in the seals’ diet. Trophic modelling is used to assess the impact of consumption on current and future seafood production, and industry questionnaires and consultation are used to assess the economic impact and the degree and nature of interactions between seals and finfish aquaculture, fisheries and marine ecotourism industries.

1.3 Objectives

Objectives of the project are as follows.

1. Assess perceptions of the fishing industry and the community on the economic impacts of operational and trophic interactions with seals on seafood and on other species such as Little Penguin, Giant Cuttlefish and the potential ecological displacement of ASL from increasing fur seal populations.

2. Estimate the costs to the fin-fish aquaculture industry from stock losses, deterrent methods and maintenance requirements associated with seal interactions.

3. Determine the importance of commercial and recreational fish and finfish aquaculture species in diets of seals.

4. Determine the spatial distribution of foraging and consumption effort of fur seals relative to important finfish aquaculture and commercial and recreational fishing areas.

5. Estimate the impacts of consumption by seals, and the implications of increasing populations on the future biomass of commercially and recreationally important marine taxa on seafood and marine ecotourism industries

2. Overview of a social perception study assessing impacts of seal populations on the seafood industry and on marine stakeholders in South Australia

Peter Shaughnessy

2.1 Introduction

The direct and perceived economic impacts of interactions between seals and finfish aquaculture and commercial fishing industries, and impacts on other marine stakeholders was investigated by socio-economic specialists from the University of Adelaide. Their report Nursey-Bray and Magnusson (2016) forms Appendix 2.1 of this report. The study was based on questionnaires, interviews and an examination of media reports. It sought to obtain information on the nature and extent of impact of direct operational interactions between seals and fishing activities, gear and catch. It also obtained information about the perceived impacts and consequences that seals have on the marine environment in general, and the consequences that increasing seal populations may have on fishers' livelihoods and on the livelihoods of other marine stakeholders. The investigation assessed how each industry perceived seals in terms of positive and negative impacts on the structure of the marine ecosystem in which they operate. It also assessed if various industries believed that seal numbers should be managed and, if so, how that should be undertaken and who should be responsible.

The report by Nursey-Bray and Magnusson (2016) builds on a chapter of an earlier study by Goldsworthy *et al*. (2009b) entitled 'Operational interactions between seals and the Southern Bluefin Tuna farming industry in Port Lincoln'. That study was undertaken in 2005 and focussed on the observed and perceived impact of operational interactions between seals and the tuna aquaculture industry. Its aims were 1) to assess the nature and extent of interactions between seals and finfish aquaculture in the Port Lincoln region to provide a baseline against which future changes could be assessed; and 2) to develop recommendations on how finfish farmers may minimise seal interactions. It provided important insights and was an important starting point for the current study, but it only focussed on tuna farming. The work presented in this report documents perceptions of all marine stakeholder groups about seal interactions in South Australia (SA), including the aquaculture sector.

The report by Nursey-Bray and Magnusson (2016) begins with a literature review that provides an international overview of interactions between seals and fisheries from an operational perspective and then from a biological perspective. This is followed by a review of literature dealing with such interactions in SA. Their report (Appendix 2.1) is included unaltered except that the references (its section 7) have been edited so that they are more complete than in the original, and the table of contents and lists of figures and tables have been omitted. This overview comprises salient points from sections of the report by Nursey-Bray and Magnusson (2016) that deal with surveys involving the aquaculture industry and other marine stakeholders. It also expands on the report's discussion, primarily by comparing some of its results with those of the earlier study (Goldsworthy *et al.* 2009a).

Objectives

The objectives of this chapter are twofold.

To estimate costs to the fin-fish aquaculture industry from stock losses, deterrent methods and maintenance requirements associated with seal interactions and their mitigation.

To determine industry perceptions of the economic impacts of operational and trophic interactions with seals on seafood and ecotourism industries.

2.2 Methods

This project adopted a qualitative social science approach, characteristics of which are described in Appendix 2.1, section 3, Methodology. It was conducted between October 2014 and September 2015 when a literature review, media analysis, semi-structured interviews and surveys with the aquaculture industry and with other marine stakeholders were undertaken. Information on conduct of the surveys is summarised here; the literature review, media analysis and semi-structured interviews are described in Appendix 2.1.

The content of the original survey was reviewed and endorsed by the FRDC Board. It was workshopped in pilot form with the Australian Southern Bluefin Tuna Industry Association (ASBTIA) in Port Lincoln and then amended. Additions included aiming to identify positive interactions, because it was found that for ecotourism operators, seal interactions were often beneficial. Questions were added that enabled data to be collected from respondents whose economic interactions with seals were positive.

To obtain an understanding of the economic impact of seals on seafood and ecotourism industries, surveys were conducted in two parts: with the finfish aquaculture industry and with other marine stakeholders.

Surveys with aquaculture operators

There were responses from 15 finfish aquaculture operators. Most surveys were undertaken by operators in Port Lincoln and were facilitated via the ASBTIA. They involved all the major tuna and Yellowtail Kingfish aquaculture operators.

Surveys with other marine stakeholders

Marine stakeholders included in the surveys were recreational fishers, commercial fishers, fisheries managers, tour operators and Indigenous people. The surveys included people from Port Lincoln, Kangaroo Island, Victor Harbor and the South East.

The survey was delivered in multiple forms. It was sent to all fisheries managers and executive officers, and to peak groups involved in commercial and aquaculture fisheries. Face-to-face surveys and interviews were conducted in Port Lincoln, the Coorong region, Victor Harbor and Kangaroo Island. The survey was also printed and filled in by Lakes and Coorong commercial fishers at a meeting of the Southern Fishermen’s Association in Tailem Bend. Some surveys were undertaken by phone.

There were 65 responses from marine stakeholders. Indigenous participation was low because it was difficult to access and talk to Aboriginal groups. Proportionately, a higher number of people participated from the Coorong region; given the political context at the time, this is not surprising as motivation there was very high.

2.3 Results

The main findings of Nursey-Bray and Magnusson (2016) concerning the surveys are summarised primarily by using their text; their tabulations are in the Appendix 2.1 and table numbers below refer to that Appendix.

Economic impact of seals on aquaculture

All 15 respondents from the aquaculture industry were male, and lived in or near Port Lincoln. Most were owner operators (20%) or in a position of managerial responsibility (67%). Most (53%) farmed Southern Bluefin Tuna, 27% farmed Yellowtail Kingfish and the remaining 20% farmed mussels or both Yellowtail Kingfish and Southern Bluefin Tuna. Responses to the survey did not distinguish between these aquaculture sectors.

Table 14 of Appendix 2.1 highlights that while all respondents experienced interactions with seal species, 79% experienced interactions with both Australian Sea Lions (ASL) and Long-nosed Fur Seals (LNFS), and 7% were unsure of the species involved. Fifty per cent of respondents experienced interactions with seals daily, 40% experienced interactions on a monthly basis, and 7% had no direct interaction. Interactions occurred throughout the year, and 13% of respondents noted that numbers of seals sighted varied, depending on the time of year and on stages in the aquaculture operations.

Most respondents (80%) were confident that populations of LNFS were increasing and 31% considered ASL numbers were also increasing.

Aquaculture respondents judged that seal interactions posed a moderate (29%), major (47%) or extreme (20%) risk to their business, with none choosing the options of insignificant or minor: the remainder did not respond. Most respondents (73%) believed that their interactions with seals had increased or significantly increased over the last five years, while 20% estimated their interactions had decreased or remained the same.

The economic impacts of seal interactions on aquaculture were diverse, with no one impact dominating; damage to equipment, including sub-surface nets was considered important, but there were also substantive issues when fish became stressed, damaged or frightened off their food. Any one of these impacts constituted a major expense, and cumulatively they could be very expensive. For example, to repair a net could cost $30,000. Given a single fish can fetch $1,000 at market, any impact that makes them unsaleable has a marked and tangible economic impact.

There was a diversity of opinion as to which seal species was responsible for which interaction. Overall, the LNFS seal was thought to be proportionately more disruptive, although ASL were seen to damage equipment, including sub-surface nets, and to harass farm workers. Aquaculture operators judged both seal species as much more culpable in comparison to other marine stakeholders who, by-and-large, had issues primarily with the LNFS.

Many aquaculture respondents indicated that the time seals were most economically damaging was just before the harvest, usually June and July.

Respondents rated the level of impact for each of 11 economic indicators at an average of 6 - 8 on a scale from 1 to 10, with 10 being the most significant and 1 being unimportant. Some respondents noted that economic stress takes a personal toll. The range of impacts that aquaculture operators identified as important is presented in Table 19 of Appendix 2.1. Overall, seal interactions were judged as having an economic impact on aquaculture businesses of between 1 and 5%, equating to hundreds of thousands of dollars in lost income.

Operators agreed that there was some loss of work productivity, but most did not estimate this to be more than ten days a year. They appeared to be quite sanguine about this effect, and accepted it as part of the 'cost' of running a business, and as such needed to be included in ongoing planning and management.

The impacts of seal interactions appeared to be most acute in terms of loss and damage of fish stock, and their subsequent sale. Many operators (47%) judged that the impact on their operations was between 1 and 5% a year, with four of 12 operators estimating the overall cost of seal interactions at $100,000 per year. A further 13% of operators judged stock loss to be between 5 and 20% a year. This is a significant financial liability. Economic impacts that resulted from seal interactions are rated in Table 19 on a scale from 1 (unimportant) to 10 (important). They covered 12 items, one of which was unspecified (‘Other’). For the 11 specified items, average responses from the 14 respondents ranged from 5.8 to 8.1, with the highest being ‘Productivity loss through stock stress and susceptibility to disease’. By comparison, ‘Time lost dealing with seals’ averaged 6.9.

Another major cost was replacing nets damaged by seals; 86% of respondents rated the cost as exceeding $1,000 per year. In this context, many respondents added that the cost of replacing nets was prohibitive, and that seal-proofing cages was a big issue. Respondents were unanimous that there was an impact to other infrastructure, such as loss of feed of more than $1,000 a year and more (as much as $50,000 to $100,000 a year).

The impact of seal interactions on the quality of the fish, whether by scarring (appearance) or meat quality (due to stress or the fish being scared off their feed) was one of the most significant issues for aquaculture operators, with 86% of them noting that the negative impact exceeded $1,000 per year.

Aquaculture operators referred to ecological impacts in terms of seal predation on other marine species including Little Penguins, other birds and cuttlefish.

Aquaculture operators use several management techniques to manage seal interactions (Table 25): anti-predator fences above water (69% of respondents), anti-predator fences below water (45%), net stiffening and cage tensioning (50%), electric fences (17%) and steel mesh nets (30%). Previous practices no longer used included acoustic deterrent devices and shooting (79% and 18% of respondents, respectively). One respondent noted that all techniques ‘work for a short duration’, but seals are ‘extremely intelligent animals’.

On the topic of policy measures that are considered effective, responses varied widely. Culling was a popular option, and a wide suite of other measures was suggested, including monitoring seal populations, reporting interactions accurately, employing deterrents such as water bombs, developing financial assistance packages and building information bases.

Economic impacts of seal interactions with other marine stakeholders

The 65 marine stakeholder respondents identified as commercial fishers (35%), ecotourism operators (32%) and recreational fishers or Indigenous (30%), with the rest (3%) identifying as being from government. Most had significant experience in their industry; 74% had worked for at least 10 years and considered they had been in it long enough to observe changes. The largest group came from the Coorong (almost 50%), followed by Kangaroo Island and then Spencer Gulf. Details of the respondents, including gender, age group, occupation and their geographical spread are in Appendix 2.1. Respondents from commercial fisheries came from the Lakes and Coorong Fishery, the western and central abalone fisheries, and fisheries for Sardines, Southern Rock Lobster and marine scale fish.

Of the 21 ecotourism operators, 18% conducted penguin tours, 18% undertook seal watching or swimming tours, 10% were boat charter operators. The remainder (11) were tour operators (outdoor adventure, research tours and shark cage diving).

All respondents had experienced interactions with seals. Most interactions were with LNFS (43% of respondents), 5% had interactions with ASL and 32% with both species. The others (21%) did not know which species they were interacting with or were unsure.

The frequency of interactions with seals varied considerably; 48% of respondents had daily interactions, down to 17% who had rare or occasional interactions. Most (75%) saw seals year-round. One Coorong respondent noted that seals were mainly observed in winter.

Many of the seal interactions involved economic consequences. Seals taking fish from gear was a key interaction for 48% of respondents. Another 34% noted damage to gear and 29% had witnessed stress to other fish or species as a result of seal interactions.

Many respondents (49%) believed seal interactions had increased while 25% did not consider seals to be a problem. Negative interactions were recorded more frequently than positive ones (41% compared with 34%). Seal interactions were considered to be extreme to moderate by 60% of respondents, and 40% felt that interactions were insignificant or minor.

Among the 61% of respondents who experienced economic impacts, the most frequent involved lost or reduced market value of business, increased operating costs and time lost dealing with seal damage. Increased income was experienced by 20% of respondents.

For the respondents who experienced economic impacts, estimates are provided in Appendix 2.1 on lost fishing or working days, loss of work productivity, loss of catch, cost of gear replacement, cost of gear maintenance and decreased value of fish at the market. Most respondents estimated an economic impact of more than a $1,000 a year, with the maximum recorded at $140,000 for loss of fish sales.

Many respondents believed that seals were responsible for stress and predation of other species, and for ruining habitat and creating ecological imbalance that will have future environmental impacts. Comments by respondents are collated in Appendix 2.1, Box 5. Not all respondents believed that seals were having a negative effect on the environment.

Responses to the question on management strategies that had been tried indicated there have been a few attempts to manage this issue. The most popular was moving away from the seals. Many suggestions were made on management strategies that respondents thought might work; the most frequent of which was culling. Further comments on management (Box 7 of Appendix 2.1) highlight the ongoing pre-occupation of respondents with the financial hardship created by the impacts of seals, the complex nature of this issue and the sensitivities around ongoing management. The perceived impact on mental health via stress and financial hardship was clear, as was the social disruption to families (largely in the Coorong region). For some respondents the perceived impact on mental health is a social and cultural management dilemma.

Most (66%) respondents regarded the government to be responsible for management of seal interactions. Primary Industries and Regions South Australia (PIRSA) and Department for Environment and Water (DEW) were identified as the key departments; some respondents were disparaging about the capacity of DEW to manage the issue.

2.4 Discussion

Aquaculture

A key finding from the surveys with the aquaculture industry is that there is an economic impact resulting from seal interactions on aquaculture which ranges from 1 to 5% of yearly operations. This accords with results from the 2005 survey in which 54% of respondent rated ‘operational interactions with seals to be moderate to very high’ (Goldsworthy *et al.* 2009a, p. 30).

Seal interactions with aquaculture became problematic from 1992; at the 2005 survey, companies were divided as to whether or not they perceived an increase or decrease in interactions (Goldsworthy *et al.* 2009a, p. 31). This contrasts with results from this survey which demonstrated an unequivocal belief that interactions had increased and intensified.

Results of the survey of interactions between seals and aquaculture at Port Lincoln in 2005 by Goldsworthy *et al*. (2009a) are compared further with those reported by Nursey-Bray and Magnusson in Appendix 2.1 and summarised above. The former study was based on two sources of information: observations at aquaculture pens by Derek Hamer between April and August 2005, and responses to a questionnaire by 11 farm managers in April and May 2005. The questions and responses were summarised in Table 6.2 of Goldsworthy *et al*. (2009a). In the recent survey conducted in 2014 and 2015 by Nursey-Bray and Magnusson (2016), there were up to 14 respondents to each question. Comparisons between the two surveys reveal several important differences.

The first difference is the identity of the seal species responsible for the attacks on fish in aquaculture pens. In 2005, fur seals 'were not considered to be a threat to farmed tuna by the majority of farm managers, even though they were frequently observed swimming past cages or resting on pontoons' (Goldsworthy *et al.* 2009a, p. 35). Furthermore, farm managers indicated that 'ASL were responsible for most of the attacks and interactions that caused stress, injury and death of tuna'. The perception of respondents in 2014 and 2015 was that fur seals were proportionately more disruptive than sea lions, although sea lions were seen to damage equipment and sub-surface nets, and to harass farm workers (Appendix 2.1, Table 18).

A second difference between the two studies is that the economic significance of seals to aquaculture has increased. In 2005, the average response to the question on this topic was 'moderate' with only two of 11 respondents indicating 'very high' and none choosing 'extremely high' (Goldsworthy *et al.* 2009a, Table 6.2). In 2014 and 2015, 47% of the respondents rated the economic impact as 'Major' with 20% rating it as 'Extreme' (Appendix 2.1, Table 16). This suggests that perceptions of interactions with seals have increased in the ten-year period. That conclusion is supported by the summary statement in Table 17 of Appendix 2.1: 'the majority of respondents (71%) also believed that their interactions have increased or significantly increased'.

A third difference is that damage to equipment was considered to be relatively rare in 2005 (Goldsworthy *et al.* 2009a, p. 31), whereas in the recent survey, 86% of respondents estimated that the cost of gear replacement exceeded $1,000 per annum.

There appear to be three important differences between the two studies in the management regime used by industry to mitigate seal attacks at the aquaculture pens. One is the use of high fences on the pontoons aimed at keeping fur seals out of the pens. In 2005, all 11 lessees reported using high fences (Goldsworthy *et al.* 2009a, Table 6.2), whereas in 2014 and 2015, anti-predator nets (above water) were used by 69% of respondents (Appendix 2.1, Table 25). The second difference refers to the removal of dead fish from aquaculture pens. In 2005, farm managers who indicated that seal attacks had reduced in recent years also indicated that they had implemented a program of 'tuna carcass removal by contract divers' (Goldsworthy *et al.* 2009a, p. 36). In 2014 and 2015, in contrast, only one respondent rated increased effort to remove dead fish as 'most important', nine of them rated it in the middle of the range and three respondents considered it to be at the unimportant end of the range (Appendix 2.1, Table 19). The third difference is net maintenance. In 2005, all 11 lessees reported one of their mitigation strategies to be frequent and regular maintenance of nets to repair holes that seals use as entry points. In 2014 and 2015, net maintenance was not mentioned although it was included in the survey questionnaire (as 'infrastructure maintenance').

In general terms, the 2005 study indicated that mitigation measures, particularly the use of seal fences (above water), worked to manage the impact of seal interactions. This contrasts with the findings of this survey, where most operators felt that seal interactions remained an issue notwithstanding their efforts at mitigation. The 2014-2015 survey also showed that a wider range of mitigation measures had been used, ranging from seal fences (above water and below water) to acoustic devices.

All marine stakeholders

Twelve key findings are provided in Appendix 2.1 from the surveys conducted with marine stakeholders. They are important and are repeated here in an abbreviated form.

- There is an economic impact resulting from seal interactions on various marine stakeholders, but this impact is diffuse, hard to quantify and is positive in some cases.
- There is an economic impact resulting from seal interactions on aquaculture that ranges from 1 to 5% of yearly operations.
- The fishing sector in the Coorong region appears to be experiencing more acute and immediate stress and economic impact than other stakeholders. Some respondents there noted losses of up to 50% and more in their profit and catch in the last five years due to seal interactions.
- In the marine tourism sector, interactions with seals have had a very positive economic impact that have saved some businesses from economic hard times (e.g., for shark cage dive operators when sharks are absent from licensed areas).
- There is a strong perception and belief held by many marine stakeholders that the economic impact of seals is major and potentially catastrophic. This has created social and emotional uncertainty; some people are suffering and are hurt by the issue. Some appear to be fearing bankruptcy, unemployment, divorce or suicide for themselves, family and friends.
- Much of the discourse around seal interactions is relayed in very emotive terms. This makes accurate estimation of economic impact difficult.
- There is a degree of historical and current angst about the significant decline of penguin populations, which is perceived largely to be the fault of seal predation. This issue is especially acute at Kangaroo Island, and to a lesser extent at Granite Island and Victor Harbor.
- Respondents identified many other potential impacts on penguin populations including predation by foxes, cats and dogs, infrastructure development, other forms of tourism and disease.
- There is much confusion and misinformation about the seal species involved in the interactions. Some respondents were unable to decide whether populations were increasing or decreasing, and some stated they knew little about the biology of the species. The LNFS is blamed for most issues.
- Management of seal interactions is overwhelmingly seen as a government responsibility.
- The most favoured management option was culling
- Respondents were unanimous in asserting the need for immediate action on the seal interaction issue.

Although, culling was favoured as a management option, nothing was reported on how that might be done, how many seals should be culled to reach a desirable end point, who would be responsible for culling and for the dead bodies, and what might be the consequences of culling.

Appendix 2.1. Report on the 'Assessment of the Impacts of Seal Populations on the Seafood Industry and Marine Stakeholders in South Australia'

Assessment of the Impacts of Seal Populations on the Seafood Industry and Marine Stakeholders in South Australia

Melissa Nursey-Bray
Meagan Magnusson

THE UNIVERSITY of ADELAIDE

2016

Acknowledgements

We would like to acknowledge all the people who participated in this project. A special thanks also to Claire Webber of the Australian Southern Bluefin Tuna Industry Association for her help in reviewing the survey and facilitating contacts. Thank you to Simon Goldsworthy and Alice Mackay from SARDI for their help during the project

Executive Summary

The interaction of seal species on fisheries is an ongoing issue and one that has gained increasing prominence in recent times. This report presents the results from a project that aimed firstly to understand the economic impact of seal interactions on aquaculture and marine industries and secondly, to document the perception of the broader impact of seals on marine communities. It builds on a survey in 2009, conducted to assess the economic significance, temporal trends and observed nature of operational interactions in the aquaculture, specifically tuna farming industry (Goldsworthy et al 2009).

A qualitative social science framework was employed and was conducted in four parts, a literature review, two surveys, a series of semi-structured interviews and a media analysis. The two surveys were conducted with the aquaculture and marine community sectors respectively. Researchers visited Port Lincoln, Goolwa, Meningie and Kangaroo Island to conduct interviews. Results revealed consistency in findings across all data sets thus enabling us to evaluate their verifiability.

The key findings demonstrate that for aquaculture there definitely is an economic impact resulting from seal interactions which ranges from 1- 5% of yearly operations. For marine stakeholders there is also a defined economic impact resulting from seal interactions on various marine stakeholders, but this impact is more diffused and harder to quantify.

There is however, a strong perception and belief held by many marine stakeholders that the economic impact of seals is major, and potentially catastrophic. This has created social and emotional uncertainty. Some people appear to be genuinely suffering and hurt by the issue and expressed fears of bankruptcy, unemployment, divorce or suicide.

Results also find that the fishing sector in the Coorong region is experiencing more acute and immediate stress and economic impact, with some respondents identifying losses of up to 50% and more in their profit/catch in the last five years due to seal interactions. It is a management ‘hot spot’ in relation to this issue.

There is also a degree of historical angst about the significant decline of penguin populations, perceived largely to be the fault of seal predation. This issue is especially acute in Kangaroo Island, and to a lesser extent Granite Island and Victor Harbor.

However, almost 30% of all respondents indicated they had experienced positive economic impact resulting from seal interactions and that their business benefitted either wholly or in a major part from people paying to see seals in the wild.

A large measure of confusion and misinformation about the seal species exists, with respondents routinely being unable to decide whether populations were increasing or decreasing. Very few knew anything about the biological and other habits of the species although the Long Nose fur seal, (which has been renamed the long-nosed fur seal (*Arctocephalus forsteri*)) is the species most often blamed for negative interactions.

The management option favoured by respondents is culling, or what was called a 'sustainable harvest'. Over two thirds of respondents believed the government was responsible for that management and all respondents are unanimous in asserting the need for immediate action on the issue.

In sum, whether real or perceived, the level of economic impacts identified in this research does not provide an evidential basis to advance a case for a cull. However, it is clear that the management of seal interactions has reached a point in the public domain, particularly the Coorong, where it has created an emotional fever pitch which necessitates management action and strategic attention in the near future.

1. Introduction

The impacts of seal populations on the seafood industry is a concern in South Australia. This report presents the results of a social perception study of marine stakeholders that documented the perceived impact of seals on the seafood industry. It is presented in four parts: (i) the selective literature review which sets the context for why the project is being conducted in the first place; (ii) the methods which describes the techniques used to obtain the data sets used; (iii) presentation of the results of each data set; and (iv) a discussion reflecting on the implications of all of the above for management policy. This project forms part a wider Fisheries Research and Development Corporation (FRDC) project that is examining the dietary and other characteristics of seals.

2. Literature Review: Common impacts of interactions between marine mammals and fisheries within South Australia and globally

2.1. Introduction

The significant ecological and socio-economic impacts resulting from interactions between fisheries and marine mammals are well known, and have been a long-standing challenge in South Australia and globally (Johnson & Lavigne 1999; Bearzi 2002; Guclusoy 2008). Such impacts can be distinguished between operational and biological interactions (Northridge & Hofman 1999; Matthiopoulos *et al.*2008). Operational interactions are distinguished by interference between fisheries and marine mammals including damage to fishing equipment (Antunes Zappes 2013; Cook *et al.*2015), boat collisions (Lewison *et al.*2004; Antunes Zappes 2013), depredation (such as damage to and prevention of catches) (Hamer & Goldsworthy 2006; Cook *et al.* 2015), as well as ghost fishing and entanglement (Goni 1998).

Biological interactions involve competition by depletion of resources, either directly or indirectly via the wider food web (Abrams *et al.*1996; Mattiopoulos *et al.*2008). These include trophic cascades; changes in demographic structures and reducing availability of prey for marine mammals (Goni 1998). These impacts are felt to varying degrees worldwide and attention has been drawn to their occurrence in South Australian waters as a result of the growing value of the seafood industry within the region (De Jong & Tanner 2004) together with the increasing vulnerability of marine mammal populations, particularly seals (Goldsworthy *et al.*2007). This section provides an overview of common impacts resulting from interactions between marine mammals and the fishing industry, as well as a synopsis of seal-fishery interactions specific to South Australia.

2.2. General impacts of marine mammal-fishery interactions

It is a great challenge to address ecological and socio-economic impacts from marine mammal-fishery interactions. Such interactions have been long-standing, originating with the onset of industrial fishing activities at the beginning of the 19th century (Pauly *et al.*2002). Since this time they have increased, adversely affecting populations of marine mammals as well as the livelihoods of coastal fishers (DeMaster *et al.*2001). Coastal fishers view marine mammals as a competitor and a threat (Lavigne 1982) due to the creatures attempts to take catches, as well as their damage to fishing gear while doing so (Northridge & Hofman 1999). Conversely, marine mammal populations suffer persecution and deliberate killing by fishermen in some places (Northridge & Hofman 1999; Guclusoy *et al.* 2004a). Moreover, they are indirectly affected through modifications of prey abundance, size structure and behaviour when occupying a shared space with fisheries (Lasalle *et al.*2012). Overall, it is evident that marine mammals and fisheries adversely impact one another both operationally and biologically (Northridge & Hofman 1999; Shaughnessy *et al*. 2003; Hamer & Goldsworthy 2006).

2.3. Operational impacts/interactions

Operational impacts are those resulting from direct contact between marine mammals and fishing gear due to the spatially retracted abundance of fish (Northridge 1991; Fraker and Mate 1999; Northridge & Hofman 1999; Shaughnessy *et al*. 2003; Hamer & Goldsworthy 2006). Such impacts have become increasingly common and are now globally widespread, with one of the most common frustrations being marine mammal damage to both fishing equipment and vessels. Common equipment and vessel damage caused by marine mammals include tearing and dragging of gill nets (Antunes Zappes 2013), ship strikes and related collisions (Lewison *et al.*2004), and damage to aquaculture installations (Guclusoy & Savas 2003; Guclusoy 2008).

Conversely, fishing equipment and vessels cause significant damage to marine mammal populations through incidental catches (known as by-catch) and associated mortalities. In some fisheries, by-catch rates are of similar or higher proportions to the species targeted (Carbonell *et al.*2003; Hamer & Goldsworthy 2006) and the issue is one of growing concern for wildlife worldwide (Adimey *et al*. 2014). Impacts from by-catch can include death or injury including loss of normal swimming ability or mobility, strangulation, suffocation and reduced growth, fitness or fecundity (Benjamins *et al.* 2012). Ingested fishing gear can also affect feeding abilities, decrease feeding resulting in starvation, and obstruct normal passage of food through the digestive tract or introduce toxic chemicals into tissue (Cassoff *et al*. 2011).

Many of these impacts are a result of highly indiscriminate fishing methods and although different fishing techniques lead to different rates of by-catch, there are a number of fishing practices that are the source of significantly high incidental catch (Goni 1998). While pelagic trawling is one such practice which is selective with regard to target species, given their large dimensions, with the mouth of the gear reaching up to several thousand square meters, and relatively high towing speed, they also cause a high incidental catch of cetaceans and pinnipeds (Goni 1998). Drifting gill nets (or driftnets) are also problematic due to the large extensions they cover and the high incidental catch of non-target species (Goni 1998). Furthermore, long-line fisheries are responsible for an estimated by-catch of more than eight million fish annually (Goni 1998). Additionally, monofilament lines, micro-multifilament lines and trap pot lines have all been documented to cause the entanglement and damage of marine mammals (Adimey 2014).

In addition to the direct impact that fishing techniques have upon marine mammals, there is also the indirect impacts they cause through accidental loss of gear or the dumping or abandoning of gear. This can lead to entanglement or other harm of marine mammals sometime after the equipment has been discarded or lost and is primarily caused by gillnets, traps, and to a lesser extent, trawl net fragments. For example, mammals often become entangled when they encounter drifting debris as they feed or migrate (Goni 1998).

2.4. Biological impacts/interactions

In addition to operational impacts, there are also significant biological impacts. One of these is the competition for shared resources, as most marine mammals are dependent on an abundant supply of local food. Fishing can negatively affect their survival by reducing the availability of prey or by inducing its dispersal (Lassalle *et al.*2012). Furthermore, ‘fishing down the food web’ is widespread among marine ecosystems (Pauly *et al.* 1998), with the most common cause being the addition of new fisheries targeting lower trophic levels (Essington *et al.*2006; Lassalle *et al.*2012). With many stocks outside safe biological limits and subject to overfishing, the extent of competition for resources between marine mammals and fisheries is of increasing concern (Cronin *et al.*2014).

Marine mammal-fishery interactions also have biological impacts through affecting demographic structures. This occurs when fisheries alter the structure of marine communities by selective removal of some species, consequently changing the physical support for the communities. Biomass replacements in which a dominant species is driven to low population levels and is substituted by another species can occur as a result of fishing and cause ‘cascading’ effects on other components of the ecosystem (Goni 1998).

2.5. Impacts of marine mammal-fishery interactions within South Australia, specifically seals

The South Australian marine mammal-fishery context creates a range of ecological and socio-economic challenges specific to the state. One of the key marine protected species groups that are impacted by fisheries are the pinnipeds (seals), with three resident species: the Australian sea lion (*Neophoca cinerea*), the Australian fur seal (*Arctocephalus pusillus doriferus*) and the long-nosed fur seal (*Arctocephalus forsteri*). All three seal species have been recorded to interact with and form by-catch in a range of fisheries, including trawl, line, trap, and gillnet (Shaughnessy *et al*. 2003; Goldsworthy *et al.* 2007).

Although populations of Australian and long-nosed fur seals have increased significantly in number in South Australia over the past 20 years (Shaughnessy & McKeown 2002; Goldsworthy *et al.* 2003; Page 2007), populations of the Australian sea lion remain low (Shaughnessy *et al.* 2006) and there is evidence of further decline (Goldsworthy & Page 2007). Consequently, the *Environment Protection and Biodiversity Conservation Act 1999* categorises the species as ‘vulnerable’ and a population viability analysis confirmed that large numbers of subpopulations with low pup productions are vulnerable to extinction (Goldsworthy *et al.* 2007). The fisheries of greatest concern and threat to the species are the trap fishery for southern and western rock lobster (*Jasus edwardsii, Panulirus Cygnus*) and the demersal gillnet sector of the southern and eastern scalefish and shark fishery that targets gummy (*Mustelus antarticus*) and school shark (*Galeorhinus galeus*) (Goldsworthy & Page 2007).

South Australian waters are of great value for marine life, being home to the majority of subpopulations of Australian sea lions and long-nosed fur seals in Australian waters (Goldsworthy *et al.* 2003). The same waters also hold high economic value, with South Australia’s southern rock lobster fisheries being the largest and most valuable in Australia ($80-100M) (Goldsworthy *et al.* 2003, Goldsworthy *et al.* 2007). The demersal gillnet fishing efforts are also extensive (Hamer *et al.*2013). Unquantified impacts of these industries upon seals have been known to occur, providing cause for further investigation, awareness and research (Goldsworthy & Page 2007). Impacts that have been monitored, such as seals becoming caught in fishing equipment and drowning or escaping with life threatening entanglements (Northridge & Hofman, 1999; Hamer & Goldsworthy, 2006; Hamer *et al.*2013) have been suggested to be one of the greatest anthropogenic threats to the seal species (Hamer *et al.*2013). Despite these impacts, in the public domain it is perceived that seals are significantly affecting the economic livelihoods of fisheries in the state. The current debate around this issue is emotive and raw, with some fishers going so far as to state in the media that their industry is moving towards bankruptcy and could result in suicides.

Overall, it is clear that effectively balancing environmental and socio-economic needs is a significant challenge. Whilst fishing industries gain immediate economic benefit from the abundance of prey both globally and within South Australian waters, it appears that the direct and indirect effects this has on ecosystems and marine mammal species have not been comprehensively considered. Furthermore, such impacts are likely to jeopardize future prosperity for the industry. Much of the literature has shown the importance of further research and consideration of impacts occurring from marine mammal-fishery interactions. This is particularly relevant for South Australia’s waters, considering they are grounds for both high economic return for fisheries and high environmental value for marine mammals, particularly seals.

To this end, this report presents the results of an impact study of seal interactions with marine stakeholders, and their perceived economic (and other) impacts across the State of South Australia. The following section outlines the methodology employed to conduct the study.

3. Methodology

This project adopted a qualitative social science approach. Qualitative research reveals the range of behaviours that may characterise the target audience, and also reveals the perceptions that drive them with regard to specific topics or issues (Denzin and Lincoln 2005). It allows researchers to go beneath the surface and obtain rich, detailed information about the subject at hand. Qualitative research is particularly useful in policy contexts as it enables the documentation of the barriers, as well as motivating factors that may explain policy acceptance or failure.

This project builds on a previous study (Goldsworthy et al. 2009), which focussed on the perceived impact of operational interactions between seals and the tuna aquaculture industry. This survey, aimed to assess: (i) the economic significance, temporal trends since tuna farming commenced, (ii) observed nature of operational interactions, typical outcomes with reference to tuna growth and market value, seal species responsible and mitigation and management measures. The study found that operational interactions were a continuing problem, that death of stock (up to 14% at times) was the key impact followed by stress and damage to the fish (Goldsworthy et al. 2009). New Zealand Fur Seals (as known then) were seen to be primarily responsible, and fishers mitigated attacks by use of seal fences, and in some cases electric fences. This study provided important insights and was an important starting point for the current study, but it only focussed on tuna farming per se. The work presented here, builds on the former survey, to also include and document the perceptions of all marine stakeholder groups about seal interactions in South Australia as well as the aquaculture sector. Our results confirm the previous study’s findings while adding depth and detail.

This project was conducted in the period between October 2014 to September 2015 in which time a literature review, media analysis semi-structured interviews and a survey were conducted[1]. While the initial brief was to conduct a survey only, it was found that in many cases the survey did not enable the researchers to capture all the relevant information. For example, when talking to recreational fishers, a number of the questions did not apply (especially in relation to impacts on livelihood). In a number of other cases, especially when talking to high profile and vocal people such as Tracey Hill (Coorong) or John Ayliffe (Kangaroo Island), it became clear there was a lot of rich data that needed documenting that was not facilitated by the survey instrument itself. Hence it was decided to also conduct a number of semi–structured interviews in Port Lincoln, Kangaroo Island and the Coorong.

---

[1] This project was also endorsed by the Human Ethics Research Committee, University of Adelaide, 2014 - 2015, Ethics Approval Number: H-2014-202

Purposive sampling was used for both the survey and the interviews (Paton 1990). Purposive sampling is a technique employed in qualitative research to gather data from people who have something in common, or can reasonably be expected to have some insights to offer in the context of the project. As such, people in the marine industry who may reasonably be expected to be affected by, or have a qualified opinion about the impact of seals were targeted. The media analysis added an overlay of information and detail that supplemented the other two data sets.

Together, the results from all three sources, presented similar patterns and consistent findings. In this case, triangulation ensured validity of the data collected. Triangulation is the technique adopted within the social science domain to ensure validation of data via cross verification from two or more sources (Webb *et al.*1966). It allows for the employment and combination of a number of research methods to investigate the same phenomenon. This creates added confidence in the results (Denzin 1970). We utilised three different forms of triangulation:

(i) *Method triangulation* as we collected data from interviews, literature, policy documents, the survey and the media analysis.

(ii) *Investigator triangulation*, where more than one investigator collected the results. In this case, two other researchers, Meg Magnusson and Gabby Priest assisted in collecting information from respondents, especially recreational fishers.

(iii) *Data triangulation* where similar messages and patterns are recorded across different data sources.

The use of multiple means of collecting information also helped offset the difficulties of trying to get people to take the survey, especially when they were busy with fishing and actually going out to work. Undertaking the media analysis helped us identify key individuals to target, and then the use of semi-structured interviews enabled us to capture their views. This was important as these were vocal people in their local community who have been influential in dominating and setting the discourse on the issue in the public sphere. Wherever possible we have included direct quotes, so as to make the text more vivid but also so we can let respondents be 'heard'.

In our analysis, while there were obviously variations due to data type, we were able to discern clear consistency around core themes. We conducted the research until we achieved ‘information saturation’. This is the point at which it becomes clear there will be no new information and the researcher can assume with confidence that the research has achieved its goals. It is at this point that information collection can cease (Denzin & Lincoln 2005).

In our analysis we additionally ensured that our work was consistent with Guba and Lincoln’s (1985) evaluative criteria for establishing trustworthiness in qualitative research. These criteria are as follows:

(i) *credibility* - confidence in the 'truth' of the findings
(ii) *transferability* - showing that the findings have applicability in other contexts
(iii) *dependability* - showing that the findings are consistent and could be repeated
(iv) *confirmability* - a degree of neutrality or the extent to which the findings of a study are shaped by the respondents and not researcher bias, motivation, or interest.

Overall, the advantage of using multiple techniques meant that we could ensure we documented all the different perspectives on the impacts of seals on marine industries over different periods of time over a year.

3.1. Media analysis

Media analysis is one way of enabling appropriate comparative analysis of a number of texts and is ‘a specialized sub-set of content analysis, a well-established research methodology’ (McNamara 2010, p. 1). It provides a structured, systematic way of conducing content analysis of a wide range of ‘texts’, in this case newspapers, books, radio transcripts and social media. Content analysis is a technique that is for:

> …gathering and analysing the content of text. The ‘content’ refers to words, meanings, pictures, symbols, ideas, themes, or any message that can be communicated. The ‘text’ is anything written, visual, or spoken that serves as a medium for communication (Neuman 1990, pp. 272–273).

The benefits of media analysis is twofold. It allows for an examination of a wide range of data over a long period of time and thus helps locate and identify the popular discourses about an issue. Secondly, it has the advantage of being able to be conducted frequently, thus further enabling a detailed description of the way the issue evolves over time and changes in public perceptions.

For this project, media was observed and collected between October 2014 and October 2015. The time period within which the project was conducted was a very dynamic one with the issue of seal interactions often occurring in the media and catalysing particularly around the issue of the presence of seals in the Coorong.

3.2. The surveys

In order to obtain some understanding of the economic impact of seals on fishing, we conducted a survey in two parts (see Appendix A and B). First, an initial survey of Fin Fish Aquaculture was conducted and the second with marine stakeholders which included recreational fishers, commercial fishers, managers, tour operators, Indigenous people and other aquaculture operators was conducted. We surveyed people in Port Lincoln, Kangaroo Island, Victor Harbor and the South East.

The survey was originally developed but then reviewed and endorsed by the FRDC Board. We also workshopped the survey, in pilot form with the Australian Southern Bluefin Tuna Industry Association in Port Lincoln. The survey was then amended. Amendments included the adition of identifying positive interactions because in the case of ecotourism operators it was found that seal interactions are often beneficial, and hence the questions asking respondents whether or not they sustained negative impacts was inappropriate. Thus, questions were added that enabled data to be collected about those who have positive economic interactions with seals.

A combination of techniques was used to access people to participate in the survey. An initial list was provided which had the names of key government fisheries managers, tuna operators and outspoken high profile commercial fishers. This list was of 25 people. This was then built on to include all the tour operators, charter fish operators, aquaculture, and commercial fishers that could be found in the State, with a particular focus on Port Lincoln, Ceduna, Kangaroo Island and the Coorong. This added 83 participants to the list.

The survey was delivered in multiple forms. It was sent to all fisheries managers and Executive Officers and peak groups in relation to commercial and aquaculture fisheries. Researchers travelled to Port Lincoln, the Coorong, Victor Harbor and Kangaroo Island to conduct face-to-face surveys and interviews, and approach recreational fishers in all locations. The survey was also printed out and filled in at a special meeting of the Southern Fishermen’s Association in Tailem Bend. Finally a number of surveys were undertaken by phone.

In the end we obtained 65 responses for the marine stakeholder survey with 15 from key aquaculture respondents. Overall, Indigenous participation was low as it was found to be hard to access and talk to Aboriginal groups. Proportionately, a higher number of people participated from the Coorong region, but given the political context at the time, this is unsurprising as motivation was very high in that region for fishers wishing to have their voice heard. Moreover, although the survey catered to a wide range of types of respondents, i.e. not just owner/operators, but others such as coxswains, deckhands, communication and project managers, in reality, only owner/operators tended to respond. This was despite sending the survey to all their own contact bases, very few others responded. Given that by and large these others were employed *by* owner /operators, it would have been harder for them to respond. In all, the diversity of stakeholders is nonetheless represented in the survey, and results are entirely consistent with the themes found in the media and interview analyses. The data from the surveys was input into Survey Monkey and results synthesised from that software.

3.3. Semi-structured interviews

The topic of seal interactions is a dynamic one, and many respondents wished to discuss the matter further. It was found that for many individuals, the survey format did not work especially well. A number of questions, particularly those that interrogated the economic angle, were not relevant. Hence, in addition to the survey instrument, 23 semi–structured interviews were conducted. The interviews reveal a range of other perceptions and themes surrounding the issue and provide good insights and richer data on the socio-economic context of seal interactions in the state. Interviewees all signed a consent form and were given an information sheet prior to conducting the interview.

Thematic analysis was used to code and categorise the key results from these interviews. Thematic analysis permits the identifying patterned meaning across a data set that provides an answer to the question being investigated (Denzin and Lincoln 2005). It is a flexible method that can be used across methodologies and questions as it assists in understanding people’s perceptions, feelings, values and experiences. We took an inductive approach to the analysis in that we let the coding and theme development be indicated by the data, rather than assume anything before beginning. We conducted the analysis in five stages: (i) familiarisation with the data, (ii) searching for themes, (iii) coding, (iv) reviewing and amending themes, and (v) writing up. To ensure validity, all researchers independently went through the interview data set and conducted their own analysis which was then compared to the others. The final set of themes, is the agreed set which all researchers agreed were the key ones. These themes are consistent with both the survey and the media analysis.

In sum, all three data sets demonstrate that while the economic impact of seals on marine stakeholders is variable, there is definitely a moderate economic impact. More importantly, the survey reveals an emotional impact that is having a significant effect on the public discourse about the issue. The research finds this is affecting the logical and rational implementation or progress to an effective management strategy for managing seal interactions.

4. Results

4.1. Media analysis

Media sources were collected over a one year period. Fifty pieces of media were analysed in that time. Media was drawn from The Australian, The Advertiser, The Sunday Mail, The Murray Valley Standard, the Coastal Leader, Kingston, The World Today, the Southern Argus (Strathalbyn), radio summaries/transcripts from ABC 891 Adelaide and TV news reports from Channel 7 and the ABC 7:30 program.

The book ‘Listen to *Ngarrindjeri* women speaking’ (Bell 2008) and the ‘*Ngarrindjeri* nation *Yarluwar-ruwe* plan: Caring for *Ngarrindjeri* Sea Country and Culture’ (The *Ngarrindjeri Tendi et al.* 2006) were also drawn from to gain some insight into Indigenous historical and cultural links to seals in the Coorong and Lower Lakes region.

A number of themes emerged from this analysis. They are presented in Table 1 below and accompanied with key quotes which indicatively exemplify the way in which the subject is being discussed and presented in the media.

This analysis shows that the subject of the economic impact of seal interactions is highly emotive and one that has engaged politicians in the debate. The media maintains an ongoing interest in the issue and appears very friendly to the ‘cause’ of the fishers. The terminology used in describing seal interactions is sensational and emotionally charged. Nonetheless, the idea of a cull, despite being discussed, does not appear to be considered a feasible measure, notwithstanding the aspirations of many reported to have one. It is hard to discern any definitive idea of the precise economic impact overall, as the media focusses very much on the Coorong region and secondly, the figures that are presented are broad, with terms like ‘costing thousands’, ‘bankruptcy’, and ‘suicide’ used to indicate enormous economic loss but provide no evidential base.

Table 1: Summary of media analysis of impacts of seals

Theme	Description	Indicative Quotes
Compromise to economic livelihood	There was persistent reiteration that seals are causing economic hardship- for example Coorong fishers estimate that seals will take $2 million out of an $8 million industry.	‘A lot of fishers are starting to weigh up the benefits of continuing to be actively involved in the industry’ (891 ABC 2 July 2015). ‘It’s like having a drought that’s never going to end and we’ve got nothing to sell at the end of it and nothing to gain from our investment. How do you go from national producer of the year to broke in 12 months through no fault of your own?’ (Murray Valley Standard 2 July 2015).
Health and emotional impacts	Media during the second half of 2016 increasingly presented the impacts caused by seals as going beyond economic and included health and emotional impacts.	‘When my husband rings me up at midnight and says he’s just put a line of nets in to catch some fish and five seals turn up, sometimes he’s almost in tears’ (Whiting, N. August 2015). ‘The bird life that they’re killing are part of our culture. It’s part of the spirit of the old people that’s gone to the Milky Way… It’s destroying me’ (Whiting, N. August 2015). ‘It’s very unfortunate that in our community her at Tailem Bend, in a six week period we suffered three suicides’ (Whiting, N. August 2015). “Concerns for Coorong Fishing Industry Mental health Share” (5MU and Tumblr 2015).
Need for active direct intervention/management	Ongoing discourse emerged around the need for various forms of management from calls for a cull to relocation. Views both for and against all options emerged in the media.	‘Short of culling them, there are no effective ways to make them go away’ (Coastal Leader, Kingston July 2015). ‘Culling won’t fix the problem’ (891 1 July 2015). ‘We cull thousands of kangaroos in managed culls, we cull... feral pigs, goats, camels… I am sure there is a program that could be put in place with permits to conserve our wildlife and also help the fishermen’ (Petherick in the SA Weekend, September 2015). ‘Greedy humans have destroyed the fishery period, to think or blame it on the seals is just plain stupid,,. people are at fault not the animals’ (7 News Adl 16 July 2015).

Numbers of seals are returning to pre-hunting populations	Discussion centres around the extent to which seals are just returning to pre-hunting populations and whether or not that means they should be 'left alone' or actively managed.	'Clearly numbers are return and that a great news story, but the impacts are also increasing…we clearly need to manage this and carefully' (ABC 891, 15 July 2015). 'We have to look at the history of the species. I mean sealing decimated many populations of the long nosed fur seal… what we're seeing right now is the recovery of this native animal population, a localised recovery I should say because the species is still listed as vulnerable in New South Wales, and Victoria and rare in Tasmania…' (891 ABC 2 July 2015).
Urgency relating to impact	There is an urgency underpinning many of the stories around seal impacts. Fishers, in the Coorong particularly, believe that it is a matter of 6–12 months, and that if something is not done soon, their businesses will fail.	'Time is our enemy… leave it any longer than six months and I don't think we'll have an industry left – we need help' (891 June 2015). 'Overabundant Long Nose fur seals require immediate management' (Southern Argus Strathalbyn, 11 June 2015). 'We're not supporting a cull at this stage but we are supporting urgent action' (SA Weekend, September 2015).
Seals are the 'dogs' or 'rats' of the sea, very smart and vicious	Many stories characterise the Long Nose fur seal as highly intelligent but vicious animals that actively enjoy killing other animals – over and beyond their need for food. Characterisations are very emotive and reflect both respect for and fear of the seals.	'They get into [lobster] pots they pull fish out of nets, they're very clever and they know basically how to survive. They're extremely aggressive' (ABC News, 25 April 2015).
Seal populations are exploding and having very negative impact	Concern has been expressed that seal populations are increasing exponentially, crowding out other species and having a devastating impact on local ecology.	'The concern that people have is that seals numbers are becoming so great that they're taking out penguins on Granite Island, they're attacking penguins, they're causing disruption in the ocean, they're popping up in the river Murray…' (891, 2 July 2015).
Impact on other recreational activities	Many media started to discuss the fact that the presence of seals in waters also used recreationally for swimming or boating may be compromised and that this, in turn, would have a negative economic impact on tourism. This came to a head after the suspension of the ski racing event at Murray Bridge after 'Murray' the Long Nosed fur seal died after a speed boat ran into him.	'Swimmers could be forced out of Lake Albert due to the abundance of Long Nose fur seals… the idea that people could be deterred from swimming… has Meningie tourism operators concerned' (Murray Valley Standard (11/06/2015).

Impact on the Coorong and Lakes Fisheries	The issue of the impact of seals on the Coorong dominates much of the recent media. The Southern Fisherman's Association is very active in promoting the impacts, and the Indigenous Ngarrindjeri Elder Darrell Sumner has attracted substantive media attention for running over seals and demanding a cull on the basis that seals are not traditionally known to be in the region.	'Coorong fishers are struggling to stay afloat financially as Long Nose seal invade waters near Meningie' (Coastal Leader Kingston, 2015). 'Cultural rangers are having to euthanase pelicans with broken wings or with their legs torn off… they've already taken the Little Penguin populations on Granite Island and Kangaroo Island… they get into tuna pens, damage fish, kill fish and cost thousands of dollars in lost production' (Southern Argus 11 June 2015). 'In the living memory of all the fish families and some of the local elders of the Ngarrindjeri, there was no record of them in the Coorong' (Australian 25 April 2015).
Self-management	Indigenous Elder Darrell Sumner from the Ngarrindjeri has publicly decided to kill fur seals and argues that they have never been seen in the region prior.	'The seals have never lived in the area before and are killing the main local totem, the pelican along with other native birds… I don't care what the Department of Environment says… I'll be culling them…' (The World Today August 2015).
Indigenous historical and cultural references to seals inhabiting the region	Historical and cultural references to seals inhabiting the region have been made in the past by the *Ngarrindjeri* in both Dreaming stories and in the form of their *Ngartjis* or totems.	Excerpt from the story of *Ngurunderi*: '*Ngurunderi* made his way across the Murray Mouth and along Encounter Bay towards Victor Harbor. He made a fishing ground near Middleton by throwing a huge tree into the sea to make a seaweed bed. Here he hunted a seal, its dying gasps can still be heard among the rocks' (Bell 2008, p. 27). 'We were here when the European invaders began stealing our land and our resources; killing our people and our *Ngartjis*, such as *Kondoli* (whale) and *Paingal* (seal); polluting our rivers, lakes and Coorong; and draining our wetlands/nurseries. And we are still here!' (The *Ngarrindjeri Tendi et al.* 2006, p. 11).
A danger to humans	In the last six months of the media analysis, the discourse increasingly started to characterise seals as not only being a threat to other marine animals and birds and an economic threat but also a safety threat to humans.	'It's getting scary out there and a seal bite is a fearsome thing says Jackson, who is a recreational fisherman' (SA Weekend September 2015). 'They're going to bite someone and they're going to rip a leg off' (SA Weekend September 2015).

4.2. Survey

As discussed above, the survey was conducted in two parts. The first with aquaculture operators and the second which included marine stakeholders. Marine stakeholders were characterised as including commercial fisheries, ecotourism operators, government officers, recreational and Indigenous fishers. We present the results according to each survey. For readability we have rounded all figures up or down.

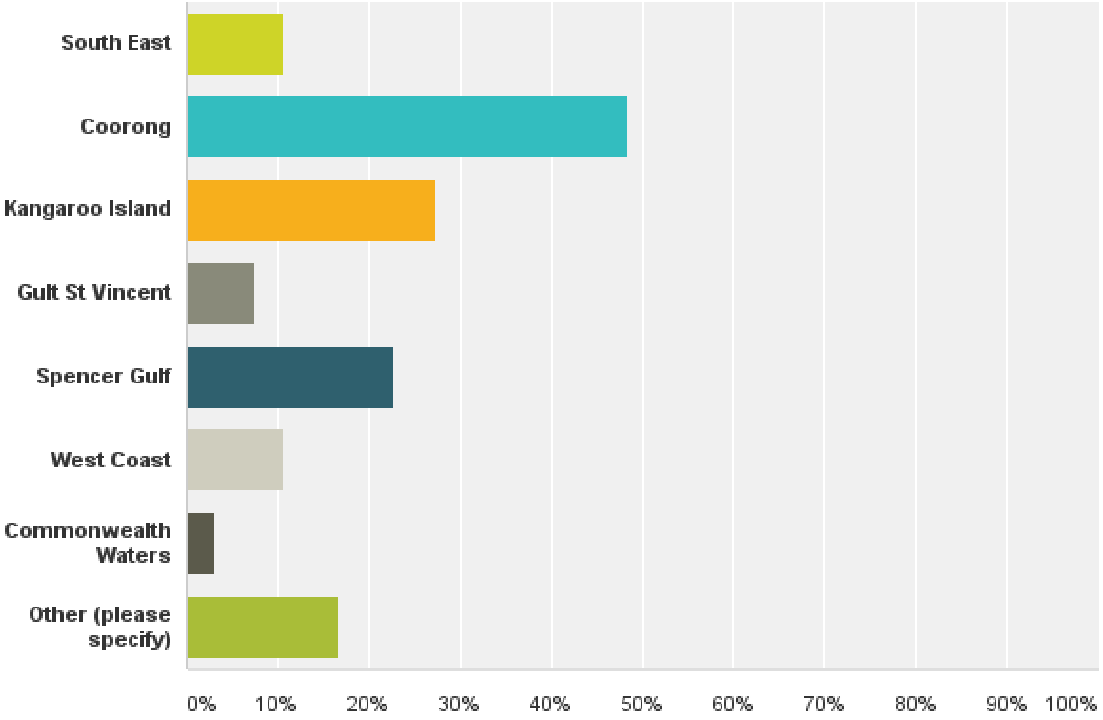
4.2.1. Economic impacts of seal interactions with marine stakeholders

Characteristics of respondents

In this survey, 85% of respondents were male and 15% female, with 47% of respondents in between 36 – 50, 11 % 18 – 35, 29% in between 51 – 65 and the rest (14%) over 65 years. 48% of all respondents had worked in the industry for 20 years and over, 11% had worked 15 – 20 years. 12% had worked in between 1 – 5 years, 14% had worked 5 – 10 and 12% had worked 10 - 15 years in their industry.

Overall, most respondents had significant experience in their industry and had been in it long enough to observe changes over time. Respondents identified as commercial fishers (35%), ecotourism (32%) and recreational or Indigenous (30%) with the rest (3%) identifying as being from government. 83% of respondents identified as being owner operators, with 4% identifying as operational managers, 4% as skippers, 4% as coxswains and 4% as other. As shown by Figure 1, the largest group came from the Coorong, followed by Kangaroo Island and then the Spencer Gulf. As noted earlier, this is unsurprising given the political and emotive context of the Coorong over the last year and also the fact that the Southern Fishermen's Association is running an organised campaign relating to seal management. Those identifying as being from other regions were from the Yorke Peninsula, Ceduna and Lower Eyre Peninsula, Encounter Bay, Granite Island, and the Murray Mouth.

Figure 1: Geographical spread of respondents.



Respondents from the commercial fisheries came from the Lakes and Coorong Fishery, the western and central abalone, miscellaneous fishery, sardines, crayfish, marine scale fish and rock lobster.

Recreational fishers identified numerous other species including: tommies, snook, whiting, snapper, mulloway, bream, salmon trout, squid, shark, tuna, garfish and carp. One hundred percent of recreational fishers used fishing rods, and /or handlines.

Of the ecotourism operators, 18% conducted penguin tours, 18% undertook seal watching or swimming tours, 5% were boat/fishing charter operators and 5% identified as charter boat fishers. 50% identified as other, which included outdoor adventure tours, research tour operators and shark diving operators. These respondents would combine a number of types of tourism activity hence chose other including seal watching and shark diving and penguin tours or a combination of any of the above. 18% of these identified as being the owner/operator; of the other 82%, 32% were tour guides, 23% general staff, 18% sales representatives and 9% communications staff. This highlights more diversity in participation via their role other than in the commercial fisheries.

Fisheries managers from the northern zone rock lobster, the southern zone abalone, central zone abalone, miscellaneous fishery and 'other' responded. Further follow up with the remaining managers resulted in them electing not to take the survey because (mostly) they did not feel the seal issue was one that affected their fishery.

Overall response: Nature of interactions

The first part of the survey asked respondents about the nature of their interactions with seals, whether they are positive or negative, with which species of seal, and the frequency and timing of those interactions.

Do you have interactions with seals, and if so, with which ones?

100% stated they had, with 43% indicating their main interaction was with the Long Nose fur seal and 5% indicating their main interaction was with the sea lion. 32% indicated that they had interactions with both. 21% indicated they did not know or were unsure which species they were interacting with.

Do you perceive populations of these species to be increasing/stable or decreasing?

In answering this question, there is a clear difference between respondents understanding of the status of seal populations. Overwhelmingly, 74% felt that the Long Nose fur seal populations were increasing, and many added in side notes descriptive terms like 'exploding' , or 'out of control'. Yet 52% were unsure as to the status of the sea lion populations as shown in Table 2 below.

Table 2: Range of respondent understanding relating to population status of Long Nose fur seals and sea lions

	Increasing	Stable	Decreasing	Unsure	Total
Fur Seal	**73.85%**	**9.23%**	**4.62%**	**12.31%**	
	48	6	3	8	65
Sea Lion	**15.38%**	**16.92%**	**15.38%**	**52.31%**	
	10	11	10	34	65

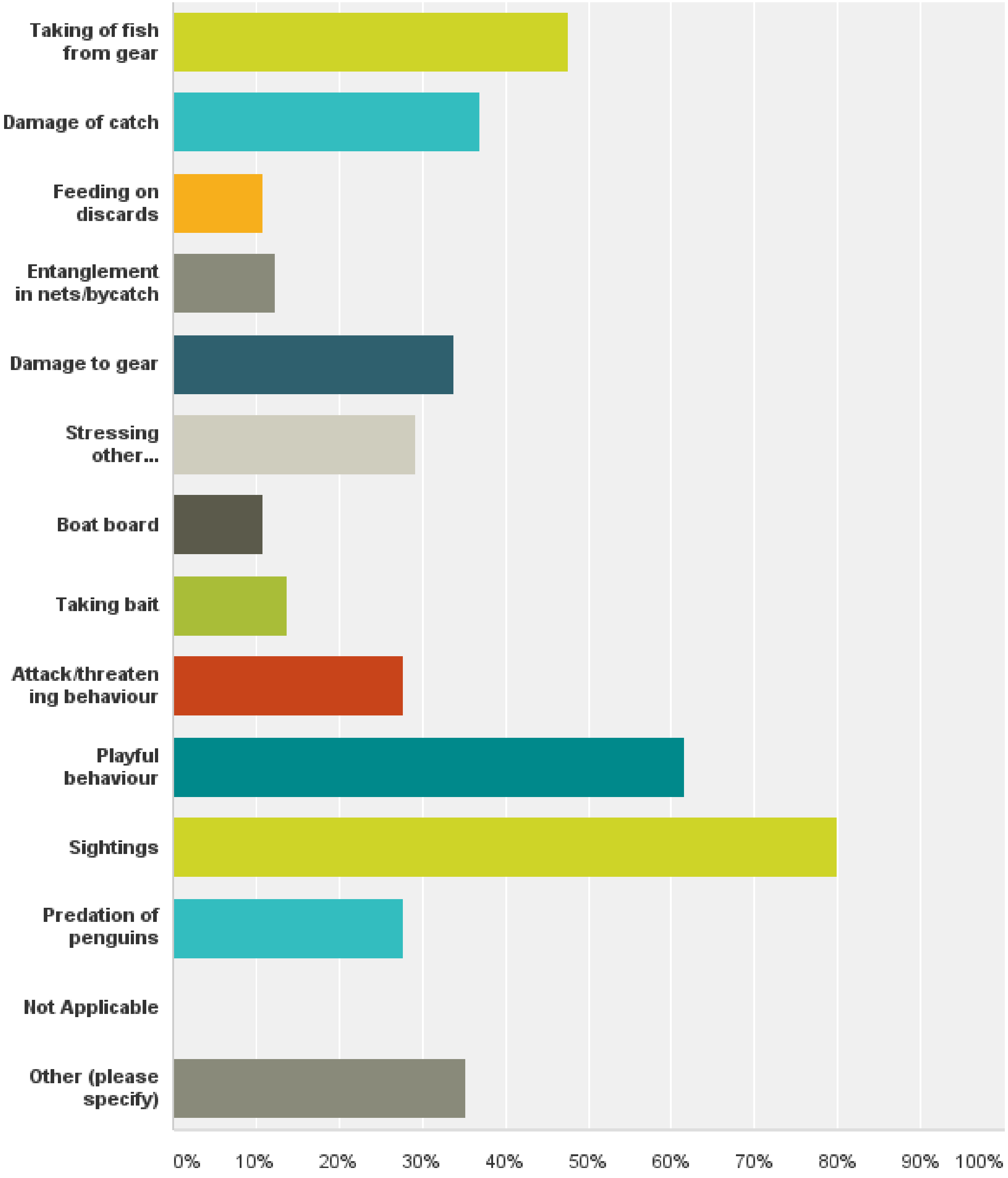
In terms of their interactions, 48% indicated they had daily interactions, 22% weekly interactions, 9% monthly interactions and 17% had rare/occasional interactions. 5% indicated they either had fortnightly interactions or interactions every three months or so. When asked at what times of the year they most often experienced these interactions, 75% indicated they saw seals all year round, followed by 12% who felt they mainly saw seals in summer. One respondent clarified that in the Coorong, seals are mainly observed in winter: ‘From my experience in the Coorong over the last ten years, the fur seals seem to be in greatest number during the winter period’. In sum, experiences varied at the edges, but most respondents felt they had ongoing interactions all year.

Fishers in particular noted that numbers seemed to vary according to fishing times: ‘Seals most often seen after tuna farmers bring back the tuna in March and April’. Building on the theme of numbers, the next question asked respondents how many seals, on average they would see, at any one time. Answers to this varied greatly, but overall 70% of respondents said they saw more than 2 seals at any one time. In Goolwa respondents identified numbers could be in between 5 - 15, 50 - 100 near the Murray Mouth, and in their hundreds near Kangaroo Island or the island groups out of Port Lincoln.

Types of interactions

The survey had one question that tried to identify the types of interactions respondents had with the seal species. It is noticeable that a number of these interactions are ones that will have economic consequences. For example, 48% of respondents stated that taking of fish from gear was one of the key interactions they have experienced, with an additional 34% noting that they had experienced damage to gear and 29% had witnessed stress to other fish/species as a result of seal interactions. Figure 2 shows this spread of issues in more detail and following, Box 1, presents additional comments and issues made by respondents on this issue which convey both issues with, and some affection for the species.

Figure 2: Types of interactions experienced with seals



Box 1: Selected descriptive statements from respondents relating to impact

- [They're] taking my fish that I want to catch!
- All positive
- Look I can hear the seals and think I heard them take a penguin once but it was dark and can't be sure and in 25 years I have only seen a seal board a boat once!
- Killing/maiming pelicans, coots
- Damage to bird life
- Killing pelicans, musk ducks, and other birds, affecting birdlife down here
- Taking Musk Ducks
- Predation of pelicans too
- In water stuff swimming with dolphins, lots of seals swimming together - its great
- In middle of nowhere have seen seals predate fish from sharks
- They are the most engaging animal in the world
- Curious I often walk around sugars beach at night with an underwater light occasionally one will follow me hoping I will spook a fish into the deeper water.
- I witnessed a seal eating a penguin
- I have freed sea lions that have been tangled in sharks nets
- Seals sometimes sunbathe on the back board of my boat whilst it is moored.

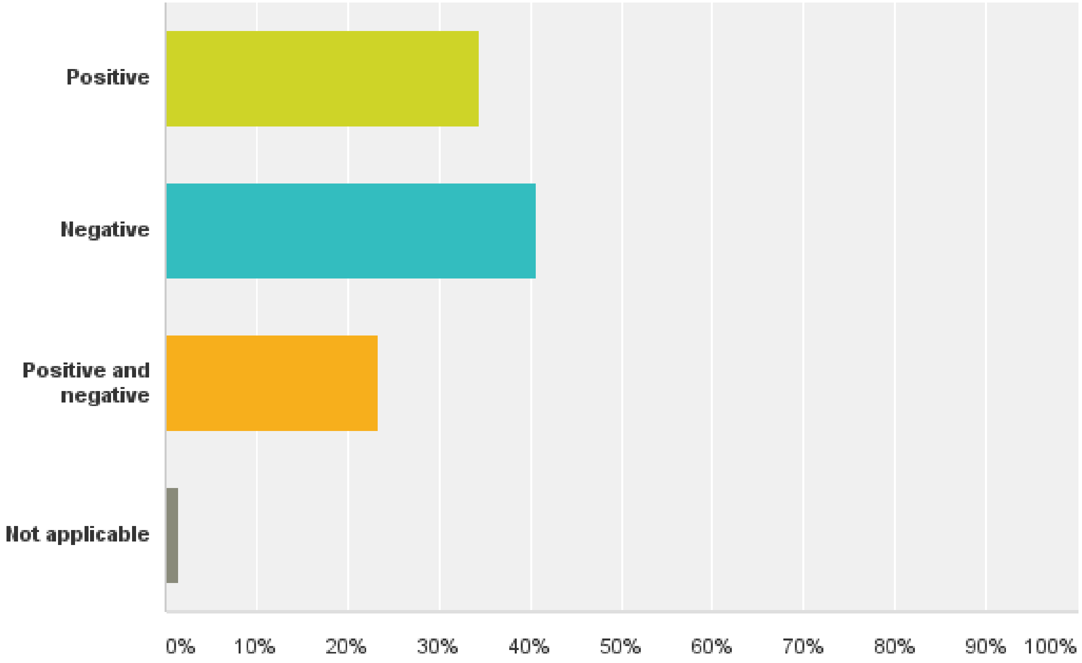
Experience of interactions

All respondents were asked about how they felt about their interactions with, and frequency of their interaction with seals. As Table 3 highlights, respondents generally feel that problems with seal species are increasing. However, when asked about their own interactions, results show an almost evenly mixed response, with 34% indicating they have had positive interactions, 41% have had negative interactions and 23% have had positive and negative interactions.

Table 3: Extent of interactions

Answer Choices	Responses
Significantly decreased	**3.17%**
Decreased	**3.17%**
Remained the same	**15.87%**
Increased	**12.70%**
Significantly increased	**36.51%**
They are not a problem	**25.40%**
Not applicable	**3.17%**

Figure 3: Type of interactions



When asked to rate the extent of interactions as an issue however, 60% felt that the issue with seals was extreme, major or moderate. 22% felt that the seal issue was insignificant, and 19% that it was minor. It was clear from follow-up interviews that this result is partly because even if respondents were not affected themselves they were keenly aware of the perceived impact seals were having on the lives of their friends and relatives. Table 4 below presents these results.

Table 4: Range of responses to the question, 'How would you rate the significance of seal problems?

Answer Choices	Responses
Insignificant	**21.54%**
Minor	**18.46%**
Moderate	**16.92%**
Major	**12.31%**
Extreme	**30.77%**

Economic impacts of seal interactions

This section sums up the types and nature of economic impacts as identified by respondents. Please note, in some cases, respondents, even if they thought seal interactions and issues around them were extreme, nonetheless did not necessarily sustain an economic impact themselves. In other cases, such as with various tour operators, seals are in fact their business, so the economic impact is positive. As a result Table 5 below shows 39% of respondents did not experience economic impact. However, of the remaining 61%, economic impacts varied across the spectrum. 20% experienced increased income. Of the other impacts, respondents were fairly divided in their response relating to increased operating costs, time lost dealing with seals, damage to gear, loss of or reduced market value of their business, costs of repair and maintenance costs. Table 5 presents this range of responses, which highlight the diversity in impacts sustained, rather than a single issue, which complicates management policy options.

Table 5: Economic impacts sustained as a result of seal interactions

Answer Choices	**Responses**
Depreciation on capital gear and other investments	**18.46%** **12**
Increased operating costs	**29.23%** **19**
Time lost dealing with seals	**23.08%** **15**
Time lost dealing with seal damage to gear	**27.69%** **18**
Lost or reduced market value of business	**30.77%** **20**
Costs of repair	**27.69%** **18**
Maintenance costs	**21.54%** **14**
Infrastructure costs	**21.54%** **14**
Increased income	**20.00%** **13**
Not applicable	**38.46%** **25**

For this question, a number of respondents also contributed comments. A selection of these comments are presented in Box 2 below to give further insight into how people feel about this issue.

Box 2: Respondent feedback on economic impacts of seal interaction on their business

- ‘Just haven't got a fish in over a month, not even a squid - seals just hanging around wherever I am - see there's one now in front of me’
- ‘I lose fish due to them simply being there, and frightening the fish away’
- ‘Decreased income in the last five years to a point where its half of my normal income and I employ people and I have had to lay one worker off’
- ‘Soon, you won't be able to give the licenses away, loss of investment into processing factories another impact and we are always fixing nets’
- ‘We seek interactions - need sharks and seals to get business’
- ‘Kayaking with seals is a life experience many people have never had. It also shows the abundance of life in the Coorong that such a top order predator can feed in the Coorong’

Detailed Economic Impacts

While many respondents had clearly experienced a wide range of economic impacts, the survey aimed to provide data about the scale and level in terms of the factors conventionally used (particularly by fisheries) as indicators of impact. The results for each of these indicators are presented below in a series of tables, which provide a synthesis of respondent views, with, where appropriate, some of the accompanying comments made by respondents.

It is important to stress that in reading these results the impacts relate only to the 30 percent or so who identified that they had experienced economic impact. Many did not experience any particular impact and the remainder experienced positive impact as presented in the results below.

Table 6: Estimated loss of fishing / working days

Answer Choices	Responses
Less than 10 per year	**4.69%**
10-15 per year	**0.00%**
15-20 per year	**0.00%**
20-50 per year	**0.00%**
50-100 per year	**7.81%**
More than 100 per year	**10.94%**

Table 7: Estimated loss of work productivity

Answer Choices	Responses
Insignificant	**1.54%**
Minor	**1.54%**
Moderate	**4.62%**
Major	**6.15%**
Extreme	**21.54%**

Table 8: Estimated loss of stock / catch

Answer Choices	Responses
Less than 1% per year	**0.00%**
1-5% per year	**3.08%**
5-10% per year	**1.54%**
10-20% per year	**1.54%**
20-50% per year	**1.54%**
More than 50% per year	**18.46%**

Table 9: Estimated cost of gear replacement

Answer Choices	Responses
\$10-\$100 per year	**0.00%**
\$100-\$200 per year	**0.00%**
\$200-\$500 per year	**1.56%**
\$500-\$1000 per year	**0.00%**
More than \$1000 per year	**23.44%**

Respondents noted that the loss of gear was in the thousands, with one noting it was $15,000 and more and another, 100s of thousands, stating: ‘Thousands of dollars of nets [have been] destroyed and can't afford to replace the gear’.

Table 10: Estimated cost of gear maintenance

Answer Choices	**Responses**
$10-$100 per year	**0.00%**
$100-$200 per year	**0.00%**
$200-$500 per year	**1.54%**
$500-$1000 per year	**1.54%**
More than $1000 per year	**21.54%**

Again respondents made specific note that these figures grossly under-estimated what they felt they spent on gear maintenance, with one noting that it cost him $30,000 a year, another said at least $15,000 a year and others noting that ‘I have to mend nets or reset damaged gear and ‘upgrading cray nets could be up to $5000 a year’.

Table 11: Estimated negative impact of seal interactions on sale value of fish at market

Answer Choices	**Responses**
$10-$100 per year	**0.00%**
$100-$200 per year	**0.00%**
$200-$500 per year	**0.00%**
$500-$1000 per year	**3.23%**
More than $1000 per year	**19.35%**

The following points were made about the sale of fish at market:

Box 3: Estimates of specific costs for industry and comments on specific issues

- Fish are just not saleable so no point taking them to market
- More than $140,000 a year
- Up to $50,000 a year
- Can't sell what you don't catch! We discard thousands of dollars of damaged fish
- Loss of money re reduced catch due to seal damage but is hard to quantify exactly
- I am not exactly sure what to say here but I definitely have lost money due to not having as many fish to sell

Other economic impacts

This was the final question in this section, and was designed to understand the overall estimated economic impact to people of seal interactions on their business. Table 12 below shows that the majority sustain economic impact overall of more than a $1000 a year, with 9% describing positive impact.

Table 12: Other economic impacts

Answer Choices	**Responses**
Positive economic impact (please estimate $ and describe below)	**9.38%**
Loss of $10-$100 per year	**0.00%**
Loss of $100-$200 per year	**0.00%**
Loss of $200-$500 per year	**1.56%**
Loss of $500-$1000 per year	**1.56%**
Loss of more than $1000 per year	**18.75%**

The comments below further detail the extent of these impacts and the scale at which they occur. In many cases, the impact is not a matter of $1000 or so but measured in the thousands, and in many cases, were perceived to have led to business failure.

Box 4: Comments on specific issues

- Increased my income the good old seal is good value!
- Lost my whole business in the end
- More than $40,000 a year
- About $50,000 a year for me
- Impact for me is 50% of my turnover a year (negative)
- With combination of seals and dolphins we are looking at increase of 35 - 40% of our business
- We used to run penguin watching tours and sometimes charter boat fishing for guests staying with us, but this has declined considerably so we have sustained a loss but it is hard to judge or pinpoint exactly what the amount is
- Had to make a one-off purchase of around $100 to install seal spikes in craypots.

Environmental impacts

Although the focus of this project was very much targeted towards understanding the economic impact of seals on marine stakeholders, we did ask one question about what respondents perceived were the impacts seals had on the marine environment. The results are presented below in Box 5 and they reveal a clear belief that seals are responsible for stress and predation of other species, or ruining habitat and creating ecological imbalance in ways that will have future consequences.

Box 5: Environmental impacts

- Penguin loss is a big one here. Upset the balance. Unidentified impacts - real research needs to be done. They are taking birds.

- Loss of fish but also I guess this is nature returning back to how it was. We just don't know.

- Devastation of fisheries.

- Positive impact -shows the habitat is better now as seals are recovering, it’s all about balance.

- Predation on other species like penguins, cuttlefish, squid - they love cuttlefish.

- Not much right now their numbers are just coming back. They do love penguins though and some birds so if their populations keep increasing may be an issue in the future.

- Look seals can be nasty, I've seen them have a go at squid, the way they come in, they kill everything, and often they just do it for fun, just because they can. So yes they sure do have an impact.

- Killing future fish stocks.

- Massive! Killing birds and devouring thousands of tonnes of fish. Causing dire consequences for the trophic food web that never had these animals historically.

- Creating havoc on the birdlife, pelicans, terns in southern lagoon. Native fish perch boneys if not stopped they will wipe out birds and fish altogether

- Penguins do seem to get knocked around. Management for that would be good. Rock lobster and prawns - perhaps affected?

- Environmentally devastating.

- All bird eggs and babies on Coorong Islands and lake banks that nest there every year will be wiped out if nothing is done.

- Several and severe.

- They are killing and wasting large numbers of fish far in excess of what they need to survive. They are killing and maiming many fish. They are going further up the river so we have no idea of the impact they have on things like the Murray Cod etc.

- Enormous environmental damage from most things native to the lakes and Coorong fishery, and bird life. I have seen native bird life been bitten in half and left to suffer baby swan, swamp hens, bites out of pelicans.

- Fish and birdlife are impacted. Poor penguins.

- Killing off breeding grounds for fish. Killing of nesting spots for pelicans.

- Total eradication of fish, impacting income of families and our community and the birdlife.

- No fishing nothing left in Coorong rookeries Extreme pressure on musk duck and other endangered bird.

- Huge impact. Nothing higher in the food chain in the lakes and Coorong than the cute cuddly little NZ Fur Seal.

- Yes I think they do have an impact but not sure what it is.

- They are like foxes they eat what they want then they kill every other fish in the nets by biting them in half.

- Taking over the environment and they will win.

- Increased predation on other marine species.

- Well not sure, actually they were hunted almost to extinction so are just coming back, so it’s hard to say what their impact is, or maybe was when you have had such a big impact, and may mean system just re-balancing.

- Positive part of the ecosystem, there are benefits for tourism.

- Don't know but there are definitely impacts from increased Long Nose fur seal numbers. They definitely are eating a lot. Obviously that's going to have an impact.

- Well they do eat A LOT of fish. LOTS of fish. You can see that on the Neptune’s. So there might be a balance issue there. Seals are supposed to have an impact but I'm not one to judge if it a positive or negative impact. I suggest the environment does a pretty good job but I am worried about the Australian sea lion, that is really worth saving.

- Food security for other marine animals - not enough fish to go around - especially for/on sea lions.

- High level predator. Need to find balance.

- The Coorong is a unique ecosystem and a nursery for many commercial and non-commercial fish species not to mention the RAMSAR listing for the bird species that use this area. It has been fished by Europeans since the 1840 and has been altered by Europeans by locks and weirs since the 1930’s Gaining base knowledge on the ecosystem prior to European’s is difficult as many accounts remember and record extremes not always the averages. It is true that there are no predators for the seals in the Coorong and in the past their numbers could have been regulated by the local Ngarrindjeri Community (This is speculative as I have little evidence) I believe that the numbers are increasing to a population where they will need to be controlled. Not completely removed from the ecosystem as high end predators do keep ecosystem healthy by removing sick and injured individuals. But control the impact that they have on the Coorong’s fragile ecosystem.

- I believe that seals are ‘totally destroying’ the Coorong and that if something is not done immediately the area’s environment and economy will collapse.

- I reject the notion that seals are not native to the Coorong area and I think that the community is engaging in ‘collective amnesia’ as there are historical reports of seals being present in the area, as well as the finding of seal remains in Aboriginal middens in the area.

- I believe that seals are eating fish from tuna, kingfish and pilchard farms which is affecting the industries.
- I think they might scare and eat fish but I don’t think that they eat too many fish. Eating fish, only if they’re eating fish that people are trying to catch.
- I do not think that seals are having impacts on the marine environment; I think it is quite healthy.
- I do not think that the seals are having a negative impact on the marine environment but I have heard extreme perspectives suggesting that seals are or are not responsible for the decline in penguin populations but I am unsure of which perspective is right. I've heard some people say that seals had always been in the area but that it was previously the Australian sea lion rather than the Long Nosed Fur Seal ... seals ae being blamed for the declines in penguin numbers but I think it’s likely to have been caused by over-fishing and competition for food resources.
- Humans are the problem, not the seals.
- Fish quantities may be declining in the Coorong as a result of the presence of seals.
- Think that the number of long nosed fur seals are increasing but that they are not a threat to the environment, which will look after itself, for instance if there were large numbers of seals, sharks are likely to keep their numbers in check.
- I feel that there is a potential problem for the Coorong ecology because the seal is an “apex predator” which could have impacts on such a “closed ecosystem”. Additionally, I am worried for the pelican population and fish stocks in the Coorong. If fish supplies are diminished it may impact on the breeding of pelicans.
- Seals could be bringing benefits to the marine environment if they are eating carp in the Murray River.
- I am concerned about the potential decline in numbers of the Coorong Mullet and the availability of local fish for consumption.
- I don't think that seals are the cause of decreasing little penguin populations as there is no scientific evidence to support that claim. Although seals do sometimes kill and eat penguins, this is likely to be opportunistic predation and there is no evidence that they make up a significant proportion of their diet.
- Seals contribute to the natural balance of the ecosystem in the Coorong and they do not have a negative impact on the marine environment.
- Seals must eat a lot of fish since there are large numbers of them.
- Do not believe that there have been any negative impacts on the marine environment. I don’t think seals are the problem, man is the problem. Fish populations are decreasing but that this is not due to seals but due to over-fishing.

Management strategies

In this section we present the results of the questions that focussed on management. Firstly, we asked respondents what kind of management strategy they had tried and if they thought they were effective. As you can see form the table below, there has been a few attempts to manage this issue, but generally, minimal trials of various techniques. We then asked people to reflect on what policy steps should be taken, who is responsible for them and their view on the impact seals have (or not) on the marine environment.

Table 13: Management strategies

Answer Choices	Responses
Steaming away	**21.54%** **14**
Acoustic deterrent devices (please specify in 'other' box)	**1.54%** **1**
Seal crackers	**0.00%** **0**
Shooting	**1.54%** **1**
Gear modification (please specify in comments box)	**1.54%** **1**
Switching gear	**4.62%** **3**
Other (please specify in comments box)	**27.69%** **18**

Of these techniques only 19% of respondents believed any of them worked, the rest disagreed anything worked or were undecided: ‘Relocation does not work’; ‘You constantly move only to move onto more seals’; ‘Nothing works’; ‘Often waste of time and energy’.

Policy suggestions

Respondents were asked to provide some ideas as to what strategies they thought might work. Culling emerged as the option discussed most often, and also was an option that respondents had divided opinions about. One respondent suggested re-stocking fish and another highlighting quotas as possible alternatives. Many respondents suggested education programs or changing fishing practice as other options. The range of suggestions are provided in a comment box below. The text has not been altered in anyway.

Box 6: Range of suggested management suggestions for management of the impact of seals

- Culling may be needed
- Work out how to re-stock fish
- Culling
- Culling is not an option. Learn how to fish better - move away, fish other areas.
- Culling. Cull 95% of them is what we need.
- Look I don't actually think there needs to be any policy intervention at present. People forget this place used to be teeming, literally heaving with seals, and then we killed them all. Nothing happening now that hasn't been here before. Maybe in 10 -12 years, there will be a problem if the populations keep increasing because then we will all be competing for smaller numbers when divided amongst us. But up till then personally, I've no problem with them. Maybe one option will be a managed harvest - research options for turning seal meat into dog food; seals smell really bad so I don't reckon we will want to be eating them. Even you can't use them for cray bait - crays will go for roadkill kangaroo over seal meat!
- Nothing really can be done - look we've had instances of using go pro videos with rock lobster - filmed the cages going down, and then the seals coming in and coming back later Really intelligent behaviour. Culling is always talked about, but don't think it’s an option really.
- CULL.
- These seals need to culled, managed, controlled.
- Quota fishing? Not culling...
- Culling NZ Fur Seals.
- Not sure, seals have to be managed or our industry is buggered and so will be all wild life species. I been here as a 4th generation fisherman and never seen seals in Coorong but now area is full of them.
- Controlling growth of seal populations so that leaves chance for others to colonize (fish species).
- Buy out licenses - exit with dignity not a slow death/bankruptcy. We need access to crackers (limited success). I think there has to be consideration given to removal of seals, de-sexing, and sustainable management through a harvest strategy.
- Steps need to be discussed between all parties, that’s best approach.
- Population is too large to manage. Something should have been done a lot sooner.
- Their population is too large.
- Manage problem by gear. Or find alternatives.
- It’s a cycle. Same as penguins. On quiet nights still heaps of penguins here and you are seeing a lot of NZFS return. Don't think it as bad a problem as people make it out to be.

But the policy is really hard. I don't think pups are a problem. I feel penguins and seals seem to co-exist - look at them in Cape Gantheaume. Numbers are increasing as conditions are good. Fish stocks are good.

- Research on both seals and penguins, breeding and recruitment strategies, needs info on diet and foraging etc., get the 'knowledge' and THEN develop strategies. NO CULLING!

- I am in favour of culling processes. Only just the Long Nose fur seals. Definitely not the sea lion. They'll be gone in 100 years anyway, the rate they are going. Also they are bottom feeders whereas the NZFS are middle eaters. Culling shouldn't be indiscriminate, should be monitored… and should use all the animal, not just shot and dropped like farmers do.

- Restriction on number of permits, understand or have policy that is responsive to the sensitive nature of the animal.

- Informal culling.

- Predator nets to stop entanglements from outside or to stop seals jumping into pens. Regulate activities more.

- Fur Seal numbers need to be looked at but also fishing techniques as well. Ultimately there needs to be a balance between the economic benefits of fishing in the region, the tourism sector and sustainability of the Coorong’s unique ecosystem. Sustainability of the Coorong’s ecosystem needs to be placed above all other users. If the Coorong is healthy, the environment, fishing sector and tourism will all thrive and be successful. If numbers are doing ecological damage to the environment then their numbers need to be controlled.

- Culling is necessary because seals are overpopulated in the area. What else can be done? They’re out of control.

- Education programs need to be provided by the government for fishers about how to interact with and manage seals. Commercial fishing gear may need to be changed and practices such as monitoring of nets may be necessary. Economic assistance for commercial fishers should be provided by the government to assist with innovation in these areas.

- It is not necessary to implement any policy steps to manage seal interactions.

- I do not believe that seals are an issue for the area, especially given that they don't appear to attack larger fish such as Samson (40kg). The occasional seal might be annoying for fishers.

- No policy steps needed to be taken to manage seal numbers.

- I do not believe that management strategies are necessary because they’re not really an issue in this area for recreational fishers.

- I do not believe that measures needed to be taken to mitigate seal interactions and am happy with how it is.

- I believe that protecting the seals is a higher priority than removing them from the area. People need to be made aware of how to interact with the seals, such as not feeding them to avoid creating an association between people and food. There is no one to police restricted areas and tourists often seek out the seals to watch them without knowing the proper rules.

- Fishers should be educated to pull their lines out of the water and either wait until the seals have left the area or to move somewhere that seals do not inhabit. If fishermen are having interactions with seals they’re in an area that they shouldn’t be fishing in. Everyone should be educated about how to manage their own interactions with seals. People need to change their behaviour and need to be aware that it’s their home. Seals are native animals and have every right to be there. How about a sanctuary zone to protect the seals from fishers?

- Management strategies should focus on educating people, particularly commercial fishermen to help them adapt to the changing environment.

- The Fisheries department should implement some kind of management plan.

- For the sake of the fishermen, something should be done to protect their livelihoods, which may be culling or relocating the seals.

- There should be management of the seals in the area in order to ensure that they remain in the area. I would like to see sustainable populations of seals, sustainable fisheries and well managed wild life in the Coorong.

- I do not feel that the seal populations currently need to be managed as they are positive for my business. I am concerned that the potential implementation of seal culling may have negative impacts on the tourist image of the Coorong. I noticed negative impacts on my business during the negative media coverage of the Murray Mouth when it closed.

- Culling might be a good option but only if it is really an issue but let’s use the meat from culled seals for consumption.

- I am not sure if anything should be done to manage the seals populations because conclusive scientific studies have not been conducted on the issue. Overall seals are great for tourism because they are cute and entertaining.

- I think they should leave the seals alone. I don’t think we should cull the seals because they are eating fish or penguins.

- If the science indicates that the numbers were becoming truly problematic a cull might be a sensible option if done humanely. However, I do not support a cull unless there is scientific evidence that it is needed and likely to be successful.

- I not think that any policies should be implemented to manage seal populations or interactions.

- I just want the Coorong to be as good for fishing as it used to be.

- I believe that buying back commercial licenses would be an appropriate policy option with some compensation to fishermen so that they can transition to other employment. I also feel that since the area is a National Park the wildlife within it, including the seals should be protected. I think that the park and other no-take zones need more policing and that recreational fishing licenses should be issued and policed.

- I think that populations of the Long Nose fur seal are on the increase and that they are present year round rather than coming and going throughout the year. However, I don’t think action should be taken to change this. It doesn't bother me that much, everything deserves a home.

Who is responsible for managing seal interactions?

Interestingly 66% of all respondents, whether they sustained negative or positive impacts from seal interactions, regarded the government as responsible for managing the issue. Of this, PIRSA and DEWNR were both identified as the key departments, although some respondents were quite disparaging about DEWNR's capacity to manage this issue:

> "NOT DEWNR! They're just not into doing anything at all. They are too conservative. DEWNR always says it needs more research. It's too late, the population of sea lions has crashed, the other is out of control. Tenfold increase on the NZFS… how much research do you need to work that out? You need to listen to the people."

And;

> "Well PIRSA. DEWNR is simply not strong enough, they are too weak."

28% of respondents had no view and the remaining felt that management was supposed to be undertaken collaboratively, as a partnership between community, industry and government, or in some cases, community led altogether:

> "I do know our biggest problem is government workers; we can do without them or a better job without them. Ownership is really important, if you don't have ownership then why would people give a shit? Whatever or whoever is responsible should think about that**."**

Finally, respondents were given the opportunity to make additional comments about the whole issue. Many chose to add extra commentary, and a selection of these comments, highlighting key points are presented below in Box 7. These comments highlight the ongoing pre-occupation with the financial hardship created by the impacts of seals, people's view of management and generally show the complex nature of this issue and the sensitivities around ongoing management. The perceived impact on mental health via stress and financial hardship, the social disruption to families (largely in the Coorong region) is very clear in this section and highlights that for some respondents this is more than an ecological or economic issue but also a social and cultural management dilemma.

Box 7: Respondent final summations on the whole issue of seal impact

- Seals have a right to exist, like anyone else, to survive.
- Let’s stop the 'she'll be right mentality'.
- Impact of seals has created unemployment; I used to employ staff and now can't even pay myself.
- Look - current hypocrisy about this issue is the main issue - how can you worry about seals if you let a trawler/mega fishing boat through? It’s ridiculous.
- Look, I do think that seals are a problem, and don't want to under-estimate that. But I also think the problem is over-stated and made out in the media to be much worse than it really is. Saying its causing suicide, well that's crap. That's just helping the politicians to push their own agendas.
- If something is not done we are all going to be bankrupt.
- Devaluation of license (superannuation) is a real issue.
- SA is the hardest state in OZ to do business. License fees are in excess of $20 K over year and are crippling many operators, Fishing regulations that were designed 30 plus years ago when license fees were only $100/year are not workable/feasible in 2015. So when seals have had a gut-full of your catch, they then play, kill or remove the rest of the fish from our nets. Nets need soak time to work properly in the L and CF. No other method works because many were tried over the 160 year history of the fishery. They are a marine mammal to estuarine and/or freshwater species.
- It just costs thousands and thousands a year. Overall our industry is on its knees. Income is cut in half and families are stressed. The environment is at risk of collapsing, the whole area is out of balance. They are sea mammals not estuary mammals. They have no place in lakes and the Coorong. Aboriginal land owners want them gone. No cultural significance. They cull crocodiles, kangaroos, koalas so why not these foxes of the sea? They are in the lakes and Coorong because they have no natural predators: sharks and killer whales. The whole deal is out of whack.
- The mental and financial stress to myself and family is extreme.
- I have had to go back shearing.
- No, just to say that I still think the problem is not as big as it is made out and we need to keep in mind, seals were almost hunted to death.
- Seals have already been culled illegally, and now are trapped and drowned behind the scenes.
- If you see a seal while out on the boat it’s a bonus but when I was a charter fisher, the way they took bait from the line was frustrating. And if a seal gets in a cray pot its $100 gone! It’s certainly frustrating but the way I see it is that they are only there for a feed, otherwise they wouldn't be there. Need to reduce the scale of the interaction.
- The presence of seals is great for tourism because people love seeing wild animals in their natural environment; there is a lot of negative media from fishermen but they have little evidence to support their claims. It would be very sad to “wipe the seals out”. There

> are more important environmental issues that need to take priority in this area such as improving the management of Granite Island by fencing it off at night to prevent people entering the island with torches to look for penguins, maybe that’s another cause for their decline. We need to manage foxes, cats and rabbits on the island and for rubbish management, particularly fishing lines, plastic bags, bottles and vandalism: these management strategies will be more effective in enticing penguins back to the area.

4.2.2. Economic impact of seals on aquaculture

Respondent characteristics

A second survey was undertaken specifically designed to understand the economic impact of seals on aquaculture operations. Most surveys were undertaken by operators in Port Lincoln and were facilitated via the Southern Bluefin Tuna Association. The survey was taken by all the major tuna and kingfish aquaculture operators in the region, but as this is a small industry, so is this survey; 15 in all responded.

All respondents were male, lived in or around Port Lincoln and were either the owner operators (20%) or in a position of managerial responsibility (67% combined) and able to provide insights into the nature and scope of economic impacts due to interactions with seals. 60% of those surveyed were in-between 36 – 50, 33% were in between 51 – 65 and 7% were between 18 – 35 years. 53% of respondents framed Southern Bluefin Tuna, 27 % farmed kingfish and the remaining 20% identified as also farming mussels, or farmed both kingfish and tuna. The majority of respondents (47%) had worked in the industry for 20 years and over, 27% for 15 - 20 years, 7% for in between 10 - 15 years, 13% for 5 – 10 years and 7% for less than 1 year. Collectively, respondents then had a wide range of experience.

Interactions with seals

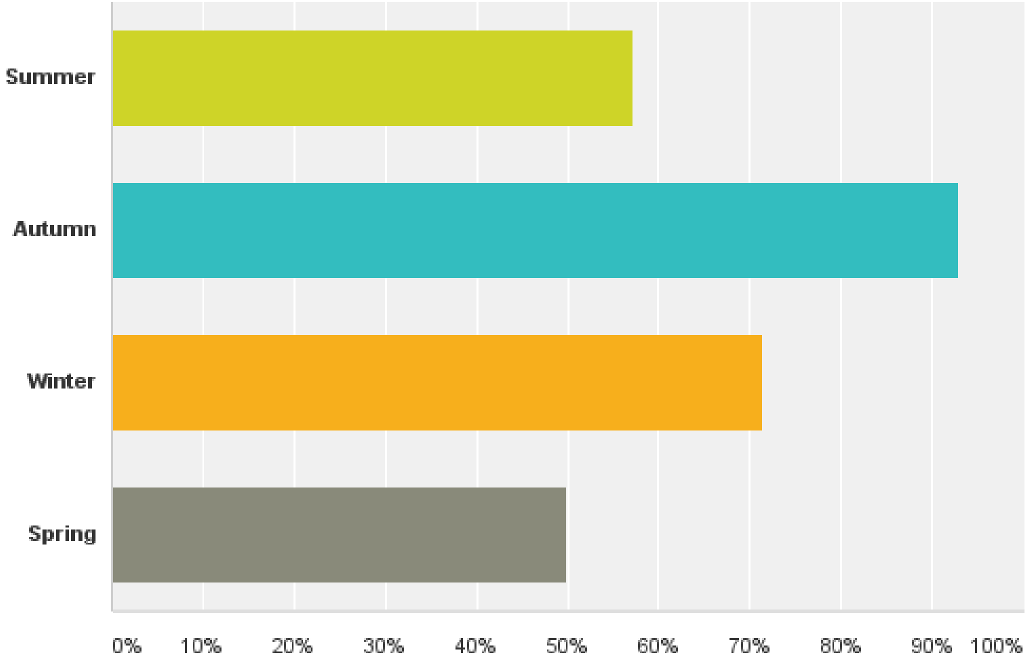
Table 14 highlights that while all respondents had experienced interactions with seal species, 79% had actually experienced interactions with both sea lions and Long Nose fur seals whilst 7% were unsure. Of these, 50% of respondents had experienced daily interactions with seal species, 40% had experienced monthly interactions, with a remaining 7% having never had a direct interaction.

Table 14: Aquaculture interaction with seal species

Answer Choices	Responses
Sea lions	**0.00%**
Fur seals	**14.29%**
Both	**76.57%**
Unsure	**7.14%**

53% of respondents stated they usually see more than 2 seals at any one time, with 27% stating they usually see 1- 2. An additional 13% noted that the numbers sighted at any particular time also depend on the time of year and various stages in the aquaculture operations: 'it depends on the weather, aquaculture operation being performed and opportunistic nature of the seals but probably between 1 - 4'. However, interactions do occur all throughout the year as shown in Figure 4 below.

Figure 4: Timing of seal interactions



Respondents overall were much more confident in their estimation that populations of Long Nose fur seals were increasing as against populations of Australian sea lions, and proportionately, a large number in each case were unsure.

Table 15: Are seal species increasing or decreasing?

	Increasing	Stable	Decreasing	Unsure
Fur Seal	**80.00%** 12	**6.67%** 1	**0.00%** 0	**13.33%** 2
Sea Lion	**30.77%** 4	**46.15%** 6	**0.00%** 0	**23.08%** 3

Nonetheless, aquaculture respondents were unanimous in their conviction that seal interactions posed a moderate to extreme risk to their business as seen in Table 16 below.

Table 16: Rating of impact of significance of seal interactions to aquaculture

Answer Choices	**Responses**
Insignificant	**0.00%**
Minor	**0.00%**
Moderate	**28.67%**
Major	**46.67%**
Extreme	**20.00%**
Not applicable	**6.67%**

The majority of respondents (71%) also believed that their interactions with seals have increased or significantly increased. A combined 21% estimated their own interactions had decreased or remained the same.

Table 17: Estimation of level of interactions with seals

Answer Choices	**Responses**
Significantly decreased	**0.00%**
Decreased	**13.33%**
Remained the same	**6.67%**
Increased	**60.00%**
Significantly increased	**13.33%**
I have not experienced any problems	**6.67%**

Economic impacts

The economic impacts os seal interactions on aquaculture are diverse, with no one impact dominating. As Figure 5 shows, damage to equipment, sub surface nets are related issues were noted, but there are also substantive issues when fish become stressed, scarred or frightened off their food. Aquaculture respondents noted any one of these impacts constitutes a major expense, but cumulatively can be very expensive. For example, to repair a net can cost $30,000. Or, given a single fish can fetch $1000 at market, any impact that makes them unsaleable has a marked and tangible economic impact.

There is also a diversity of opinion as to which seal species is responsible for which interaction as shown Table 18 below. Overall, the Long Nose fur seal is thought to be proportionately more disruptive, although sea lions are seen to cause damage to equipment, sub surface nets and harass farm workers. Collectively, aquaculture operators see both species as much more culpable in comparison to other marine stakeholders who by-and-large have issues primarily with the Long Nose fur seal.

Table 18: Estimation of which seal species is responsible for which impact

	Fur Seal	Sea Lion	Both	Unsure	Not Applicable
Damage to equipment	**26.67%** **4**	**26.67%** **4**	**20.00%** **3**	**0.00%** **0**	**26.67%** **4**
Damage to sub-surface net	**40.00%** **6**	**26.67%** **4**	**20.00%** **3**	**0.00%** **0**	**13.33%** **2**
Fish become stressed	**33.33%** **5**	**6.67%** **1**	**46.67%** **7**	**0.00%** **0**	**13.33%** **2**
Scarred fish	**33.33%** **5**	**6.67%** **1**	**46.67%** **7**	**6.67%** **1**	**6.67%** **1**
Fish mortality	**40.00%** **6**	**6.67%** **1**	**46.67%** **7**	**0.00%** **0**	**6.67%** **1**
Harassment of farm workers	**30.77%** **4**	**23.08%** **3**	**15.38%** **2**	**7.69%** **1**	**23.08%** **3**
Hauling out on cages	**38.46%** **5**	**7.69%** **1**	**38.46%** **5**	**0.00%** **0**	**15.38%** **2**
Entanglement in nets/bycatch	**7.69%** **1**	**7.69%** **1**	**7.69%** **1**	**23.08%** **3**	**53.85%** **7**

Figure 5: Impacts experienced by aquaculture of seal interactions

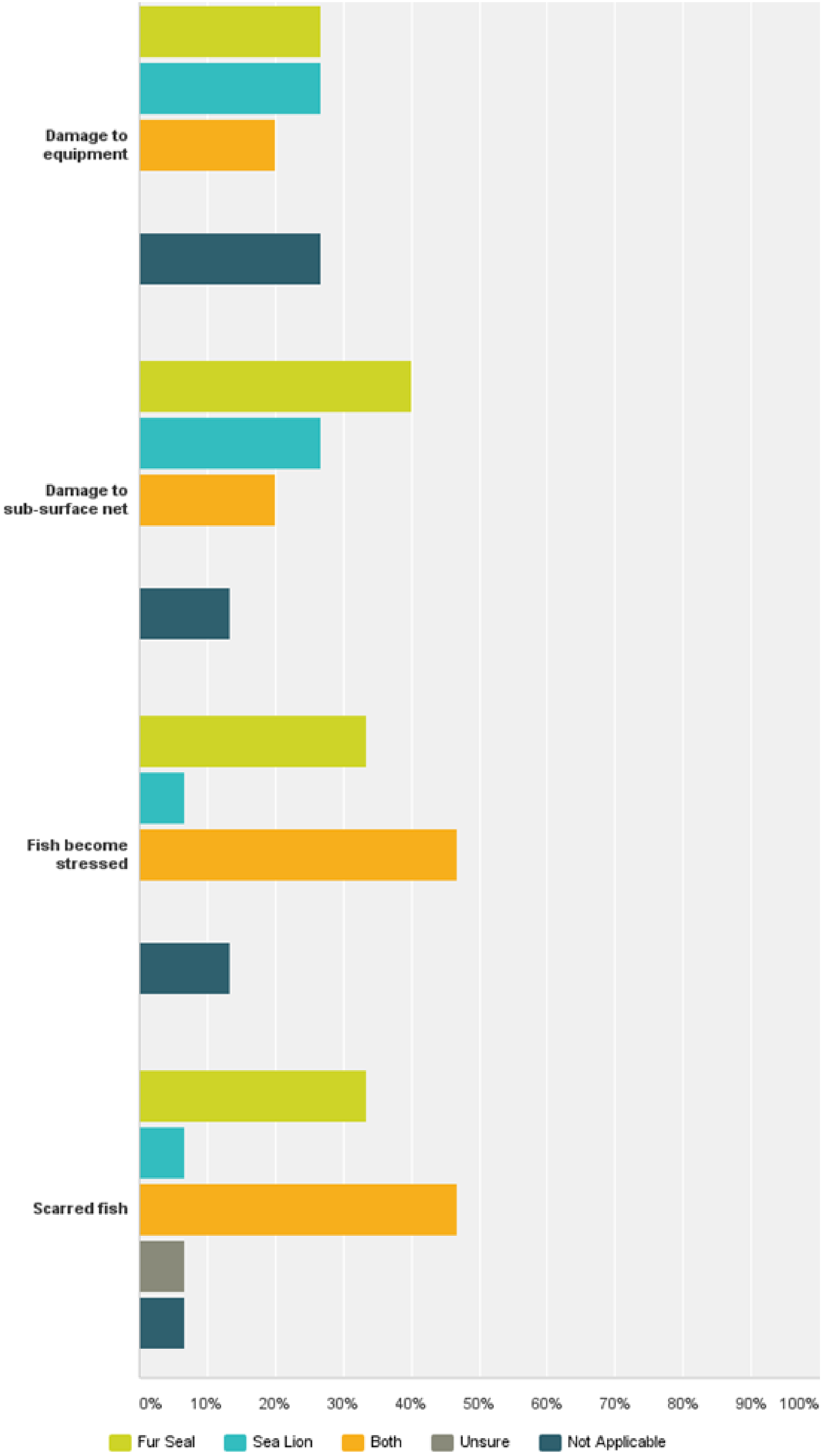
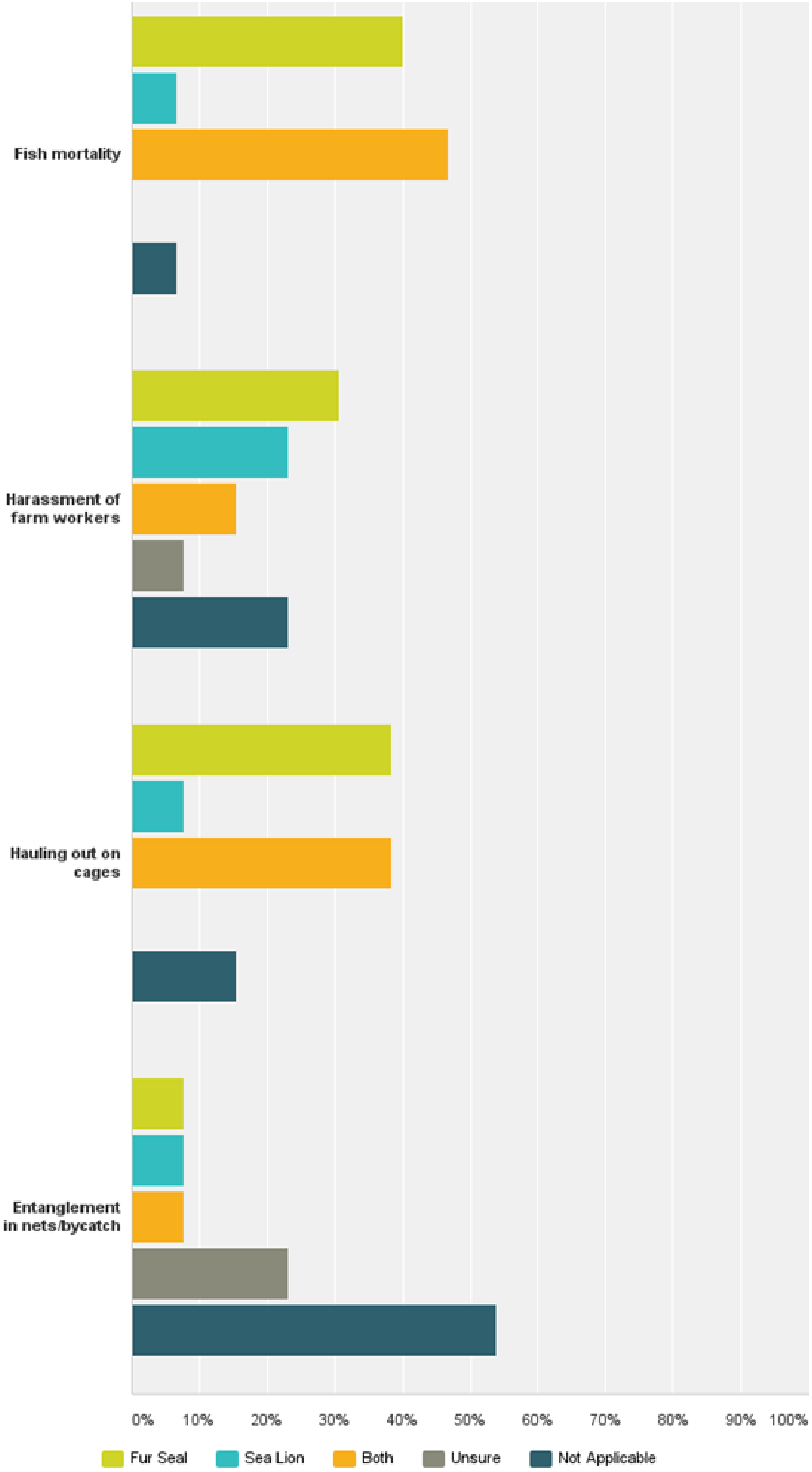


Figure 5: Impacts experienced by aquaculture of seal interactions (Continued)



Timing of Impact

Respondents were asked at what stage their interactions with seal species were most economically damaging. Many respondents talked about the time period just before harvest, usually January to July, when, having invested thousands of dollars in harvesting and growing out the fish, the seals would come in.

Box 8: Timing of seal interactions

- Larger mesh net, fish at 500g, poor site maintenance.
- Just before harvest.
- From transfer into cage to harvest.
- When fish are in cages.
- As they get bigger the fish get more valuable, but really, seals start at them from the beginning.
- At all stages of our fishing operations. Just prior to harvests is worse, right when we have invested all the money and ready to harvest for market.
- Pre-harvest - you've spent lots of money on them and they are about to go out....seals come in.
- Feeding, January to July. They become unsaleable, especially as they tend to come in in those last few weeks when the fish are fat and ready for harvest.
- As they get bigger, fish are of more value, larger fish is what they target, but it also starts right from the beginning of the grow-out process.

Range of economic impacts experienced as a result of seal interactions

Table 19 shows a detailed summary of the range of impacts that aquaculture operators identified as important. Respondents were asked to rate the level of impact of each indicator from 1- 10 with 10 being the most significant and 1 being not important. A review of the collected responses shows that operators weight the economic impacts on an average of 6 - 8 across all impacts. Additionally, a number of respondents noted that economic stress takes a personal toll.

Table 19: Range of economic impacts experienced by aquaculture as a result of seal interactions

	Not Important									**Most Important**	**N/A**	**Total**	**Weighted Average**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
Depreciation on capital gear and other investments	**0.00%**	**14.29%**	**0.00%**	**0.00%**	**0.00%**	**28.57%**	**0.00%**	**28.57%**	**0.00%**	**7.14%**	**21.43%**	**14**	**6.36**
	0	**2**	**0**	**0**	**0**	**4**	**0**	**4**	**0**	**1**	**3**		
Increased operating costs	**0.00%**	**7.14%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**35.71%**	**28.57%**	**7.14%**	**14.29%**	**7.14%**	**14**	**7.54**
	0	**1**	**0**	**0**	**0**	**0**	**5**	**4**	**1**	**2**	**1**		
Productivity loss through stock stress and susceptibility to disease	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**14.29%**	**0.00%**	**7.14%**	**28.57%**	**28.57%**	**14.29%**	**7.14%**	**14**	**8.08**
	0	**0**	**0**	**0**	**2**	**0**	**1**	**4**	**4**	**2**	**1**		
Productivity loss through worker stress	**14.29%**	**0.00%**	**7.14%**	**7.14%**	**14.29%**	**7.14%**	**0.00%**	**14.29%**	**7.14%**	**14.29%**	**14.29%**	**14**	**5.83**
	2	**0**	**1**	**1**	**2**	**1**	**0**	**2**	**1**	**2**	**2**		
Productivity loss through stock mortality	**7.14%**	**0.00%**	**0.00%**	**0.00%**	**14.29%**	**7.14%**	**0.00%**	**21.43%**	**28.57%**	**14.29%**	**7.14%**	**14**	**7.46**
	1	**0**	**0**	**0**	**2**	**1**	**0**	**3**	**4**	**2**	**1**		
Time lost dealing with seals	**0.00%**	**0.00%**	**7.14%**	**0.00%**	**14.29%**	**21.43%**	**14.29%**	**7.14%**	**21.43%**	**7.14%**	**7.14%**	**14**	**6.92**
	0	**0**	**1**	**0**	**2**	**3**	**2**	**1**	**3**	**1**	**1**		
	Not									**Most**	**N/A**	**Total**	**Weighted**

	Important									Important			Average
	1	2	3	4	5	6	7	8	9	10			
Increased effort removing dead fish	**0.00%**	**21.43%**	**0.00%**	**0.00%**	**0.00%**	**21.43%**	**21.43%**	**21.43%**	**0.00%**	**7.14%**	**7.14%**	**14**	**6.08**
	0	**3**	**0**	**0**	**0**	**3**	**3**	**3**	**0**	**1**	**1**		
Lost or reduced market value of business	**0.00%**	**0.00%**	**0.00%**	**14.29%**	**21.43%**	**0.00%**	**0.00%**	**7.14%**	**21.43%**	**28.57%**	**7.14%**	**14**	**7.54**
	0	**0**	**0**	**2**	**3**	**0**	**0**	**1**	**3**	**4**	**1**		
Costs of repair	**0.00%**	**7.14%**	**0.00%**	**0.00%**	**7.14%**	**21.43%**	**7.14%**	**28.57%**	**14.29%**	**7.14%**	**7.14%**	**14**	**7.08**
	0	**1**	**0**	**0**	**1**	**3**	**1**	**4**	**2**	**1**	**1**		
Maintenance costs	**0.00%**	**0.00%**	**0.00%**	**7.69%**	**15.38%**	**15.38%**	**7.69%**	**15.38%**	**7.69%**	**15.38%**	**15.38%**	**13**	**7.09**
	0	**0**	**0**	**1**	**2**	**2**	**1**	**2**	**1**	**2**	**2**		
Infrastructure costs	**7.14%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**14.29%**	**28.57%**	**35.71%**	**7.14%**	**7.14%**	**14**	**7.85**
	1	**0**	**0**	**0**	**0**	**0**	**2**	**4**	**5**	**1**	**1**		
Other (please specify in comment box below)	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**40.00%**	**0.00%**	**60.00%**	**5**	**9**
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**3**		

Detailed economic impacts

As with the survey of marine stakeholders, the aquaculture industry were asked to rate the impact of these interactions according to economic indicators that was meaningful to the industry. The summary of these results are presented in a series of tables below. They highlight an overall trend which indicates that seal interactions are having an economic impact on business of between 1 - 5% of operations, but that, in the case of the aquaculture industry, equates to hundreds of thousands of dollars in lost income.

Estimated impact of loss of work productivity

While operators agreed that there was some loss of work productivity, most did not estimate this to be more than 10 days a year.

Table 20: Estimated loss of working days/productivity due to seal interactions

Answer Choices	Responses
Less than 10	**66.67%**
10-15	**0.00%**
15-20	**0.00%**
20-50	**20.00%**
50-100	**0.00%**
More than 100	**0.00%**
Not applicable	**13.33%**

Estimated impact of loss of work productivity

While agreeing that work productivity was affected, operators appeared quite sanguine about this effect, and considered it as part of the 'cost' of running a business that needed to be factored in as part of ongoing planning.

Table 21: Impact of the loss of work productivity

Answer Choices	Responses
Insignificant	**0.00%**
Minor	**13.33%**
Moderate	**40.00%**
Major	**33.33%**
Extreme	**0.00%**
Not applicable	**13.33%**

Estimated loss of stock to seal interactions

It is in the area of fish stock, loss, damage and their sale that the impacts of seal interactions appeared to be most acute. For example, operators judged that the impact on their operations was in between 1 - 5% a year (47%) with a further 14% judging stock loss to be in between 5 - 20% a year. This is a significant financial liability.

Table 22: Loss of stock to seal interactions

Answer Choices	Responses
Less than 1% per year	**33.33%**
1 - 5% per year	**46.67%**
5 - 10% per year	**6.67%**
10 - 20% per year	**6.67%**
20 - 50% per year	**0.00%**
More than 50% per year	**0.00%**
Not applicable	**6.67%**

Estimated cost of gear replacement/maintenance due to seal interactions

The cost of replacing nets, damaged by seals was also often raised and of concern, with over 84% citing this as a major cost.

Table 23: Cost of gear replacement

Answer Choices	Responses
$10 - $100 per year	**0.00%**
$100 - $200 per year	**7.14%**
$200 - $500 per year	**0.00%**
$500 - $1000 per year	**0.00%**
Over $1000 per year	**85.71%**
Not applicable	**7.14%**

In the context of this question, many respondents added that the cost of replacing nets was prohibitive, and that seal proofing cages was a big issue:

> "Net cleaning control costs about $6000/year, Predator nets - well double that! Then there are rigging issues, keeping gaps between the nets. Need to password protect yourself but the real deterrent is for jobs, for when you can't have that - external predator nets, it’s a horrendous cost, keeping them clean..."

Respondents were unanimous that there was an impact to other infrastructure, such as feed loss, of more than $1000 a year, with respondents noting that in fact this cost could be as much as $50,000-$100,000 a year. The survey did not uncover why such a range in different estimates occurred.

Negative impact of sale on fish at market

The impact of seal interactions on the quality of the fish, whether by scarring (appearance) or meat quality (due to fish stress or being scared off their feed) was one of the most significant issues for aquaculture operators.

Table 24: Negative impact of sale on fish at market

Answer Choices	Responses
$10 - $100 per year	**0.00%**
$100 - $200 per year	**0.00%**
$200 - $500 per year	**0.00%**
$500 - $1000 per year	**14.29%**
More than $1000 per year	**64.29%**
Not applicable	**21.43%**

Respondents added that:

> ‘Some of these fish will be B grade but overall it is classed as a mort and therefore a stock loss’.

Or:

> ‘That's more than a $100K a year actually when you think about the fact that each fish fetches $1000 each’.

Annual overall percentage of cost to aquaculture industry as a result of seal interactions

Respondents were asked to identify what the overall cost of seal interactions to the industry is. As noted earlier, this ranged from 1 - 5% of operations and averages at about $100,000. Box 9, below, shows the range of costs.

Box 9: Estimated annual overall percentage of cost of seal interactions to aquaculture

- Not quantified yet.
- 100,000.
- 100,000.
- Not sure.
- 10%.
- About 5%.
- 5%? Plus the cost of stress...
- It’s not big for us, hard to put a figure on it maybe $5000/year.
- About 1-5% loss to our operations overall, a cost we need to anticipate in annual budget cycles.
- About $100K – that’s an average.
- Well it would be about $100,000 a year. You have to buy infrastructure prematurely, you get unsalable fish and scarring.
- Capital 5% and operating costs 10%.

Ecological Impacts

As with the survey for marine stakeholders, we asked aquaculture operators what their views were about the impact seals have on the environment. Consistent with the views of other stakeholders, aquaculture operators talked about ecological imbalance, seal predation and impact on other marine species as being core issues.

Box 10: Ecological impacts of seals from perspective of aquaculture

- Predator-prey interaction, I guess.
- Devastating.
- Negative.
- They can have negative impact as they are destructive (to stock-even if don't eat all the stock they destroy) and they're very intelligent.
- Kill little penguins in spring.
- Imbalance to environment from impact of seals on other species.
- Don't know, a big one I'd imagine. Got to be impacting on other species.
- Well in my time I have seen so many many more seals when out to sea than before. Got to be having an impact - cleaning up all the other fish species.
- Significant one you know, wiped out the cuttlefish.
- Eating other fish, know it is having impact on penguins, maybe causing imbalance. We need more science to tell is specifics.
- Creating imbalance.
- Puts pressure on fish stocks, penguins, birds, increase in one species, puts pressure on another. Some others are going to suffer.

Management Strategies

Consistent with the survey of other marine stakeholders, we asked aquaculture operators what techniques they either currently, or have, used to manage seal interactions. It is noticeable that respondents in this survey had both trialled many more techniques and were more confident in stating which ones they had, or had not, used. As Table 25 shows, acoustic deterrent devices have been popular in the past but today, many operators rely on anti-predator fences both above and below water.

Table 25: Types of deterrents that have been used by the aquaculture industry

	Previously trialled	Currently used	Not applicable	Total Respondents
Acoustic deterrent devices (please specify type in 'comment' box below)	78.57% 11	0.00% 0	21.43% 3	14
Anti-predator fences (above water)	15.38% 2	69.23% 9	15.38% 2	13
Anti-predator fences (below water)	18.18% 2	45.45% 5	36.36% 4	11
Net stiffening/cage tensioning	16.67% 2	50.00% 6	33.33% 4	12
Electric fence	41.67% 5	16.67% 2	41.67% 5	12
Use of steel mesh	10.00% 1	30.00% 3	60.00% 6	10
Shooting	18.18% 2	0.00% 0	81.82% 9	11
Other (please specify in box below)	40.00% 2	20.00% 1	40.00% 2	5

Respondents also made a number of other comments as seen below, which indicate ongoing engagement and thinking about these issues.

Box 11: Respondent views on management/deterrent techniques for managing seal interactions

- We use blunt poles to make noise and poke them away. Divers also release seals on a regular basis over the head-net. Mostly they enter through chewed holes in the net

- We are trialling brass mesh. Used to have shooting permits like in Tassie. Might have to try electric fence. There is a lot of extra effort in putting in these types of measures. Lowering the fence down every time. Need lots of buffers. Tension nets - the seals can get to them. It’s not very cost effective given they only work for a short time! And also, it’s a huge cost - measures like this, say the nets, they cost 10 times what a normal net does. That's $330K as against $30K.

- They all work for a short duration. Then they work out how to get closer to the cages. When seals jump in, each cage for tuna, puts them off, they stop feeding, so it affects the whole biomass even if they don't actually attack/scar the fish. Have also tried a seal scarer. And as for shooting - I'm not allowed to do that, but if I could, I would.

- We use a fire net called Dyneema. Seals don't like it

- Some have tried seal whistles. One year we built 5 nets stainless in poly mesh - cost time and money and didn't work. Electric fences were all the rage there, but the seals worked out how to get in. What are some non-destructive methods? Must be made available, bean bag guns? But they all have massive costs.

Policy Measures

Respondents were also asked to consider and describe what they thought were effective policy measures. Responses varied widely with culling being explored as a policy option. However, aquaculture operators also suggested a wide suite of other measures, including monitoring of seal populations, accurate reporting, employing deterrents such as water bombs, developing financial assistance packages, and building information bases.

Box 12: Suggested management options

- Active and proper government of seal populations. Not relying on industry conform[ing] to policy that is outdated and not properly monitored. Allow for the continued develop for aquaculture in the region through economic prosperity, something that can grow regional communities; so by any means, regulate predator interactions, as long as it is done properly and is sustainable for industry, environment and tourism.
- Better net design.
- Culling.
- Ensure accurate reporting of the problem.
- Some deterrents are needed. Maybe we should look to Tasmania.
- Look, deterrents are needed. Shooting is not acceptable, but what can we do? How do we scare them off? There needs to be some recognition in policy that regulation needs to incorporate deterrents of some kind, or make their use legal. But it is extremely difficult to think of a way to engineer it. What about seal exclusion jump devices?
- Deploy similar systems/protocols to what Tasmania salmon industry is doing at the moment. Water bombs. Paint ball guns. Should also be able to cull, entrap, relocate and use those methods when appropriate. Two thirds of them could be eradicated then and there would be no problem. They are the dogs of the sea. Look being able to use guns IS quite aggressive but it would be an additional string to our bow.
- Culling, population increase is too much – massive.
- More information. New policies.
- Maybe culling, not sure - more information may be and advice on deterrent methods. What are other people doing?
- Some financial assistance and information on methods. Options we can try without facing huge losses. Need some more information and science on this. We are all tightening our belts so it has to be PRACTICAL. Latest discussion of course is culling - but will it work? But it’s always been a battle.
- Deterrent is needed. Shooting not acceptable. Need to work out how to scare them off, teach them they are not welcome. Recognition in policy, by regulation, needs to be built in. Research on what the impacts are on other species too. What about seal exclusion jump devices/ Managing tensions on nets? Investment in that.

Only 20% of the respondents felt that management responsibility should be shared, everyone else felt that policy and its implementation should be managed by government, reinforced by legislation and resourced. PIRSA and DEWNR were both cited as relevant management bodies.

A number of final comments, highlighted in Box 13, show some of the perspectives in detail.

Box 13: Respondent final summations on the whole issue of seal impact

- Need to be vigilant with this issue. Need accurate data on interactions to ensure mitigation strategies can be developed to deal with this issue.

- Look in our industry we farm 30,000 fish a year. If we lose about 5% of our stock to seal interactions then that makes it about $100 k a year. We have covered this impact quite well, but still it would be good to change this for the better especially if seal populations keep increasing. What happens is that even if you have all of your cages protected, if there is just one weak link, then it is not seal proofed. Then they all go there and you're stuffed'.

- Well what I want to know is what is the current status of seal populations? What are the outcomes and what are we getting out of all the research? There are a lot of misconceptions out there and everyone wants to help or do something about penguins but there's not much done about tuna... There is a perception out there too that a seal eats double what we catch but I am not sure about that - that's where culling comes into it - if that's true we should think about it. Basically just tell me what to do and I'll do it but need to be clear.

- Thing is seals learn quickly! ALL get it in the end, so money ends up being wasted. Extremely intelligent animals.

4.3. Interviews

Results from the interviews show consistent, if often opposing, narratives around seal interactions. These narratives are consistent with the themes identified within the media analysis and that also emerged in the survey. Due to the fact that many of the themes overlap with the other data sets, and hence do not really need further exposition, in Table 26, we present instead a summary of the key themes as a series of narrative tensions because ultimately what the interviews revealed is that for every narrative there is a counter narrative.

Table 26: Interview narrative and counter-narrative themes

Narrative 1:	Seal populations are exploding and should be culled
Counter-narrative 1:	Seals are only coming back from the brink of extinction due to previous human predation and nature should be left alone to recover and 'do her job'
Narrative 2:	Seals have killed the penguins
Counter-narrative 2:	Penguins have also been killed/impacted on by other factors apart from seals (e.g. predation by fox, cat, disease, climate change and structural adjustments to their habitat [sic] the new mooring for Sealink)
Narrative 3:	Seals are causing severe ecological imbalance (e.g. killing pelicans, other birds and marine species)
Counter-narrative 3:	Fishers are causing severe ecological imbalance by overfishing
Narrative 4:	Seals are having a catastrophic economic impact on marine industries
Counter-narrative 4:	Seals are a tourist attraction and provide positive economic return
Narrative 5:	Seals are causing social and familial disruption, including suicide, divorce, unemployment

Counter-narrative 5: This claim is over exaggerated

Narrative 6: Scientists are not to be trusted, neither are information sources they construct around seals

Counter-narrative 6: It is fishers who need to be educated in how to change their practice so as to ensure interactions with seal species decrease or are managed

Narrative 7: Government is handling the situation really badly

Counter-narrative 7: Government and industry should work together

Interviewees framed their discussions about seal species in the context of all of the above narratives. Unsurprisingly, they also tended to hold to clusters of these narratives or counter-narratives. For example, interviewees who believed that seals had a catastrophic economic impact, also tended to distrust science and scientists, believed populations were exponentially exploding, in turn causing ecological imbalance that can only be solved by culling.

Adherence to these narratives also seemed to create some interesting social and political alliances across all the regions. For example, a community of practice[2] emerged within seal watching/shark cage diving operators, from Baird Bay to Kangaroo Island, and which acted to also verbalise opposition to the view that seals were destroying penguin habitat and hence other forms of tourism. Interviews also revealed the importance of communities of practice in general in providing focal points for people to actively engage in finding solutions or support for their issues or experiences.

Interview analysis also highlighted the extensive and long-standing social networks of the people working in the various industries affected by seal interactions. Everyone knew each other in each place, and often, even if they did not like that person, would refer the researcher to them for information. Interview results also highlight people's reliance on other types of networks, such as membership of various peak groups like the Recreational Fisherman's Association or the Southern Bluefin Tuna Association. These networks also acted as conduits of information about policy, seal interactions and whereabouts, and resources to assist people to adapt to the impacts. The power of these networks should not be under-estimated, as the people within them have forged relationships, often over decades, (whether through love, friendship, opposition or working with each other), that form an important psychological back drop to current articulations and responses to the issue of seal interactions. Part of creating responses to these issues, will require an engagement with the community in this sense.

Cumulatively, the interviews were helpful in informing the researcher’s understanding of the collective emotional and political landscape that dominated this issue throughout the period of research and helped to corroborate with detailed and rich data, the themes and concerns already expressed via the media analysis and surveys.

---

[2] By communities of practice we mean a groups of people who share a concern or passion about something they do and learn how to do better as they interact regularly, working together for a common goal/end/means. This draws on Wenger’s work on communities of practice (Wenger 1998).

5. Discussion and Summary of Key Findings

This research project aimed to firstly understand the economic impact of seal interactions on aquaculture and marine industries and secondly, to document the perception of the broader impact of seals on marine communities. The project comprised four parts, a literature review, two surveys, a series of semi-structured interviews and a media analysis. Results revealed consistency in findings across all data sets.

The key findings are as follows:

- There is an economic impact resulting from seal interactions on aquaculture which ranges from 1-5% of yearly operations.
- There is an economic impact resulting from seal interactions on various marine stakeholders, but this impact is more diffused, harder to quantify and sometimes positive.
- The fishing sector in the Coorong region appears to be experiencing more acute and immediate stress and economic impact, with some respondents identifying losses of up to 50 % and more in their profit and catch in the last five years due to seal interactions.
- Interactions with seals have had a very positive economic impact in the marine tourism sector, and that in some cases, have saved businesses from economic hard times (i.e. for shark cage dive operators when sharks are absent from licensed areas).
- There is a strong *perception* and belief held by many marine stakeholders that the economic impact of seals is major, and potentially catastrophic. This has created social and emotional uncertainty, and it is clear that, whatever the 'facts' may be, some people are genuinely suffering and hurt by the issue, with some appearing to experience fears of bankruptcy, unemployment, divorce or suicide for themselves or family and friends.
- Discourse around is often relayed in very emotive terms. This makes accurate estimation of economic impact that much harder.
- There is a degree of historical and current angst about the significant decline of penguin populations, perceived largely to be the fault of seal predation. This issue is especially acute in Kangaroo Island, and to a lesser extent Granite Island and Victor Harbor.
- Respondents identified many other potential impacts on penguin populations including predation by foxes, cats and dogs, infrastructure development, other forms of tourism, and disease.
- There is a large measure of confusion and misinformation about the seal species, with respondents routinely being unable to decide whether populations were increasing or decreasing, and often stating they knew very little about the biological and other habits of the species. Having said this, the Long Nose fur seal is clearly the species most often blamed for issues.
- Management of the issue is overwhelmingly construed as the responsibility of government.
- The management option that is most favoured is culling.
- However, all respondents are unanimous in asserting the need for immediate action on the issue.

As noted earlier this project builds on a previous study (Goldsworthy et al. 2009), which focussed on the perceived impact of operational interactions between seals and the tuna aquaculture industry. The survey aimed to broadly assess the nature and extent of interactions between seals and finish aquaculture in the Port

Lincoln region to provide a baseline against which future changes can be assessed and secondly to develop recommendations on how finfish farmers may minimise seal interactions. Specifically, the survey assessed: (i) the economic significance, temporal trends since tuna farming commenced, (ii) observed nature of operational interactions, typical outcomes with reference to tuna growth and market value, seal species responsible and mitigation and management measures.

Study results demonstrated that the operational impact of seal-farmed tuna interactions were a continuing problem with over half (54%) of companies surveyed believing that operational interactions with seals were moderate to high and economically significant. This accords with our survey which also finds that interactions are perceived to have economic significance, although our survey alas found that in some cases this impact was positive. Further analysis highlighted that seal interactions really only became problematic from 1992 onwards and companies were divided as to whether or not they perceived an increase or decrease in that time. This is in contrast to this survey which demonstrated an unequivocal belief that interactions had increased and intensified. However, both surveys were consistent in identifying perceptions that death to tuna stock was a major impact (up to 14% at times) followed by stress and damage to the fish (Goldsworthy et al. 2009). Consistent with the results of this survey, New Zealand Fur Seals (as known then) were also seen to be primarily responsible for most damage and interactions, and fishers mitigated attacks by use of seal fences, and in some cases electric fences. The former study also highlighted that by and large operators felt that mitigation measures, particularly the use of seal fences worked to manage the impact of seal interactions. This contrasts with the findings of this survey, where most operators felt that seal interactions remained an issue notwithstanding their efforts at mitigation. This survey also shows a wider range of mitigation measures used, ranging from seal fences, to acoustic devices.

This original study provides important insights and was an important starting point for the current study. The current study builds on it in key ways. Firstly, while the original study focussed on tuna farming per se and primarily in Port Lincoln, this study reports on the perceptions of both aquaculture operators and also marine stakeholders across the whole state. We also provide a detailed analysis of other factors, including the perception of economic impacts, which seals were considered issues, a wider range of impacts (both positive and negative) and the role of other factors. The current study also finds a demonstrable increase in angst and worry about the impact of seal interactions, and a perception that seal numbers have significantly increased. Together, both studies provide evidence of a history of seal-marine stakeholder interactions that is attracting increasing policy and media attention, that it is affecting multiple stakeholders across the state and that it is perceived to be an issue needing policy and management action.

6. Conclusion

The impact of seals on marine communities is a classic example of a wicked problem, as typified by Rittel and Webber (1973 and see Box 14 below). As such there will be no easy solutions to solving this problem.

Box 14: Rittel and Webber's 1973 formulation of wicked problems in social policy planning.

They specified ten characteristics:

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rule.
3. Solutions to wicked problems are not true-or-false, but good or bad.
4. There is no immediate and no ultimate test of a solution to a wicked problem.
5. Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial and error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The social planner has no right to be wrong (i.e., planners are liable for the consequences of the actions they generate).

Whether real or perceived, results highlight that the economic impacts of seal interactions across the sectors are differentiated and diverse, and include substantial positive as well as negative impacts. These factors will have to be considered carefully when constructing policy responses. Nonetheless, the management of seal interactions has reached an emotional fever-pitch in certain regional areas such as the Coorong which require management action and strategic attention in the near future. In the words of one respondent: ‘It just needs to get sorted, one way or the other’.

7. References

Adimey, N. M., Hudak, C. A., Powell, J. R., Bassos-Hull, K., Foley, A., Farmer, N. A., White, L. and Minch, K. (2014). Fishery gear interactions from stranded bottlenose dolphins, Florida manatees and sea turtles in Florida, U.S.A. Marine Pollution Bulletin 81: 103-115.

Antunes Zappes, C., Ventura da Silva, C., Pontalti, M., Danielski, M. L. and Di Beneditto, A. P. M. (2013). The conflict between the southern right whale and coastal fisheries on the southern coast of Brazil. Marine Policy 38: 428-437.

Bearzi, G. (2002). Interactions between cetaceans and fisheries in the Mediterranean Sea. In: Notarbartolo di Sciara, G. (Ed.). Cetaceans of the Mediterranean and Black Seas: state of knowledge and conservation strategies. A report to the ACCOBAMS Secretariat, Monaco, February 2002. Section 9, 1–20.

Bell, D. (2008). Listen to Ngarrindjeri Women Speaking, Spinifex Press. North Melbourne, Victoria.

Benjamins, S., Ledwell, W., Huntington, J. and Davidson, A. R. (2012). Assessing changes in numbers and distribution of large whale entanglements in Newfoundland and Labrador, Canada. Marine Mammal Science 28: 579–601.

Berger, A. (2014). Media Analysis Techniques. Sage Publications, Newbury Park, CA.

Bosetti, V. and Pearce, D. (2003). A study of environmental conflict: the economic value of grey seals in southwest England. Journal of Biodiversity and Conservation 12: 2361-2392.

Carbonell, A., Alemany, F., Merella, P., Quetglas, A. and Román, E. (2003). The by-catch of sharks in the western Mediterranean (Balearic Islands) trawl fishery. Fisheries Research 61: 7–18.

Cassoff, R. M., Moore, K. M, McLellan, W. A, Barco, S. G, Rotstein, D. S. and Moore, M. J. (2011). Lethal entanglement in baleen whales. Diseases of Aquatic Organisms 96: 175–185.

Cook, T. C., James, K. and Bearzi, M. (2015). Angler perceptions of California sea lions (*Zalophus californianus*) depredation and marine policy in southern California. Marine Policy 51: 573-583.

Cowling, M., Kirkwood, R., Boren, L. J. and Scarpaci, C. (2014). The effects of seal-swim activities on the New Zealand fur seal (*Arctophoca australis forsteri*) in the Bay of Plenty, New Zealand, and recommendations for a sustainable tourism industry. Marine Policy 45: 39-44.

Cronin, M., Jessopp, M., Houle, J. and Reid, D. (2014). Fishery-seal interactions in Irish waters: Current perspectives and future research priorities. Marine Policy 44: 120-130.

Denzin, N. K. (1970). The Research Act in Sociology. Aldine, Chicago.

Denzin, N. and Lincoln, Y. (2005). The Handbook of Qualitative Research. SAGE Publications, Newbury Park, CA.

DLima, C., Marsh, H., Hamann, M., Sinha, A. and Arthur, R. (2014). Positive interactions between Irrawaddy dolphins and artisanal fishers in the Chilika Lagoon of eastern India are driven by ecology, socioeconomics, and culture. Ambio 43 (5): 614-624.

De Jong, S. and Tanner, J. S. (2004). Environmental risk assessment of marine finfish aquaculture in South Australia. South Australian Research and Development Institute, Adelaide, South Australia. SARDI Aquatic Sciences Publication No. RD03/004/4. SARDI Research Report Series No. 130. 122 pp.

DeMaster, D. P., Fowler, C. W., Perry, S. L. and Richlen, M. F. (2001). Predation and competition: the impact of fisheries on marine mammal populations over the next one hundred years. Journal of Mammalogy 82: 641-651.

Engel, M. T., Marchini, S., Pont, A. C., Machado, R. and Rosa de Oliveira, L. (2014). Perceptions and attitudes of stakeholders towards the wildlife refuge of Ilha dos Lobos, a marine protected area in Brazil. Marine Policy 45: 45-51.

Essington, T. E., Beaudreau, A. H. and Wiedenmann, J. (2006). Fishing through marine food webs. Proceedings of the National Academy of Sciences of the US 103: 3171–3175.

Goldsworthy, S., Page, B., Shaughnessy, P., Hamer, D., Peters, K. D., McIntosh, R. R., Baylis, A. M. M. and McKenzie, J. (2009).). Innovative solutions for aquaculture planning and management: addressing seal interactions in the finfish aquaculture industry. FRDC Project number: 2004/201 Final report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication Number F2008/000222-1. SARDI Research Report Series No. 288. 291 pp.

Goldsworthy, S. D., Page, B., Rogers, P. and Ward, T. (2011). Establishing ecosystem-based management for the South Australian sardine fishery: developing ecological performance indicators and reference points to assess the need for ecological allocations. Final report to Fisheries Research and Development Corporation. South Australian Research and Development Institute, Adelaide, South Australia. SARDI Aquatic Sciences Publication No. F2010/000863-1. SARDI Research Report Series No. 529. 173 pp.

Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J. and Littnan, C. (2003). Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In: Gales, N., Hindell, M. and Kirkwood, R. (Eds.). Marine mammals: Fisheries, tourism and management issues. CSIRO Publishing, Melbourne, pp. 62–99.

Goldsworthy, S. D., Hamer, D. and Page, B. (2007). Assessment of the implications of interactions between fur seals and sea lions and the southern rock lobster and gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) in South Australia. South Australian Research and Development Institute, Adelaide, South Australia. SARDI Aquatic Sciences Publication No. 2007/000711-1. SARDI Research Report Series No. 255.

Goni, R. (1998). Ecosystem effects of marine fisheries: an overview. Ocean and Coastal Management 40: 37-64.

Lincoln, Y. S. and Guba, E. G. (1985). Naturalistic Inquiry. Sage Publications, Newbury Park, CA.

Guclusoy, H. (2008). Damage by monk seals to gear of the artisanal fishery in the Foca Monk Seal Pilot Conservation Area, Turkey. Fisheries Research 90: 70-77.

Guclusoy, H. and Savas, H. (2003). Interaction between monk seals *Monachus monachus* (Hermann, 1779) and marine fish farms in the Turkish Aegean and the management of the problem. Aquaculture Research 34: 777- 783.

Guclusoy, H., Kırac, C. O, Veryeri, N. O. and Savas, Y. (2004). Status of the Mediterranean monk seal *Monachus monachus* (Hermann, 1779) in the coastal waters of Turkey. E.U. Journal of Fish and Aquatic Science 21 (3/4): 201–210.

Guclusoy, H. and Savas, H. (2003). Interaction between monk seals *Monachus monachus* (Hermann, 1779) and marine fish farms in the Turkish Aegean and the management of the problem. Aquaculture Research 34: 777- 783.

Hale, R., Pires, R., Santos, P. and Karamanlidis, A. A. (2011). Mediterranean monk seal (*Monachus monachus*): Fishery interactions in the Archipelago of Madeira. Aquatic Mammals 37: 298-304.

Hamer, D. J. and Goldsworthy, S. D. (2006). Seal-fishery operational interactions: Identifying the environmental and operational aspects of a trawl fishery that contributes to by-catch and mortality of Australian fur seals (*Arctocephalus pusillus doriferus*). Biological Conservation 130: 517-529.

Hamer, D. J., Goldsworthy, S. D., Costa, D. P., Fowler, S. L., Page, B. and Summer, M. D. (2013). The endangered Australian sea lion extensively overlaps with and regularly becomes by-catch in demersal shark gill-nets in South Australian shelf waters. Biological Conservation 157: 386-400.

Johnson, W. M. and Lavigne, D. M. (1999). Monk seals in antiquity. The Mediterranean monk seal (*Monachus monachus*) in ancient history and literature. The Netherlands Commission for International Nature Protection, Leiden 35: 1–101. 17 figs.

Lasalle, G., Gascuel, D., Le Loch, F., Lobry, J., Pierce, G. J., Ridoux, V., Santos, M. B., Spitz, J. and Niquil, N. (2012). An ecosystem approach for the assessment of fisheries impacts on marine top predators: the Bay of Biscay case study. ICES Journal of Marine Science 69 (6): 925-938.

Lewison, R. L., Freeman, S. A., and Crowder, L. B. (2004). Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecological Letters 7: 221–231.

Matthiopoulos, J., Smout, S., Winship, A. J., Thompson, D., Boyd, I. L. and Harwood, J. (2008). Getting beneath the surface of marine mammal – fisheries competition. Mammal Review 38: 167-188.

Morissette, L., Christensen, V. and Pauly, D. (2012). Marine mammal impacts in exploited ecosystems: Would large scale culling benefit fisheries? Plos One 7 (9): 1-18.

McNamara, J. (2010). Media content analysis: Its uses; benefits and best practice methodology. Asia Pacific Public Relations Journal 6 (1): 1–34.

Ngarrindjeri Tendi, Ngarrindjeri Heritage Committee, Ngarrindjeri Native Title Management Committee (2006). *Ngarrindjeri* nation *Yarluwar-ruwe* plan: Caring for *Ngarrindjeri* Sea Country and Culture. Australian Government Department of Environment, Meningie, South Australia.

Northridge, S. P. (1991). An updated world review of interactions between marine mammals and fisheries. FAO Fisheries Technical Paper 251. 58 pp.

Northridge, S. P. and Hofman, R. J. (1999). Marine mammal interactions with fisheries. In: Twiss, J. R. Jr and Reeves, R. R. (Eds). Conservation and Management of Marine Mammals. Smithsonian Institution Press, Washington DC, USA pp. 99-119.

Patton, M. Q. (1990). Qualitative evaluation and research methods (2nd ed.). Sage Publications, Newbury Park, CA.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J. and Zeller, D. (2002). Towards sustainability in world fisheries. Nature 418: 689-695.

Pauly, D., Trites, A. W., Capuli, E. and Christensen, V. (1998). Diet composition and trophic levels of marine mammals. ICES Journal of Marine Science 55: 467-481.

Rittel, H. and Webber, M. (1973). Dilemmas in a general theory of planning. Policy Sciences, 4: 155-169. Elsevier Scientific Publishing Company, Inc., Amsterdam. [Reprinted in Developments in Design Methodology. Cross, N. (Ed.). J. Wiley and Sons, Chichester, 1984, pp. 135–144.]

Shaughnessy, P., Kirkwood, R., Cawthorn, M., Kemper, C. and Pemberton, D. (2003). Pinnipeds, cetaceans and fisheries in Australia: a review of operational interactions. In: Gales, N., Hindell, M. and Kirkwood, R. (Eds.). Marine mammals: Fisheries, tourism and management issues. CSIRO Publishing, Melbourne, pp. 136-152.

Shaughnessy, P. D. and McKeown, A. (2002). Trends in abundance of New Zealand fur seals, *Arctocephalus forsteri*, at the Neptune Islands, South Australia. Wildlife Research 29: 185–192.

Varjopuro, R. (2011). Co-existence of seals and fisheries? Adaptation of a coastal fishery for recovery of the Baltic grey seal. Marine Policy 35: 450-456.

Webb, E. J., Campbell, D. T., Schwartz, R. D. and Sechrest, L. (1966). Unobtrusive Measures: Nonreactive Measures in the Social Sciences. Rand McNally, Chicago.

Weise, M. J. and Harvey, J. T. (2005). Impact of the California sea lion (*Zalophus californianus*) on salmon fisheries in Monterey Bay, California. Fishery Bulletin 103: 685-696.

Wenger, E. (1998). Communities of practice: learning, meaning, and identity. Cambridge University Press, Cambridge, UK.

3. Dietary assessment of seal populations in South Australia using a new molecular (metabarcoding) tool

Andrew PA Oxley

3.1 Introduction

Molecular dietary analyses are rapidly evolving tools which offer the ability to improve our understanding of trophic interactions between species (Pompanon *et al.* 2012, Thomas *et al.* 2014). These DNA-based approaches represent a significant advance over traditional methods by providing more robust, definitive measures of dietary composition whereby species-level assignments may be more accurately attained (Casper *et al.* 2007, Deagle *et al.* 2013). This is particularly useful where the ability to discern prey species is hindered by the absence or differential survival of hard structures within the digesta or excreted remains (Cottrell *et al.* 1996, Gales and Cheal 1992). To this end, recent developments in high through-put methods such as next generation sequencing (NGS), now allow the direct characterisation and deep-surveillance of hundreds of samples simultaneously (Pompanon *et al.* 2012, Shokralla *et al.* 2012), and have been used to evaluate the dietary composition of a range species including seals (Deagle *et al.* 2009, Méheust *et al.* 2015); reducing the reliance on otherwise laborious visual assessments. Reports from seals have revealed that these animals consume a range of prey taxa including, among others, fish, cephalopods, birds, sharks and rays (Deagle *et al.* 2009, Peters *et al.* 2014). To capture the spectrum of prey consumed by these animals, earlier studies have implemented multi-target approaches whereby DNA fragments from various mitochondrial or nuclear encoded genes (e.g., mt16S rRNA, CytB, 18/28S rRNA) are amplified using species or group-specific primers (Deagle *et al.* 2009, Deagle *et al.* 2005, Emami-Khoyi *et al.* 2016, Jarman *et al.* 2004, Peters *et al.* 2014, Tollit *et al.* 2009). Whilst such approaches have been used to successfully identify an array of prey species from these animals, they require prior knowledge of diets and may overlook prey items in species with uncharacterised diets or which target a diverse array of taxa (Dunshea 2009). This may be of particular importance for seals, whose diet may vary considerably between species or with sex and/or age, or where differential foraging behaviours may lead to the varied consumption of local or regionally endemic seasonal prey items (Page *et al.* 2005a). Thus, strategies which target a broader diversity of taxa (e.g., using “universal” primers) and are transferrable across systems have been suggested in this regard (Dunshea 2009, Leray *et al.* 2013b).

In line with this, a shift towards the adoption of alternative, single gene markers like the mitochondrial gene-encoding Cytochrome *c* oxidase subunit I (COI) has been proposed (Bucklin *et al.* 2011). This gene target has been reported to have exceptionally broad taxonomic breadth (covering a wide range of marine metazoa) with the capacity to provide high species-level resolution and accurate estimates of diversity (Geller *et al.* 2013, Hebert *et al.* 2003, Lobo *et al.* 2013, Tang *et al.* 2012), particularly over nuclear targets like 18S rRNA where high levels of conservation may exist between distantly related species (Krieger and Fuerst 2002, Stock *et al.* 1991). The establishment of the COI gene as a universal marker follows the international efforts of the “Barcode of Life” project (Costa and Carvalho 2010), which aims to provide a public repository of genetic barcodes from all living species to expedite molecular ecological studies. Such an approach offers a simplified strategy with the capacity to identify a diverse array of taxa from almost any sample when used in conjunction with NGS procedures as a metabarcoding assay (Leray and Knowlton 2015), and has been implemented for cetaceans (Harbour Porpoises, *Phocoena phocoena*) and other pinniped species (Grey Seals, *Halichoerus grypus*) (Méheust *et al.* 2015). However, in using “universal” primers to assess samples like digesta or faeces, which comprise a mixture of both highly degraded prey DNA and more abundant high-quality DNA from the predator itself (Deagle *et al.* 2006, Kohn and Wayne 1997), predator co-amplification may prevent or bias prey recovery in the absence of preventative (Leray *et al.* 2013a, O’Rorke *et al.* 2012, Vestheim and Jarman 2008). To reduce the amount of predator material being amplified, and thus the likely numbers of predator sequence reads obtained from these assays, specific strategies like the use of predator blocking primers have been proposed. These primers are modified oligonucleotides which are specific to the predator target sequence and do not prime amplification, and act by competing with the universal primers in a mix to block predator DNA amplification (Vestheim and Jarman 2008). Whilst blocking primers have only been implemented for the mitochondrial 16S rRNA gene in seals (Deagle *et al.* 2009), they have been used successfully for restricting the amplification of the COI gene from predatory fish to reveal an array of prey taxa (Leray *et al.* 2013a, 2013b, Leray and Knowlton 2015, Leray *et al.* 2015). This metabarcoding approach thus offers a powerful new tool for assessing the dietary compositions of these animals and supporting the broader evaluation of their feeding ecology and impacts on the seafood industry in South Australia.

Objectives

Here, we investigate the application of the mitochondrial COI gene as a marker for the molecular dietary assessment of Australian Sea Lions – ASL (*Neophoca cinerea*), Australian Fur Seals – AFS (*Arctocephalus pusillus*) and Long-nosed Fur Seals – LNFS (*Arctocephalus forsteri*). A NGS metabarcoding approach targeting the 5´ region of the COI gene (COI-5P) was used to capture the likely array of prey species consumed by these seals, and was developed and validated in conjunction with blocking primers for limiting amplification of the DNA from these predators. This study represents the first to implement a metabarcoding approach for assessing the diets of seals and highlights the sensitivity of the method over traditional approaches for evaluating their impacts on the seafood industry in South Australia.

3.2 Methods

Sample collection and DNA extraction

Tissue samples from the three seal species and 39 prey taxa representing 14 species of fish, 12 species of sharks/rays, 7 species of cephalopods and other molluscs, 3 species of Crustacea and 3 species of birds were obtained for the establishment and optimisation of the molecular assays from a combination of sources including SARDI surveys, the Australian Biological Tissue Collection (ABTC, South Australian Museum) and the Australian National Fish collection (CSIRO) (Table 3.1). Where possible, all samples were preserved or obtained from specimens stored in 96% molecular-grade ethanol prior to DNA extraction.

In addition, to assess the application of the downstream molecular assays for evaluating the dietary composition of seals, a total of 465 scat samples were obtained in 2014/15 from a combination of ASL, AFS and LNFS from a total of 27 sites across ten locations within South Australia over various seasons (Table 3.2). At collection, samples were assigned to a specific seal species (based on visual assessment), placed in bags or collection vials, mixed with molecular-grade 96% ethanol and, where possible, stored at 4°C prior to DNA extraction. In addition, to increase the coverage of areas of particular commercial significance, a further 46 scat samples were obtained in 2016 from a combination of LNFS and ASL from Donington Reef in Spencer Gulf (SG) (Table 3.3). These samples were collected and stored in the same manner as those obtained in 2014/15 except that they were mixed with RNAlater (Ambion) rather than ethanol, as a more robust and non-hazardous sample (DNA) protectant. In total, 511 scat samples were extracted.

DNA was extracted from tissues using the DNeasy Blood and Tissue Kit (Qiagen), and from 1g aliquots of homogenised scat samples (as achieved by vigorous shaking) using the QIAamp Fast DNA Stool Mini Kit (Qiagen), following the manufacturer’s instructions. DNA extracts were assessed for yield and purity using the NanoDrop 2000 spectrophotometer (Thermo Scientific) and were stored at -20°C prior to use in downstream assays.

Table 3.1. List of tissue specimens obtained from seals and various prey taxa for DNA extraction and validation of the molecular assays.

		Species	**Specimen source*** (DNA extract no.)
SEALS	(1 family, 3 species)	Australian Sea Lion, *Neophoca cinerea* (Otariidae)	SA Museum 12614; (112)
		Australian Fur Seal, *Arctocephalus pusillus* (Otariidae)	SA Museum ABTC 73640; (110)
		Long-nosed Fur Seal, *Arctocephalus forsteri* (Otariidae)	SA Museum ABTC 27080; (108)
PREY (35 families, 39 species)	**FISH** (12 families, 14 species)	Australian Salmon, *Arripis trutta* (Arripidae)	SARDI; (40)
		Bight Redfish, *Centroberyx gerrardi* (Berycidae)	SARDI; (15)
		Jack Mackerel, *Trachurus declivis* (Carangidae)	SARDI; (11)
		Silver Trevally, *Pseudocaranx dentex* (Carangidae)	SARDI; (7)
		Yellowtail Kingfish, *Seriola lalandi* (Carangidae)	SARDI; (113)
		Australian Pilchard, *Sardinops sagax* (Clupeidae)	SARDI; (5)
		Bluethroat Wrasse, *Notolabrus tetricus* (Labridae)	SARDI; (64)
		Sixspine Leatherjacket, *Meuschenia freycineti* (Monocanthidae)	SARDI; (54)
		Rock Ling, *Genypterus tigerinus* (Ophidiidae)	SARDI; (43)
		Tiger Flathead, *Platycephalus richardsoni* (Platycephalidae)	SARDI; (72)
		Southern Bluefin Tuna, *Thunnus maccoyii* (Scombridae)	SARDI; (57)
		Sweep, *Scorpis lineolata/aequipinnis* (Scorpididae)	SARDI; (34)
		King George Whiting, *Sillaginodes punctatus* (Sillaginidae)	SARDI; (41)
		Snook, *Sphyraena novaehollandiae* (Sphyraenidae)	SARDI; (36)
	SHARKS/RAYS (11 families, 12 species)	Gummy Shark, *Mustelus antarcticus* (Triakidae)	SARDI; (97)
		School Shark, *Galeorhinus galeus* (Triakidae)	SARDI; (95)
		Port Jackson Shark, *Heterodontus portusjacksoni* (Heterodontidae)	SARDI; (99)
		Gulf Wobbegong Shark, *Orectolobus halei* (Orectolobidae)	CSIRO GT 182; (115)
		Southern Saw Shark, *Pristiophorus nudipinnis* (Pristiophoridae)	SARDI; (99)
		Australian Angelshark, *Squatina australis* (Squatinidae)	CSIRO GT 1285; (121)
		Southern Eagle Ray, *Myliobatis tenicaudatus* (Myliobatidae)	CSIRO GT 250; (127)
		Southern Fiddler Ray, *Trygonorrhina dumerilii* (Rhinobatidae)	CSIRO GT 282; (122)
		Smooth Stingray, *Dasyatis brevicaudata* (Dasyatidae)	SA Museum 94729; (143)
		Banded Stingaree, *Urolophus cruciatus* (Urolophidae)	SA Museum 69572; (141)
		Melbourne Skate, *Dipturus whitleyi* (Rajidae)	CSIRO 031 Dip whi 03; (123)
		White-spotted Dogfish, *Squalus acanthias* (Squalidae)	CSIRO GT 5434; (117)
	Cephalopods and other molluscs (6 families, 7 species)	Southern Calamari Squid, *Sepioteuthis australis* (Loliginidae)	SARDI; (79)
		Red Arrow Squid, *Nototodarus gouldi* (Ommastrephidae)	SARDI; (81)
		Nova Cuttlefish, *Sepia novaehollandae* (Sepiidae)	SARDI; (83)
		Giant Australian Cuttlefish, *Sepia apama* (Sepiidae)	SARDI; (82)
		Maori Octopus, *Octopus maorum* (Octopodidae)	SARDI; (84)
		Pacific Oyster, *Crassostrea gigas* (Crassostreinae)	SARDI; (74)
		Southern Cockle, *Acrosterigma cygnorum* (Cardiidae)	SARDI; (73)
	Crustacea (3 families, 3 species)	Blue Swimmer Crab, *Portunus pelagicus* (Portunidae)	SARDI; (86)
		Western King Prawn, *Melicertus latisulcatus* (Penaeidae)	SARDI; (90)
		Southern Rock Lobster, *Jasus edwardsii* (Palinuridae)	SARDI; (94)
		Balmain Bug, *Ibacus peronii* (Scyllaridae)	SARDI; (88)
	Birds (3 families, 3 species)	Little Penguin, *Eudyptula minor* (Spheniscidae)	SA Museum ABTC 2528; (104)
		Silver Gull, *Larus novaehollandiae* (Laridae)	SA Museum ABTC 18064; (106)
		Short-tailed Shearwater, *Puffinus tenuirostris* (Procellariidae)	SA Museum ABTC 3015; (102)

*Specimens not obtained in-house from the South Australian Research and Development Institute (SARDI) were sourced either from the South Australian Museum, Australian Biological Tissue Collection (SA Museum, ABTC), or from the Australian National Fish Collection (CSIRO).

Table 3.2. List of scat samples obtained in 2014-2015 for DNA extraction and COI gene metabarcoding analysis from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS), and associated collection sites.

Species	Geographic location ID	Geographic location name	Site ID	Site name	Collection Date	Season	No. samples
ASL	G1	Nuyts Reef	S1	Nuyts Reef	Dec-14	Spring/Summer	4
	G2	Nuyts Archipelago	S2	Purdie	Jul-14	Autumn/Winter	4
	G2	Nuyts Archipelago	S3	Lounds	Jul-14	Autumn/Winter	4
	G2	Nuyts Archipelago	S4	Liliput	Jul-14	Autumn/Winter	4
	G2	Nuyts Archipelago	S5	Blefuscu	Jul-14	Autumn/Winter	4
	G3	Chain of Bays	S6	Olive	Jul-14	Autumn/Winter	7
	G3	Chain of Bays	S6	Olive	Dec-14	Spring/Summer	13
	G4	South-west Eyre	S7	Rocky North	Feb-14	Spring/Summer	3
	G4	South-west Eyre	S7	Rocky North	Jul-14	Autumn/Winter	17
	G5	Southern Spencer Gulf	S8	Albatross	Mar-14	Autumn/Winter	2
	G5	Southern Spencer Gulf	S8	Albatross	Jul-14	Autumn/Winter	18
	G5	Southern Spencer Gulf	S11	Lewis Island	Feb-14	Spring/Summer	13
	G5	Southern Spencer Gulf	S11	Lewis Island	Jul-14	Autumn/Winter	26
	G5	Southern Spencer Gulf	S12	Liguanea	Feb-14	Spring/Summer	10
	G6	Kangaroo Island	S9	South Pages	Jun-14	Autumn/Winter	6
	G6	Kangaroo Island	S10	North Pages	Jun-14	Autumn/Winter	13
TOTAL (ASL)							**148**
LNFS	G3	Chain of Bays	S24	West Waldegrave	Jul-14	Autumn/Winter	25
	G4	South west Eyre	S7	Rocky North	Jul-14	Autumn/Winter	25
	G5	Southern Spencer Gulf	S12	Liguanea	Feb-14	Spring/Summer	23
	G5	Southern Spencer Gulf	S12	Liguanea	Jul-14	Autumn/Winter	28
	G6	Kangaroo Island	S13	Ballast Head	Jul-Sep-14	Winter/Spring	5
	G6	Kangaroo Island	S14	Cape du Couedic	Jul-Sep-14	Winter/Spring	3
	G6	Kangaroo Island	S15	Cape Gantheaume	Jul-Sep-14	Winter/Spring	10
	G6	Kangaroo Island	S16	Cape Kersaint	Jul-Sep-14	Winter/Spring	6
	G6	Kangaroo Island	S17	Hummocky	Jul-Sep-14	Winter/Spring	11
	G6	Kangaroo Island	S18	Kingscote	Jul-Sep-14	Winter/Spring	9
	G6	Kangaroo Island	S19	Penneshaw	Jul-Sep-14	Winter/Spring	11
	G7	Fleurieu peninsula	S20	Seal/Granite Island	Jul-Sep-14	Winter/Spring	12
	G7	Fleurieu peninsula	S21	West Island	Jul-Sep-14	Winter/Spring	10
	G8	Spencer Gulf	S22	Donington Rocks	Jul-14	Autumn/Winter	25
	G8	Spencer Gulf	S23	Wedge North	Jul-14	Autumn/Winter	25
	G9	Gulf St Vincent	S25	Outer Harbour	Sep-15	Spring/Summer	25
	G10	Coorong	S26	Coorong/Tauwitcheree Barrage	Aug-15	Autumn/Winter	17
	G10	Coorong	S26	Coorong/Tauwitcheree Barrage	Sep-15	Spring/Summer	22
TOTAL (LNFS)							**292**
AFS	G6	Kangaroo Island	S27	North Casuarina	Jan-14	Spring/Summer	25
TOTAL (AFS)							**25**
TOTAL samples							**465**

Table 3.3. List of scat samples obtained for DNA extraction and COI gene metabarcoding analysis in 2016 from Long-nosed Fur Seal (LNFS) and Australian Sea Lion (ASL), and associated collection sites.

Species	Geographic location ID	Geographic location name	Site ID	Site name	Collection Date	Season	No. samples
LNFS	G8	Spencer Gulf	S22	Donington Rocks	Jul-16	Autumn/Winter	35
ASL	G8	Spencer Gulf	S22	Donington Rocks	Jul-16	Autumn/Winter	11
TOTAL samples							**46**

Primer development and validation

COI gene primers

To capture the range of prey taxa likely to be consumed by seals, universal metazoan primers targeting the mitochondrial cytochrome *c* oxidase subunit I (COI) gene were considered as a conventionally accepted marker for the identification and barcoding of species (Bucklin *et al*. 2011). Specifically, primers mlCOIintF/jgHCO2198 (Table 3.4) were investigated; they were designed to amplify and discriminate taxa from a broad range of marine phyla and were successfully used for assessing the gut contents of fish (Geller *et al*. 2013, Leray *et al*. 2013a, Lobo *et al*. 2013). These primers target a short (313 bp) fragment of the 5´ region of the COI gene (COI-5P), making them particularly suitable for use in next generation sequencing (NGS) applications. Thus, as a first step in assessing their suitability here, the corresponding primer target regions in the COI gene sequences from representative prey taxa were evaluated, as identified from other molecular and hard-part studies (Allen and Huveneers 2005, Deagle *et al*. 2009, Gales and Pemberton 1994; Page *et al*. 2005, Peters *et al*. 2014). Sequences from a total of 121 species (representing 3 seals, 69 fish, 12 sharks/rays, 10 cephalopods, 10 crustacea, 8 birds and 9 other taxa) were mined from the BOLD systems database (Ratnasingham and Hebert 2007) and were manually aligned alongside the primer sequences in BioEdit v7.2.5 (Hall 1999). To determine the likelihood of PCR amplification (*in silico*), the total number of nucleotide (nt) mismatches in both the forward (mlCOIintF) and reverse (jgHCO2198) primer target regions were assessed for each prey species, with mismatches (predominantly in the last two nucleotides of the 3´ region) indicative of poor or negative amplification (Appendix 3.1, Table 1).

Table 3.4. List of COI primers used in this study.

Primer name	Target species	Application	Sequence (5'-3')	Source
mlCOIintF	Marine metazoa	PCR	GGWACWGGWTGAACWGTWTAYCCYCC	Leray *et al*. 2013
jgHCO2198	"	"	TAIACYTCIGGRTGICCRAARAAYCA	Geller *et al*. 2013
CO15P_DPOblk-AFS†	Australian Fur Seal (AFS)	Blocking	GGTTTACCCTCCCCTAGCGGGAAACCTGGCCCATGCAGGAIIIIICGTAGACTTGA	This study
CO15P_DPOblk-ASL†	Australian Sea Lion (ASL)	"	GGTTTACCCTCCCCTAGCAGGGAACCTAGCCCACGCAGGGIIIIICGTAGACTTGA	"
CO15P_DPOblk-LNFS†	Long-nosed Fur Seal (LNFS)	"	AGTTTACCCTCCTCTAGCAGGAAATCTAGCCCATGCAGGAIIIIICGTAGACTTAA	"
CO15P_DPOblk-Universal-Seals†	All seals	"	RGTTTACCCTCCYCTAGCRGGRAAYCTRGCCCAYGCAGGRIIIIICGTAGACTTRA	"

†Blocking primers were synthesised with and without a C3 spacer CPG modification at the 3' end. I=deoxyinosine.

In addition, to further validate the capability of these primers to amplify the COI-5P region from a range of prey taxa, mlCOIintF and jgHCO2198 were used in the PCR amplification of DNA extracts from the tissues of seals and 40 representative prey species comprising up to 4 nt mismatches in the forward primer target region, and included 14 fish, 12 sharks/rays, 5 cephalopods, 4 crustacea, 3 birds and 2 other taxa (Table 3.1). Each PCR contained 2.5 µl of 10x TaKaRa Hot Start buffer (Clontech), 25 µM of each dNTP, 1 µM of each primer, 1 U of TaKaRa Taq Hot Start DNA polymerase (Clontech), ~50-100 ng of DNA template and were made up to 25 µl with PCR grade H_2O (Qiagen). Due to the degeneracy of the primers, all COI reactions were subjected to a "touchdown" PCR profile as recommended by Leray *et al*. (2013a) which consisted of an initial denaturation at 94°C for 3 min followed by 6 cycles comprising denaturation for 30 s at 94°C, annealing for 30 s at 54°C (-1°C per cycle) and extension for 30 s at 72°C followed by 29 cycles at 48°C annealing temperature and a final elongation step at 72°C for 5 min. As a negative (no template) control, water was run alongside the other reactions with the resultant PCR products visualised by agarose gel electrophoresis.

Predator blocking primers

As scat samples comprise both highly degraded prey DNA and more abundant high-quality DNA from the predator itself (Deagle *et al*. 2006, Kohn and Wayne 1997), predator co-amplification may prevent or bias prey recovery in the absence of preventative measures (Leray *et al*. 2013b, O'Rorke *et al*. 2012, Vestheim and Jarman, 2008). As such, several blocking primers were designed to assist in the reduction of seal DNA amplification. A total of four annealing inhibiting Dual Priming Oligonucleotide (DPO) blocking primers (COI5P_DPOblk) were designed based on the recommendations of Vestheim and Jarman (2008) and included one specific to each of the three seal species (i.e. ASL, AFS and LNFS) and a single non-specific ("universal seals") primer (Table 3.4). Each primer was designed to overlap the 3´ region of the universal COI-5P forward primer mlCOIintF, and comprised two priming regions separated by a polydeoxyinosine linker, and terminated with a C3 spacer for preventing elongation (Appendix 3.1, Table 2**)**. The efficiency of the "universal seals" and seal species-specific DPO primers for blocking the amplification of the COI-5P gene region from ASL, AFS and LNFS, and their influence on the amplification of the same region from Australian Sardines (as a representative prey species), was assessed by PCR at a recommended concentration of 10:1 and 5:1 blocker: universal forward (mlCOIintF) primer using the same reactions conditions given above. As controls, reactions were also performed using blockers without the addition of a C3 spacer (thereby allowing amplification to occur), as well as with water (as a no template negative control) and with DNA from Australian Sardines without blocking primers (as a positive control). The resultant PCR products were subsequently visualised by agarose gel electrophoresis, with amplification denoted by the presence of a band and the signal intensity reflecting the amount of amplification.

Whilst the rationale for using "universal" blocking primers was due to the lack of certainty around the visual identification of scats as belonging to a particular seal species (since haul-out sites may not be used exclusively by a single seal species), visualisation of the resultant PCR products revealed that whilst both the "universal" and species-specific primers were successful at blocking the amplification of the COI-5P region from all three seals (based on the absence of a signal), prey species amplification was also influenced (Appendix 3.2, Figure 1). In particular, the "universal" primers completely arrested amplification from the prey species, indicating that they are likely to be too universal. Furthermore, the species-specific blocking primers also appeared to influence prey amplification, though largely at the 10:1 concentration, indicating that, independent of the specificity of the primers, high blocking primer concentrations may also contribute to the loss of prey signal. As such, a "pooled" DPO blocking primer prepared using equimolar concentrations of the three species-specific primers was also assessed by PCR using the same approach, though over a lower concentration range of 6:1, 5:1, 3:1 and 2:1 "pooled" blocker: universal forward (mlCOIintF) primer (Appendix 3.2, Figure 2). An optimal "pooled" blocker concentration of 2:1, determined as the point where the lowest predator and highest prey signals were observed, was subsequently evaluated in the PCR amplification of DNA extracts obtained from the tissues of seals and 40 representative prey species (as defined above and listed in Table 3.1**)**.

Deep-sequencing of scat samples

PCR amplification and Illumina sequencing

To elucidate the prey composition of the seal scat DNA extracts, an Illumina deep-sequencing approach previously established for multiplexing hundreds of samples for evaluating bacterial community diversity (Camarinha-Silva *et al.* 2014, Chaves-Moreno *et al.* 2015) was adapted here for use with the universal metazoan primers mlCOIintF and jgHCO2198. This procedure implements a multi-step PCR based strategy, whereby sample-specific barcodes and Illumina specific indices, adaptors and multiplex sequencing primer regions are integrated over consecutive cycles of PCR following pre-enrichment of the target region (in this case COI-5P) (Appendix 3.2, Figure 3). As a first step in establishing this approach, the effect of the "pooled" seal blocking primer on the assay were assessed with and without the presence of the primer at a concentration of 2:1 blocker: COI gene forward (mlCOIintF) primer using DNA extracts obtained from two representative prey taxa (Australian Sardines and Australian Salmon) and AFS. Reactions were performed according to methods detailed by Camarinha-Silva *et al*. (2014) for generating Illumina MiSeq ready libraries, though using the conditions given above for the COI primers. In brief, 2 μl of each DNA sample was first subjected to 20 cycles of PCR, whereby 1 μl of this mixture from the first round was used as template in a further 15 cycles of PCR for incorporating individual 6 nt barcodes and Illumina specific adaptors. One microlitre of this reaction subsequently served as a template in a final 10-cycle PCR for incorporating the Illumina multiplex and sequencing primers. PCR products were visualised by agarose gel electrophoresis whereby positive amplification was denoted by the presence of consecutively larger bands over the 3 rounds of PCR from ~300-500 bp, indicating that the "pooled" blocking primer did not have an effect on the successful construction of the prey libraries (Appendix 3.2, Figure 4). Furthermore, whilst amplification of the predator (AFS) DNA was also observed, it was substantially reduced in comparison to the controls, reflecting the capacity of the blocking primers to moderate the contribution of the predator DNA and thus promote the enrichment of the likely prey species signatures in the samples.

Using this validated Illumina (COI-5P) metabarcoding approach, a total of 511 scat DNA extracts were evaluated of which 130/465 samples collected in 2014/15 and 39/46 samples collected in 2016 produced libraries which could be sequenced. Libraries were subsequently purified using Agencourt AMPure XP beads (Beckman Coulter), quantified using the Quant-iT™ Picogreen® dsDNA kit (Life Technologies) and pooled in equimolar ratios before being sequenced on two runs of the MiSeq platform (Illumina, San Diego, CA) using 250 nt paired-end sequencing chemistry through the Australian Genome Research Facility (AGRF). Amplicons generated from DNA from a single fish species (Jack Mackerel, *Trachurus declivis*) were sequenced alongside the samples as a control.

Bioinformatics and DNA verification of samples

The 130 sequenced samples from 2014/15 and the 39 samples from 2016 returned ~ 5.82 and 6.1 million raw paired-end reads respectively (Tables 3.5 and 3.6). Reads were paired using PEAR (version 0.9.5) (Zhang *et al*. 2014), where primers were identified and removed. The paired-end reads were subsequently quality filtered, with removal of low-quality reads, full-length duplicate sequences (after being counted) and singleton sequences using Quantitative Insights into Microbial Ecology (QIIME 1.8) (Caporaso *et al*. 2010), USEARCH (version 8.0.1623) (Edgar 2010) and UPARSE software (Edgar 2013). Reads were mapped to Operational Taxonomic Units (OTUs) using a minimum identity of 97%.

Table 3.5. Summary of the numbers of raw and pre-/post-processed COI-5P reads obtained following the Illumina MiSeq sequencing of 130 samples obtained from Australian Sea Lion, Long-nosed Fur Seal and Australian Fur Seal in 2014-2015.

	Mean	**SD**	**Min**	**Max**
Raw reads	44,772	14,889	12,379	85,390
Pre-processed (QC checked) reads	41,913	13,893	11,288	82,135
Post-processed (filtered) reads	41,880	13,887	11,280	82,118
Total sequence reads 5,820,387				

Table 3.6. Summary of the numbers of raw and pre-/post-processed COI-5P reads obtained following the Illumina MiSeq sequencing of 39 samples obtained from Long-nosed Fur Seal and Australian Sea Lion in 2016.

	Mean	**SD**	**Min**	**Max**
Raw reads	155,475	58,404	89,901	322,964
Pre-processed (QC checked) reads	151,979	57,135	87,827	314,206
Post-processed (filtered) reads	151,911	57,147	87,788	314,193
Total sequence reads (6,063,522)				

A total of ~11.3 million high-quality, paired-end reads were binned into OTUs representing predator (seal), prey (fish/cephalopods/crustacea/sharks/rays/birds) and other (non-prey) taxa (i.e. taxa that are likely to represent accidental or secondary prey species). Interrogation of the resultant OTUs was conducted using the BOLD systems database (Ratnasingham and Hebert, 2007), whereby taxonomic lineages were assigned to each OTU at the lowest possible level based on sequence identity values of >99% (Species), 95-99% (Genus), 90-95% (Family), 85-90% (Order) and 80-85% (Class). Prey taxa were checked within the Atlas of Living Australia (http://www.ala.org.au/) to verify their likely distribution (and thus positive detection in seals) in South Australian waters.

Using the residual seal sequence reads obtained within each sequenced scat sample (as co-amplified by the universal primers), verification as to which seal species that each scat sample belonged was determined (thus removing the reliance on visual assessment). With this information, the final dataset was updated to reflect the numbers of DNA-verified samples belonging to the three seal species for the collections obtained in 2014/15 and 2016 (Tables 3.7 and 3.8).

Table 3.7. List of DNA verified scat samples obtained in 2014-2015 from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS).

Species	Geographic location ID	Geographic location name	Site ID	Site name	Collection Date	Season	No. DNA verified samples*
ASL	G2	Nuyts Archipelago	S4	Liliput	Jul-14	Autumn/Winter	2
	G2	Nuyts Archipelago	S5	Blefuscu	Jul-14	Autumn/Winter	1
	G3	Chain of Bays	S6	Olive	Jul-14	Autumn/Winter	1
	G4	South-west Eyre	S7	Rocky North	Jul-14	Autumn/Winter	3
	G5	Southern Spencer Gulf	S8	Albatross	Jul-14	Autumn/Winter	2
	G5	Southern Spencer Gulf	S11	Lewis Island	Feb-14	Spring/Summer	1
	G5	Southern Spencer Gulf	S11	Lewis Island	Jul-14	Autumn/Winter	9
	G5	Southern Spencer Gulf	S12	Liguanea	Feb-14	Spring/Summer	2
	G6	Kangaroo Island	S9	South Pages	Jun-14	Autumn/Winter	4
	G6	Kangaroo Island	S10	North Pages	Jun-14	Autumn/Winter	3
	G6	Kangaroo Island	S17	Hummocky	Jul-Sep-14	Winter/Spring	1
	G8	Spencer Gulf	S22	Donington Rocks	Jul-14	Autumn/Winter	2
	G9	Gulf St Vincent	S25	Outer Harbour	Sep-15	Spring/Summer	1
TOTAL (ASL)							**32**
LNFS	G4	South-west Eyre	S7	Rocky North	Jul-14	Autumn/Winter	3
	G5	Southern Spencer Gulf	S12	Liguanea	Feb-14	Spring/Summer	14
	G5	Southern Spencer Gulf	S12	Liguanea	Jul-14	Autumn/Winter	18
	G6	Kangaroo Island	S13	Ballast Head	Jul-Sep-14	Winter/Spring	1
	G6	Kangaroo Island	S14	Cape du Couedic	Jul-Sep-14	Winter/Spring	1
	G6	Kangaroo Island	S15	Cape Gantheaume	Jul-Sep-14	Winter/Spring	7
	G6	Kangaroo Island	S16	Cape Kersaint	Jul-Sep-14	Winter/Spring	2
	G6	Kangaroo Island	S17	Hummocky	Jul-Sep-14	Winter/Spring	4
	G6	Kangaroo Island	S18	Kingscote	Jul-Sep-14	Winter/Spring	6
	G6	Kangaroo Island	S19	Penneshaw	Jul-Sep-14	Winter/Spring	4
	G6	Kangaroo Island	S27	North Casuarina	Jan-14	Spring/Summer	1
	G7	Fleurieu peninsula	S20	Seal/Granite Island	Jul-Sep-14	Winter/Spring	4
	G7	Fleurieu peninsula	S21	West Island	Jul-Sep-14	Winter/Spring	5
	G8	Spencer Gulf	S22	Donington Rocks	Jul-14	Autumn/Winter	2
	G8	Spencer Gulf	S23	Wedge North	Jul-14	Autumn/Winter	4
	G9	Gulf St Vincent	S25	Outer Harbour	Sep-15	Spring/Summer	14
	G10	Coorong	S26	Coorong/Tauwitcheree Barrage	Sep-15	Spring/Summer	1
TOTAL (LNFS)							**91**
AFS	G6	Kangaroo Island	S27	North Casuarina	Jan-14	Spring/Summer	6
	G6	Kangaroo Island	S14	Cape du Couedic	Jul-Sep-14	Winter/Spring	1
TOTAL (AFS)							**7**
TOTAL DNA verified samples*							**130**

*Based on positive identifications obtained from interrogation of the seal COI gene sequences against the BOLD database (http://boldsystems.org/); Values include those samples which were visually misidentified as a different seal species at collection.

Table 3.8. List of DNA verified scat samples obtained in 2016 from Long-nosed Fur Seal (LNFS) and Australian Sea Lion (ASL).

Species	Geographic location ID	Geographic location name	Site ID	Site name	Collection Date	Season	No. DNA verified samples*
LNFS	G8	Spencer Gulf	S22	Donington Rocks	Jul-16	Autumn/Winter	20
ASL	G8	Spencer Gulf	S22	Donington Rocks	Jul-16	Autumn/Winter	19
TOTAL DNA verified samples*							**39**

*Based on positive identifications obtained from interrogation of the seal COI gene sequences against the BOLD database (http://boldsystems.org/); Values include those samples which were visually misidentified as a different seal species at collection.

Statistical analysis

Data matrices comprising the prey sequence counts across scat samples from both 2014/15 and 2016 datasets were used to explore for patterns between seal species (AFS, LNFS and ASL), locations and season, where scat samples were ordinated using principal coordinate analysis (PCoA). Vector overlays visualise potential linear and monotonic relationships between prey species as well as indicate in which group of seals that particular prey species is being predominantly targeted. Each vector was determined using a multiple partial correlation algorithm. Vector length and direction indicates the strength and sign of the relationship between species and the orientation of samples, where only those species with a correlation >0.2 were superimposed onto the PCoA plots. Note that the 2014/2015 and 2016 collection periods were analysed independently because the 2016 samples were preserved in RNAlater rather than ethanol to increase the recovery of DNA and hence the number of samples that could be sequenced. Due to an array of factors that determine the final prey-profile for each scat sample (e.g., variations in prey digestibility, time since consumption, and prey quantity and size), the data matrices were transformed to presence/absence (binary) data prior to the construction of a sample-similarity matrix using the Bray-Curtis algorithm (Bray and Curtis 1957). Significant differences between the prey-profiles of *a priori* predefined groups of samples (predator species, locations and/or seasons, where there were sufficient numbers of samples to make such comparisons) were evaluated using Permutational Multivariate Analysis of Variance (PERMANOVA), allowing for type III (partial) sums of squares, fixed effects to sum to zero for mixed terms, and exact p-values generated using unrestricted permutation of raw data (Anderson 2001). In addition, significant differences between other univariate variables (such as measures for species richness and diversity) comparing LNFS and ASL groups were evaluated using the Mann Whitney U test (the non-parametric version of the two-sample independent t-test). Groups of scat samples were considered significantly different if the p-value was <0.05. In addition, the frequency and abundance (rank-ordered) of prey OTUs were evaluated across the different seal groups using histograms. Taxonomic diversity of prey species within each scat sample was also evaluated using algorithms for taxonomic distinctness: average taxonomic distinctness (delta+) and variation in taxonomic distinctness (lambda+) (Clarke *et al.* 2001). Delta+ represents the average taxonomic distance between all pairs of prey species within each sample, and thus is a summary of average taxonomic breadth of each sample, while lambda+ reports how consistent each level of organisation within the Linnaean classification is represented (Pienkowski *et al.* 1998, Warwick and Clarke 1995). The expected delta+ values were calculated by sampling different numbers of prey OTUs (from 2 to 40 in increments of 1) from the master list of 181 OTUs, with 999 iterations. Rarefaction analysis was conducted to evaluate prey sequencing depth and subsequent coverage of prey species. Multivariate and diversity analyses were performed in PRIMER (v.7.0.11) PRIMER-E, Plymouth Marine Laboratory, UK, (Clarke *et al.* 2001). Univariate analyses were performed in Prism (v. 7.01) Graphpad Software Inc. Histograms were generated in Excel.

3.3 Results and Discussion

Assay development and validation

In line with the objectives of this work, an alternative simplified molecular-based approach for evaluating the dietary compositions of ASL, LNFS and AFS was investigated using the mitochondrial COI-5P gene region as a single “universally” applicable target. As a first step in developing this assay, “universal” COI-5P primers (mlCOIintF/jgHCO2198) previously designed for marine metazoa (Geller *et al.* 2013, Leray *et al.* 2013b) were assessed for their potential capacity to target a range of taxa which are likely to be consumed by these animals, as reported earlier (Allen and Huveneers 2005, Deagle *et al.* 2009, Gales and Pemberton 1994, Page *et al.* 2005a, Peters *et al.* 2014). To do this, the COI sequences from the three seals and 118 potential prey taxa (comprising fish, sharks/rays, cephalopods, crustacea, birds and other) were obtained from the BOLD systems database (Ratnasingham and Hebert 2007) and the corresponding primer target regions assessed *in silico* for their likelihood for amplifying the prey DNA based on the numbers of nucleotide (nt) mismatches. Within the forward (mlCOIintF) primer region, a mean total of 2 ± 1 mismatches (with a minimum of 0 and maximum of 6) were observed across all species with most mismatches being located centrally or at the 5′ end and not occurring within the last 2 bases of the 3′ region (Appendix 3.1, Table 1). Furthermore, whilst it was difficult to assess the target region of the reverse (jgHCO2198) primer (due to the lack of corresponding database sequences for this region), no mismatches were apparent for the 37 species (covering all major prey groups) where sequences were available. Given this and that the 3′ end rather than centrally located mismatches are the most detrimental to PCR amplification (Kwok *et al.* 1994), these primers appear suitable for amplification of a broad range of prey taxa. Indeed, as assessed in PCR using DNA obtained from tissue extracts of the three seals and 40 prey species (which comprised up to 4 nt mismatches in the forward primer target region), these primers could amplify all taxa except for those where poor or low quality DNA was recovered (Appendix 3.2, Figure 5). Given the broad taxonomic range of these tested prey species (representing 12 fish, 12 shark/ray, 4 cephalopod, 2 other mollusc, 4 Crustacea and 3 bird families), their amplification highlights the "universal" nature of these primers and their capacity to target relevant prey groups here in seals; a likely factor of the substantial degeneracy in the primers (i.e., 7 nt in the forward and 8 nt in the reverse), which allow base mismatching between the primers and template at specific nucleotide sites. The application of this "universal" primer set thereby simplifies earlier assays by eliminating the need for the use of multiple gene targets for capturing different prey groups (like cephalopods and sharks/rays), as conducted previously (Deagle *et al.* 2009, Deagle *et al.* 2005, Jarman *et al.* 2004, Peters *et al.* 2014, Tollit *et al.* 2009).

Key finding 1: A new molecular (metabarcoding) assay was developed for evaluating the prey composition of seals using the COI gene as a "universal" marker, simplifying earlier assays by eliminating the need for the use of multiple markers for capturing different prey groups.

As a further step in the development of this molecular (COI-5P) assay, the application of seal DNA blocking primers were also assessed for limiting the impact of naturally abundant predator DNA on the capacity to recover prey sequences from scat samples. As indicated earlier, this is important given that predator co-amplification may prevent or bias prey recovery in the absence of preventative measures (Leray *et al.* 2013b, O'Rorke *et al.* 2012, Vestheim and Jarman 2008). As such, a pooled Dual Priming Oligonucleotide (DPO) blocking primer (comprising an equal mix of ASL, LNFS and AFS species-specific blocking primers) was adapted for use with NGS (Illumina) assay procedures at an empirically determined optimum concentration of 2:1 blocker: universal forward (mlCOIintF) primer (see Methods and Appendix 3.2, Figures 1, 2 and 4). To ensure that the newly designed pooled blocking primer did not interfere with the amplification of DNA from potential prey species, the primer was subsequently evaluated in PCR using DNA extracts from the tissues of the three seal and 40 prey species. Evaluation of the PCR products from reactions performed using the pooled blocking primers modified with (+) and without (-) a C3 spacer (which respectively prevents or allows amplification to proceed), revealed that the blocking primers could substantially reduce the amplification of the seal DNA whilst having little or no influence on the amplification of the DNA from prey (Appendix 3.2, Figure 6). Thus, in line with previous reports of the successful use of DPO primers for restricting the amplification of the COI gene from other predators such as reef fish (Leray *et al.* 2013a, 2013b, Leray and Knowlton 2015, Leray *et al.* 2015), this pooled seal species-specific blocking primer offers a viable approach for the enrichment of prey taxa from scat samples.

Key finding 2: A highly specific, predator blocking primer was successfully designed and tested to reduce the impact of seal DNA on the recovery of potential prey species in scat samples.

Deep-sequencing of scat samples

In total, 511 scat samples were collected and extracted for use with the new molecular (metabarcoding) assay. After amplification, 169 samples comprised enough high quality amplified DNA to sequence, and after sequencing on the Illumina MiSeq, produced ~11 million high-quality reads for analysis. From the 2014/15 collection period, where samples were preserved in ethanol (not in RNAlater), only 28% of the samples (i.e. 130/465 total samples; comprising 29/148 ASL, 94/292 LNFS, and 7/25 AFS) could be amplified to produce Illumina MiSeq libraries for sequencing (Table 3.9). However, during the 2016 collection period, when samples were preserved in RNAlater (as a preferred storage medium), 85% of the samples (i.e. 39/46 total samples; comprising 30/35 LNFS and 9/11 ASL) could be amplified to produce Illumina MiSeq libraries for sequencing (Table 3.10). Whilst this finding, in part, reflects the generally poor, highly degraded nature of the prey DNA in these types of samples (Deagle *et al.* 2006, Kohn and Wayne

1997) and raises questions about the capacity of ethanol in comparison to RNAlater to prevent their further degradation prior to analysis, it is likely that many factors will determine the overall quantity/quality of prey DNA. These include, among others, the length of time between collection and defecation; fasting period (contributing to higher amounts of predator and microbial DNA); prey-specific biases in DNA survival in the digestive tract; animal age/developmental stage; seasonality and environmental factors (e.g., humidity, temperature and sun exposure); homogenisation/dispersal efficiency of the scat material within the preservative; the occurrence and extent of protectant evaporation; and sample storage/transport conditions (e.g., whether the samples can be maintained at 4°C or lower prior to processing) (Casper *et al.* 2007, Deagle and Tollit 2007, Deagle *et al.* 2005, Hale *et al.* 2016, McInnes *et al.* 2017, Panasci *et al.* 2011, Reddy *et al.* 2012). Despite this, the findings here clearly indicate that the use of RNAlater over ethanol as a preservativegreatly enhances the ability to recover PCR amplifiable DNA from these samples, and it has been recommended elsewhere (Vlčková *et al.* 2012). Furthermore, when used in conjunction with complementary molecular (qPCR)-based methods designed to quantify the amount of damaged/fragmented DNA in a sample (Deagle *et al.* 2006), pre-screening of appropriately preservativesamples could be used to optimise amplification success.

Key finding 3: Recovery of prey DNA is highly dependent on the preservation of scat samples at collection, and RNAlater is highly recommended.

Following DNA-verification of the seal COI reads within the 169 sequenced scat samples (i.e. 130 from 2014/15 and 39 from 2016, Tables 3.7-10), a total of 21 (i.e. 11 from 2014/15 and 10 from 2016) were re-assigned to a different species than was originally determined via visual assessment (Tables 3.9 and 10). Each sequenced scat sample comprised a mean of ~42,000 reads for the 2014/15 samples and ~152,000 reads for the 2016 samples (Tables 3.5 and 3.6), with each read assigned as belonging to “Seal”, “Prey” (i.e. Fish, Cephalopods, Crustacea, Sharks/Rays, Birds or Other likely prey), or “Other (non-prey)” taxa. The proportion between seal and prey reads varied greatly between samples, with seal reads the predominant component in most samples (mean = 63.9-90.8%) and accounting for as much as 99.9% of the total sequences in a couple of cases (Tables 3.9 and 3.10). Whilst this may appear, at first, to indicate a failure of the blocking primers to prevent amplification of the seal DNA in these samples, PCR validation of the pooled blocking primers showed a consistent and substantial reduction in the amount of predator target (as indicated by a decreased amplicon signal for the seal DNA samples, see Appendix 3.2, Figures 2, 4 and 6). Thus, failure of the predator blocking primers does not appear likely. Instead, the abundance of predator:prey reads is likely to be due to various other biological factors associated with the samples themselves. Indeed, as indicated above, factors such as variation in prey digestibility, animal age and/or the presence of fasting scats are likely major drivers leading to the absence or substantial reduction in prey DNA at the time of defecation (Deagle and Tollit 2007, McInnes *et al.* 2017), thus also contributing to the amount and quality of template (prey DNA) available for PCR, where already highly degraded and proportionally very low prey templates may give way to the further predominance of predator DNA, which is generally more intact and in higher quantity (Deagle *et al.* 2006, Kohn and Wayne 1997). In this regard, it has been recommended that fresh samples from non-fasting adult animals be collected to optimise prey recovery (McInnes *et al.* 2017).

Key finding 4: The newly developed molecular (metabarcoding) assay can also be used to definitively identify the seal species from which each scat is derived, thereby removing the bias and guess work from visual assessments.

In addition, whilst the overall amount of other (non-prey) reads was generally very low in the sequenced libraries (mean = 0.5-3.9%) (Tables 3.9 and 3.10) and may reflect the co-amplification of accidental or secondary prey species or host microbial/parasite DNA from these samples (Jarman *et al*. 2004, McInnes *et al*. 2017). These reads may also indicate the presence of contaminating DNA, which could result from the sample collector/s themselves, from disturbance by insects or other animals, or from the surfaces on which the material was collected (McInnes *et al.* 2017). For example, DNA signatures associated with obscure bird species in this work (i.e., parrots) were detected in the scat of a single animal and may reflect cross-contamination from co-inhabiting birds. Thus, the careful collection of fresh material from surfaces with minimal contamination (e.g. rock) has also been recommended in this regard (McInnes *et al.* 2017).

Key finding 5: Amount of predator (seal) DNA in scat samples may interfere with the recovery of prey sequences in the molecular assays, and the collection of fresh samples from non-fasting animals and from minimally contaminated sites is highly recommended.

Though predator (seal) DNA sequences dominated the libraries, a reasonable proportion of prey sequences were also recovered which could be used for downstream analysis. On average, ~9.3% prey reads were obtained for samples from the 2014/15 collection period and 26.7% from those obtained in 2016, with ~39% (50/130) of the samples from 2014/15 and ~74% (29/39) from 2016 containing >5% prey sequence reads (Tables 3.9 and 3.10). However, a further 28% (37/130) of the samples from 2014/15 and 11% (4/39) from 2016 comprised a minimum of 1-5% prey reads which could still be analysed. Like that observed for the seal reads, sequences from prey were also highly variable, and could contribute to as much as 94.4% of the total reads from some samples. As discussed above and reported elsewhere (Deagle and Tollit 2007, McInnes *et al.* 2017), this is likely dependent on a range of overarching biological factors surrounding feeding behaviour, prey digestibility and sample integrity which lead to the preferential abundance and quality of prey DNA available for PCR amplification. Though not any less important, it is the ability to detect the likely array of prey taxa consumed by these animals within the remaining reads, however, which is of principal concern. To this end, rarefaction curves were used to inspect (retrospectively) prey sequencing depth within each sample, thereby allowing inferences to be made regarding the adequacies of read-depth for such sample types (Appendix 3.2, Figure 7). Overall, between 1 and 27 prey species were detected within each of the 165 scat samples (4 scat samples were removed from the analysis at this point because they provided no confirmed prey reads). In general, the rarefaction curves showed an early plateau within 1000 reads, whereby the majority of prey species were captured, with few new prey species (OTUs) being detected with increased read-depth beyond 10-15,000 reads. However, it should be noted that to achieve a prey read-depth of a few thousand reads, each sample still needs to be sampled much more deeply to account for the frequent predominance of predator reads. Nonetheless, a minimum of 1-5% prey reads is sufficient to capture the likely array of prey targeted by these animals and highlights the capacity and sensitivity of the newly developed NGS metabarcoding (COI-5P) approach for the dietary compositional analysis of scat samples.

Key finding 6: The amount of prey DNA in scat samples may vary considerably and is likely influenced by a range of biological factors.

Key finding 7: Sequencing depth of a few thousand reads is sufficient to capture the likely diversity of prey species despite the predominance of seal reads in the scat samples; this validates the approach as a sensitive tool for evaluating the dietary compositions of these animals.

Table 3.9. Summary of the numbers of scat samples extracted and sequenced using the COI gene metabarcoding assay from samples collected in 2014-2015 from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS). The number of DNA verified samples (as being target or non-target seal species) and the percentage of sequences assigned to seals, prey and other (non-prey) taxa is given alongside the total number of samples comprising >5% and <1% prey sequence reads.

Species	Geographic location ID	Geographic location name	Site ID	Site name	Collection Date	Season	No. samples collected/ extracted	No. samples sequenced[*]	No. DNA verified samples target seal species[†]	No. DNA verified samples non-target seal species[‡]	% Sequence reads[¶]: Seals		Prey		Other		Total samples with >5% prey reads	Total samples with <1% prey reads
											Min-Max	Mean ±SD	Min-Max	Mean ±SD	Min-Max	Mean ±SD		
ASL	G2	Nuyts Archipelago	S2	Purdie	Jul-14	Autumn/Winter	4	0	-	-	-	-	-	-	-	-	-	-
	G2	Nuyts Archipelago	S3	Lounds	Jul-14	Autumn/Winter	4	0	-	-	-	-	-	-	-	-	-	-
	G2	Nuyts Archipelago	S4	Liliput	Jul-14	Autumn/Winter	4	2	2	-	2.7-40.6	-	0.3-52.5	-	6.9-97.1	-	1/2	1/2
	G2	Nuyts Archipelago	S5	Blefuscu	Jul-14	Autumn/Winter	4	1	1	-	58.8	-	41.1	-	0.1	-	1/1	0
	G3	Chain of Bays	S6	Olive	Jul-14	Autumn/Winter	7	1	1	-	42.6	-	55.5	-	1.8	-	1/1	0
	G3	Chain of Bays	S6	Olive	Dec-14	Spring/Summer	13	0	-	-	-	-	-	-	-	-	-	-
	G4	South-west Eyre	S7	Rocky North	Feb-14	Spring/Summer	3	0	-	-	-	-	-	-	-	-	-	-
	G4	South-west Eyre	S7	Rocky North	Jul-14	Autumn/Winter	17	5	2	3 (LNFS)	92.1-98.6	-	1.1-7.0	4.1 ± 2.9	0.0-0.3	0.2 ± 0.2	1/3[§]	0
	G5	Southern Spencer Gulf	S8	Albatross	Mar-14	Autumn/Winter	2	0	-	-	-	-	-	-	-	-	-	-
	G5	Southern Spencer Gulf	S8	Albatross	Jul-14	Autumn/Winter	18	2	2	-	41.2-99.0	-	0.5-58.4	-	0.3-0.5	-	1/2	1/2
	G6	Kangaroo Island	S9	South Pages	Jun-14	Autumn/Winter	6	4	4	-	82.1-99.7	92.9 ± 8.5	0.2-16.7	6.5 ± 7.9	0.1-1.2	0.6 ± 0.6	2/4	2/4
	G6	Kangaroo Island	S10	North Pages	Jun-14	Autumn/Winter	13	3	3	-	98.2-99.8	99.2 ± 0.9	0.0-1.8	0.6 ± 1.0	0.0-0.2	0.1 ± 0.1	0/3	2/3
	G5	Southern Spencer Gulf	S11	Lewis Island	Feb-14	Spring/Summer	13	1	1	-	78.1	-	21.8	-	0.1	-	1/1	0
	G5	Southern Spencer Gulf	S11	Lewis Island	Jul-14	Autumn/Winter	26	9	9	-	63.5-97.0	86.8 ± 10.9	2.6-35.3	12.5 ± 10.4	0.0-3.7	0.7 ± 1.2	7/9	0
	G5	Southern Spencer Gulf	S12	Liguanea	Feb-14	Spring/Summer	10	1	1 (2)	-	82.3-97.4	-	0.2-17.6	-	0.1-2.4	-	1/2[§]	1/2[§]
TOTAL (ASL)							**148**	**29**	**26** (32)	**3** (LNFS)	**2.7-99.8**	**81.5 ± 23.0**	**0.0-58.4**	**14.5 ± 17.5**	**0.0-97.1**	**3.9 ± 17.1**	**19/32**[§]	**8/32**[§]
LNFS	G6	Kangaroo Island	S13	Ballast Head	Jul-Sep-14	Winter/Spring	5	1	1	-	86.6	-	13.0	-	0.5	-	1/1	0
	G6	Kangaroo Island	S14	Cape du Couedic	Jul-Sep-14	Winter/Spring	3	2	1	1 (AFS)	97.4	-	2.6	-	0.02	-	1/1	0
	G6	Kangaroo Island	S15	Cape Gantheaume	Jul-Sep-14	Winter/Spring	10	7	7	-	57.6-99.7	87.4 ± 15.0	0.3-19.9	6.3 ± 7.6	0.0-41.7	6.3 ± 15.6	3/7	3/7
	G6	Kangaroo Island	S16	Cape Kersaint	Jul-Sep-14	Winter/Spring	6	2	2	-	97.8-98.5	-	1.1-2.0	-	0.2-0.3	-	0/2	0
	G6	Kangaroo Island	S17	Hummocky	Jul-Sep-14	Winter/Spring	11	5	4	1 (ASL)	95.7-99.6	97.2 ± 1.8	0.4-3.4	1.9 ± 1.2	0.0-2.2	0.9 ± 1.0	0/4	1/4
	G6	Kangaroo Island	S18	Kingscote	Jul-Sep-14	Winter/Spring	9	6	6	-	91.4-99.2	97.1 ± 2.9	0.7-8.2	2.8 ± 2.7	0.0-0.5	0.1 ± 0.2	1/6	1/6
	G6	Kangaroo Island	S19	Penneshaw	Jul-Sep-14	Winter/Spring	11	4	4	-	91.5-99.8	96.8 ± 3.7	0.1-6.6	2.6 ± 2.8	0.0-2.0	0.6 ± 0.9	1/4	1/4
	G7	Fleurieu peninsula	S20	Seal/Granite Island	Jul-Sep-14	Winter/Spring	12	4	4	-	88.9-99.6	96.0 ± 4.9	0.4-11.0	4.0 ± 4.9	0.0-0.1	0.03 ± 0.02	1/4	1/4
	G7	Fleurieu peninsula	S21	West Island	Jul-Sep-14	Winter/Spring	10	5	5	-	95.4-99.9	98.4 ± 1.7	0.1-4.2	1.5 ± 1.6	0.0-0.4	0.09 ± 0.6	0/5	2/5
	G8	Spencer Gulf	S22	Donington Rocks	Jul-14	Autumn/Winter	25	4	2	2 (ASL)	89.4-95.4	-	4.6-10.6	-	0.01-0.02	-	1/2	0
	G8	Spencer Gulf	S23	Wedge North	Jul-14	Autumn/Winter	25	4	4	-	71.7-94.5	85.1 ± 10.7	5.3-27.8	14.7 ± 10.6	0.0-0.5	0.3 ± 0.2	4/4	0
	G4	South west Eyre	S7	Rocky North	Jul-14	Autumn/Winter	25	1	0 (3)	1 (ASL)	96.3-98.8	97.8 ± 1.3	0.0-3.6	1.4 ± 1.9	0.0-1.2	0.8 ± 0.7	0/3[§]	2/3[§]
	G3	Chain of Bays	S24	West Waldegrave	Jul-14	Autumn/Winter	25	0	-	-	-	-	-	-	-	-	-	-
	G9	Gulf St Vincent	S25	Outer Harbour	Sep-15	Spring/Summer	25	15	14	1 (ASL)	1.0-98.9	77.6 ± 28.5	0.2-42.1	11.4 ± 13.6	0.0-98.6	11.0 ± 29.0	8/14	2/14
	G10	Coorong	S26	Coorong/Tauwitcheree Barrage	Aug-15	Autumn/Winter	17	0	-	-	-	-	-	-	-	-	-	-
	G10	Coorong	S26	Coorong/Tauwitcheree Barrage	Sep-15	Spring/Summer	22	1	1	-	99.9	-	0.0	-	0.1	-	0/1	1/1
	G5	Southern Spencer Gulf	S12	Liguanea	Feb-14	Spring/Summer	23	15	14	1 (ASL)	89.1-99.9	97.6 ± 3.1	0.0-10.5	2.0 ± 3.1	0.0-2.0	0.4 ± 0.5	2/14	8/14
	G5	Southern Spencer Gulf	S12	Liguanea	Jul-14	Autumn/Winter	28	18	18	-	0.5-99.9	87.1 ± 24.3	0.0-45.9	6.2 ± 11.0	0.0-99.5	6.7 ± 23.5	6/18	8/18
TOTAL (LNFS)							**292**	**94**	**87** (91)	**7** (ASL)	**0.5-99.9**	**90.8 ± 17.5**	**0.0-45.9**	**5.5 ± 8.7**	**0.0-99.5**	**3.7 ± 16.1**	**28/91**[§]	**31/91**[§]
AFS	G6	Kangaroo Island	S27	North Casuarina	Jan-14	Spring/Summer	25	7	6 (7)	1 (LNFS)	13.5-99.9	73.3 ± 41.3	0.0-86.5	23.4 ± 41.1	0.0-1.3	0.3 ± 0.5	3/7[§]	4/7[§]
TOTAL (AFS)							**25**	**7**	**6** (7)	**1** (LNFS)	**7.6-99.9**	**63.9 ± 45.1**	**0.0-92.2**	**35.8 ± 45.0**	**0.0-1.3**	**0.3 ± 0.4**	**3/7**[§]	**4/7**[§]
TOTAL (all samples)							**465**	**130**	**119** (130)	**11** (4 LNFS, 7 ASL)	**0.5-99.9**	**87.1 ± 21.9**	**0.0-92.2**[§]	**9.3 ± 16.3**	**0.0-99.5**	**3.6 ± 15.5**	**50/130**[§]	**43/130**[§]

[*] Of the 130 sequenced samples, 32 were verified as ASL, 91 as LNFS and 7 as AFS based on positive identification of the seal COI gene sequences from each of the samples.

[†] Values in parentheses denote the total number of DNA verified samples, including those from other seals which were visually misidentified at collection.

[‡] DNA verified non-target seal species indicated in parentheses.

[#] Values derived from a total of 32 ASL, 91 LNFS and 7 AFS DNA verified samples; Mean values (± SD) are provided where n ≥ 3.

[§] Values include those DNA verified samples which were visually misidentified as a different seal species at collection.

[¶] As assigned to seals, likely prey and other (non-prey) taxa based on interrogation of the COI gene sequences against the BOLD database (http://boldsystems.org/).

Table 3.10. Summary of the numbers of scat samples extracted and sequenced using the COI gene metabarcoding assay from samples collected in 2016 from Long-nosed Fur Seal (LNFS) and Australian Sea Lion (ASL). The number of DNA verified samples (as being target or non-target seal species) and the percentage of sequences assigned to seals, prey and other (non-prey) taxa is given alongside the total number of samples comprising >5% and <1% prey sequence reads.

Species	Geographic location ID	Geographic location name	Site ID	Site name	Collection Date	Season	No. samples collected/ extracted	No. samples sequenced[*]	No. DNA verified samples target seal species[†]	No. DNA verified samples non-target seal species[‡]	% Sequence reads[¶]:						Total samples with >5% prey reads	Total samples with <1% prey reads
											Seals		Prey		Other			
											Min-Max	Mean ±SD	Min-Max	Mean ±SD	Min-Max	Mean ±SD		
LNFS	G8	Spencer Gulf	S22	Donington Rocks	Jul-16	Autumn/Winter	35	30	20	10 (ASL)	5.5-99.9	75.6 ± 27.3	0.0-94.4	24.0 ± 27.2	0.0-1.5	0.4 ± 0.4	12/20	6/20
ASL	G8	Spencer Gulf	S22	Donington Rocks	Jul-16	Autumn/Winter	11	9	9	0	10.6-98.5	69.9 ± 24.2	1.5-89.4	29.5 ± 24.0	0.0-3.5	0.6 ± 0.8	17/19	0/19
TOTAL							**46**	**39**	**29** (39)	**10** (ASL)	**5.5-99.9**	**72.8 ± 25.7**	**0.0-94.4**[§]	**26.7 ± 25.5**	**0.0-3.5**	**0.5 ± 0.7**	**29/39**	**6/39**

[*] Of the 39 sequenced samples, 20 were verified as LNFS and 19 as (ASL) based on positive identification of the seal COI gene sequences from each of the samples.

[†] Values in parentheses denote the total number of DNA verified samples, including those from other seals which were visually misidentified at collection.

[‡] DNA verified non-target seal species indicated in parentheses.

[#] Values derived from a total of 20 LNFS and 19 ASL DNA verified samples.

[§] Values include those DNA verified samples which were visually misidentified as a different seal species at collection.

[¶] As assigned to seals, likely prey and other (non-prey) taxa based on interrogation of the COI gene sequences against the BOLD database (http://boldsystems.org/).

Important considerations of the biological data obtained from scat samples

From these 165 scat samples, a total of 181 prey species were positively identified (Table 3.11), establishing a reference database of molecular (DNA barcode) signatures from prey species consumed by ASL, LNFS and AFS in the South Australian region. Most prey OTUs (~71%) could be identified to the species level (i.e., at a sequence identity of >99% to reference sequences within the BOLD systems database); with 89% (108/121) of the fish, 85% (11/13) of the sharks/rays and 83% (5/6) of the bird OTUs assigned a species name. In contrast, only 44% (11/25) of the cephalopods and 29% (4/14) of the Crustacea OTUs could be resolved to the species level. Whilst this highlights the utility of the approach for identifying sequences with a high level of certainty from the majority of prey taxa, it also reflects the under representation of species from specific prey groups like cephalopods and Crustacea in the public sequence repositories, a limitation reported elsewhere (Leray and Knowlton 2015). To this end, the ability of this molecular approach to identify prey to a species level could be increased by the provision of COI gene barcodes from vouchered specimens from these prey groups and follows the international efforts of the “Barcode of Life” project for expediting molecular ecological studies (Costa and Carvalho 2010). Nevertheless, this approach represents a significant advance over traditional procedures reliant on the morphological identification of hard-parts, and has identified a broader array of taxa from a greater range of prey groups than has been previously reported for these seal species. That said, it can also not be excluded that the species identified are not secondary prey items. For example, whilst it is evident from this work that there is an association between LNFS with Australian Sardines and Arrow Squid (see below), Australian Sardines are also a primary component of the prey of these squid, along with juvenile Barracouta, various Crustacea and other cephalopods (Machida 1983, O'Sullivan and Cullen 1983). Therefore, whilst these deep-sequencing approaches are powerful tools for detailing the prey composition of predators like seals, they also introduce a degree of ambiguity. In this regard, the interpretation of prey species requires careful consideration in line with the broader feeding ecology of these animals and the associated trophodynamic linkages within these systems.

Key finding 8: A reference database of 181 molecular (DNA-) identified seal prey species was established for the South Australian region, identifying a broader array of taxa from a greater range of prey groups than previously reported.

With this molecular approach, sequence data obtained from these samples can be analysed to yield biologically informative insights into the prey compositions of seals. While the count of prey sequences indicates the relative abundance of each prey species within each of the scat samples at the time of sequencing, several considerations are warranted before assuming that the most abundant prey species in the scat sample was the most numerically abundant prey species in the seal diet. In particular, variations in prey digestibility, time since consumption and prey quantity and size have been acknowledged as key determinants for the limitations of using relative prey reads as an explicit measure of numerical abundance in the diet. Several reports have already cautioned against attempting to “glean” insights from the relative differences in the proportions of species DNA sequences that result from amplicon sequencing approaches (Deagle *et al.* 2013, Thomas *et al.* 2015, Zhou *et al.* 2011). Indeed, this recommendation holds here. Though a variety of methods have been proposed to correct for such biases and include tissue/relative correction factors (T/RCFs) which are empirically derived values obtained from the sequencing of prey libraries comprising mixtures of prey tissues (Deagle and Tollit 2007, Thomas *et al.* 2015, Thomas *et al.* 2014), these methods have their own inherent constraints. Alternatively, prey sequence counts can still provide biological informative insights and inferences about the numerical abundance of prey in the diet without relying solely on their relative abundance. One approach is simply to transform the data matrix so as to not rely so heavily on the prey abundances themselves, but rather consider the prey species in rank-order or as a presence/absence data matrix (binary data), and powerful statistical analyses can still be achieved without compromising its significance. Also, from deep-sequencing hundreds of samples, the frequency of prey species within each seal population derived from presence/absence data becomes a principal advantage of the data (especially for those prey taxa where hard-parts can not be easily detected or identified). To this end, while some data in this report presents the relative abundance of prey reads for technical reasons or as examples, the statistical analyses and biological interpretations have been made from presence/absence data only.

Table 3.11. Molecular (COI gene) metabarcoding identifications of prey taxa and their prevalence from scat samples collected in 2014-2015 from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS), and in 2016 from LNFS and ASL. Prey taxa are listed alphabetically in groups comprising the most to least number of species, with the corresponding operational taxonomic unit (OTU) number, % sequence similarity and BOLD ID given for each alongside the relevant fisheries sectors associated with all key commercial species. Prevalence is denoted as the number of scat samples with positive detections (from the total number of samples collected from each seal species), with the % prevalence denoted by the graded shading of cells from >50% to <10%. The top 10 most prevalent taxa in the 2014-2015 samples and the top 3 most prevalent taxa in 2016 samples (based on rank order) are marked with asterisks.

					§**Prevalence** (/total samples):				
		BOLD assignments‡			**2014-2015 samples**			**2016 samples**	
†**PREY TAXA** (Total = 181 species) (2014/15 = 166 spp; 2016 = 78 spp.)	**OTU**	**Similarity**	**ID**	**Fishery**$^{\#}$	**ASL** (32)	**LNFS** (91)	**AFS** (7)	**LNFS** (20)	**ASL** (19)
FISH (Total = 121 species)						(111 species)		(53 species)	
Tasselled Anglerfish, *Rhycherus filamentosus* (Antennariidae)	27	1	ANGBF538-12	-	3	-	-	-	1
Southern Cardinalfish, *Vincentia conspersa* (Apogonidae)	203	1	Early-release	-	1	1	-	-	4
Western Smooth Boxfish, *Anoplocapros amygdaloides* (Aracanidae)	19	1	Early-release	-	1	2	-	-	-
Australian Herring, *Arripis georgianus* (Arripidae)	30	1	FOAC344-05	MSF, REC	-	12*	-	1	-
Australian Salmon, *Arripis truttaceus* (Arripidae)	70	1	BW-A1089	MSF, REC, CBF	1	7	-	1	-
Unclassified Hardyhead species, *Atherinason* sp. (Atherinidae)	54	0.968	Private	-	-	5	-	-	-
Pikehead Hardyhead, *Kestratherina esox* (Atherinidae)	68	1	Early-release	-	-	1	-	1	-
Sergeant Baker, *Latropiscis purpurissatus* (Aulopidae)	34	0.9968	Early-release	-	2	2	1	-	1
Bight Redfish, *Centroberyx gerrardi* (Berycidae)	244	1	Private	GABTF, REC, CBF	-	2	1	-	-
Swallowtail, *Centroberyx lineatus* (Berycidae)	98	1	Private	REC, CBF	-	13*	2	-	-
Mueller's Flounder, *Arnoglossus muelleri* (Bothidae)	346	1	Early-release	-	1	-	-	-	-
Spotted Stinkfish, *Repomucenus calcaratus* (Callionymidae)	108	1	Early-release	-	1	-	-	-	3
Common Stinkfish, *Synchiropus calauropomus* (Callionymidae)	252	0.9968	GBGCA9115-15	-	2	1	-	-	-
Silver Trevally, *Pseudocaranx dentex* (Carangidae)	187	1	FOAC429-05	MSF, REC, CBF	-	3	-	-	-
Skipjack Trevally, *Pseudocaranx wrighti* (Carangidae)	5	1	FOAC424-05	-	1	6	-	4	9
Yellowtail Kingfish, *Seriola lalandi* (Carangidae)	48	1	TZSAL034-04	REC	-	-	-	10*	9
Common Jack Mackerel, *Trachurus declivis* (Carangidae)	616	0.9869	GBGCA9161-15	-	-	8	3	9*	-
Yellowtail Scad, *Trachurus novaezelandiae* (Carangidae)	4	1	GBGC4148-08	-	1	13*	3	10*	2
Blue Warehou, *Seriolella brama* (Centrolophidae)	323	1	FOAD467-05	CTF	-	4	-	-	-
Coves' Horned Anglerfish, *Cryptopsaras couesii* (Ceratiidae)	528	1	Early-release	-	-	-	1	-	-
Jackass Morwong, *Nemadactylus macropterus* (Cheilodactylidae)	357	1	Early-release	-	-	-	1	-	-
Southern Kelpfish, *Chironemus georgianus* (Chironemidae)	556	0.9968	Early-release	-	-	-	-	-	1
Southern Crested Weedfish, *Cristiceps australis* (Clinidae)	194	1	Early-release	-	1	-	-	-	1
Rosy Weedfish, *Heteroclinus roseus* (Clinidae)	522	0.9967	Early-release	-	1	-	-	-	-
Sandy Sprat, *Hyperlophus vittatus* (Clupeidae)	221	0.9967	Early-release	-	-	3	-	-	-
Dotted Gizzard Shad, *Konosirus punctatus* (Clupeidae)$^{\Delta}$	36	1	ANGBF2236-12	-	-	-	-	5	-
Bony Bream, *Nematalosa erebi* (Clupeidae)	610	0.9968	Private	REC	-	1	-	-	-
Australian Pilchard (Sardine), *Sardinops sagax* (Clupeidae)	297	1	Early-release	SASF	1	8	-	4	-
Unclassified Sprat species, *Spratelloides* sp. (Clupeidae)	220	0.9871	Private	-	-	1	-	-	-
Unclassified Conger Eel species, *Gnathophis* sp. (Congridae)	50	0.9583	Private	-	6	1	-	-	4
Unclassified Conger Eel species, *Gnathophis* sp. (Congridae)	635	0.9935	Early-release	-	1	-	-	-	-

Table 3.11. Continued

					[§]**Prevalence** (/total samples):				
		BOLD assignments[‡]			**2014-2015 samples**			**2016 samples**	
[†]**PREY TAXA** (Total = 181 species) (2014/15 = 166 spp; 2016 = 78 spp.)	**OTU**	**Similarity**	**ID**	**Fishery**[#]	**ASL** (32)	**LNFS** (91)	**AFS** (7)	**LNFS** (20)	**ASL** (19)
FISH (Total = 121 species) cont'd					(111 species) cont'd			(53 species) cont'd	
Southern Tongue Sole, *Cynoglossus broadhursti* (Cynoglossidae)	97	1	Private	-	3	1	-	-	2
Asian Carp, *Cyprinus carpio* (Cyprinidae)	498	1	BCFB775-06	LC, REC	-	2	-	-	-
Longfin Pike, *Dinolestes lewini* (Dinolestidae)	451	1	Early-release	-	2	2	-	-	-
Australian Burrfish, *Allomycterus pilatus* (Diodontidae)	255	0.9936	GBGCA5227-13	-	1	1	1	-	-
Maray/Herring, *Etrumeus teres* (Dussumieriidae)	93	0.984	Private	-	1	6	-	-	-
Redbait, *Emmelichthys nitidus* (Emmelichthyidae)	58	1	ANGBF7785-12	-	-	-	1	-	-
Bigscale Rubyfish, *Plagiogeneion macrolepis* (Emmelichthyidae)	7	1	FOAC354-05	-	1	3	2	-	-
Australian Anchovy, *Engraulis australis* (Engraulidae)	17	1	ANGBF1281-12	-	-	10	-	2	1
Old Wife, *Enoplosus armatus* (Enoplosidae)	106	1	Early-release	-	1	-	-	-	-
Slender Escolar, *Paradiplospinus gracilis* (Gempylidae)	576	0.9902	Early-release	-	-	1	-	-	-
Gemfish, *Rexea solandri* (Gempylidae)	232	1	Early-release	-	-	1	1	-	-
Barracouta, *Thyrsites atun* (Gempylidae)	24	1	GBGC6972-09	-	2	26*	-	-	-
Western Silverbelly, *Parequula elongata* (Gerreidae)	132	1	Early-release	-	1	-	-	-	-
Silverbelly, *Parequula melbournensis* (Gerreidae)	18	1	Early-release	-	5	5	-	-	10
Sculptured Goby, *Callogobius mucosus* (Gobiidae)	192	1	Early-release	-	1	-	-	-	3
Southern Garfish, *Hyporhamphus melanochir* (Hemiramphidae)	3	1	FOAD333-05	MSF, REC, CBF	5	36*	1	1	-
Snakeskin Wrasse, *Eupetrichthys angustipes* (Labridae)	153	1	Early-release	-	2	-	-	-	-
Braun's Wrasse, *Pictilabrus laticlavius* (Labridae)	228	1	Early-release	-	-	-	-	1	1
Rosy Wrasse, *Pseudolabrus rubicundus* (Labridae)	447	0.9936	Private	-	-	1	-	-	-
Bridled Leatherjacket, *Acanthaluteres spilomelanurus* (Monacanthidae)	66	0.9967	Early-release	MSF	4	1	-	1	9
Toothbrush Leatherjacket, *Acanthaluteres vittiger* (Monacanthidae)	26	1	Early-release	MSF	17*	8	-	1	6
Spinytail Leatherjacket, *Acanthaluteres brownii* (Monacanthidae)	86	1	Early-release	MSF	3	-	-	1	-
Southern Pygmy Leatherjacket, *Brachaluteres jacksonianus* (Monacanthidae)	209	1	Early-release	MSF	1	-	-	-	3
Gunn's Leatherjacket, *Eubalichthys gunnii* (Monacanthidae)	29	0.9968	Private	MSF	2	1	-	-	2
Mosaic Leatherjacket, *Eubalichthys mosaicus* (Monacanthidae)	159	1	GBGCA4861-13	MSF	2	1	-	-	3
Fourspine Leatherjacket, *Eubalichthys quadrispinis* (Monacanthidae)	613	0.9935	Private	MSF	1	-	-	-	-
Brownstriped leatherjacket, *Meuschenia australis* (Monacanthidae)	184	0.9451	Early-release	MSF	1	-	-	-	-
Sixspine leatherjacket, *Meuschenia freycineti* (Monacanthidae)	122	1	Early-release	MSF	3	-	-	-	1
Velvet leatherjacket, *Meuschenia scaber* (Monacanthidae)	126	1	Early-release	MSF	3	1	1	-	-
Ocean Jacket, *Nelusetta ayraud* (Monacanthidae)	43	1	GBGCA4855-13	MSF	1	5	1	-	1
Rough Leatherjacket, *Scobinichthys granulatus* (Monacanthidae)	82	1	Early-release	MSF	9*	-	-	-	-
Degens Leatherjacket, *Tetraodontiformes degeni* (Monacanthidae)	13	1	Early-release	MSF	14*	14*	-	-	12*
Southern Rock Cod, *Pseudophycis bachus* (Moridae)	379	1	Private	-	-	1	-	-	-
Bearded Cod, *Pseudophycis barbata* (Moridae)	324	1	Private	-	-	1	-	-	-
Unclassified Cod species (Moridae)	95	0.9216	Early-release	-	2	2	-	-	3
Coorong Mullet/Yelloweye Mullet, *Aldrichetta forsteri* (Mugilidae)	148	1	GBGCA10935-15	MSF, REC	-	1	-	-	-
Red Mullet, *Upeneichthys vlamingii* (Mullidae)	16	1	FOA727-04	-	19*	8	-	2	12*

Table 3.11. Continued

					§**Prevalence** (/total samples):				
		BOLD assignments‡			**2014-2015 samples**			**2016 samples**	
†**PREY TAXA** (Total = 181 species) (2014/15 = 166 spp; 2016 = 78 spp.)	**OTU**	**Similarity**	**ID**	**Fishery#**	**ASL** (32)	**LNFS** (91)	**AFS** (7)	**LNFS** (20)	**ASL** (19)
FISH (Total = 121 species) cont'd					(111 species) cont'd			(53 species) cont'd	
Hector's Lanternfish, *Lampanyctodes hectoris* (Myctophidae)	475	0.9968	Private	-	-	1	-	-	-
Bright Lanternfish, *Myctophum phengodes* (Myctophidae)	334	1	GBGCA11147-15	-	-	2	-	-	-
Barnard's Lanternfish, *Symbolophorus barnardi* (Myctophidae)	492	0.9968	Early-release	-	-	3	-	-	-
Blue Cubehead, *Cubiceps caeruleus* (Nomeidae)	127	1	DSFSG832-12	-	-	4	-	-	-
Blackring Waryfish, *Scopelosaurus meadi* (Notosudidae)	468	0.9935	Early-release	-	-	1	-	-	-
Unclassified Waryfish species (Notosudidae)	298	0.9385	Early-release	-	-	1	-	-	-
Little Weed Whiting, *Neoodax balteatus* (Odacidae)	378	1	Early-release	-	1	-	-	1	-
Longray Weed Whiting, *Siphonognathus radiatus* (Odacidae)	37	1	Early-release	-	1	1	-	-	-
Shorthead Worm Eel, *Scolecenchelys breviceps* (Ophichthidae)	23	1	Early-release	-	6	11*	-	2	5
Rock Ling, *Genypterus tigerinus* (Ophidiidae)	543	1	Early-release	-	1	-	-	-	-
Smalltooth Flounder, *Pseudorhombus jenynsii* (Paralichthyidae)	518	1	Early-release	-	1	-	-	-	1
Slender Bullseye, *Parapriacanthus elongatus* (Pempheridae)	63	1	Early-release	-	-	11*	-	1	1
Bigscale Bullseye, *Pempheris multiradiata* (Pempheridae)	59	1	Early-release	-	2	2	-	-	-
Short Boarfish, *Parazanclistius hutchinsi* (Pentacerotidae)	527	0.9934	Early-release	-	-	2	-	-	-
Longsnout Boarfish, *Pentaceropsis recurvirostris* (Pentacerotidae)	222	0.9968	FOA766-04	-	1	-	-	-	-
Murray-Darling Golden Perch, *Macquaria ambigua* (Percichthyidae)	67	1	FOA547-04	LC, REC	-	1	-	-	-
Wavy Grubfish, *Parapercis haackei* (Pinguipedidae)	628	0.9967	Early-release	-	1	-	-	-	-
Southern Sand Flathead, *Platycephalus bassensis* (Platycephalidae)	61	1	FOA500-04	REC	12*	1	-	-	4
Long-spine Flathead, *Platycephalus longispinis* (Platycephalidae)	96	1	FOA531-04	REC	2	-	-	-	-
Southern Bluespotted Flathead, *Platycephalus speculator* (Platycephalidae)	540	1	FOA545-04	-	-	-	-	-	1
Rock Flathead, *Thysanophrys cirronasa* (Platycephalidae)	53	0.9968	FMVIC308-08	-	3	-	-	-	1
Greenback Flounder, *Rhombosolea tapirina* (Pleuronectidae)	371	1	FOAD544-05	REC	-	1	-	-	-
South Australian Catfish, *Cnidoglanis macrocephalus* (Plotosidae)	32	1	Private	-	3	-	-	-	2
Congolli/Freshwater Flathead, *Pseudaphritis urvillii* (Pseudaphritidae)	71	1	GBGCA12274-15	REC	-	3	-	-	-
King Gar/Saury, *Scomberesox saurus* (Scomberesocidae)	99	1	DSLAR029-08	-	-	10	-	-	-
Southern Bluefin Tuna, *Thunnus maccoyii* (Scombridae)	33	1	FOA876-04	SBT, CBF	-	-	-	4	-
Blue Mackerel, *Scomber australasicus* (Scombridae)	47	1	FOA801-04	-	-	5	-	1	-
Soldierfish, *Gymnapistes marmoratus* (Scorpaenidae)	28	1	Early-release	-	1	-	-	1	6
Little Gurnard Perch, *Maxillicosta scabriceps* (Scorpaenidae)	236	0.9968	Private	-	-	-	-	-	4
Gulf Gurnard Perch, *Neosebastes bougainvillii* (Scorpaenidae)	182	0.9968	Private	-	1	-	-	-	-
Southern Rockcod, *Scorpaena papillosa* (Scorpaenidae)	251	1	Early-release	-	-	-	-	-	1
Unclassified Gurnard Perch species (Scorpaenidae)	420	0.945	Private	-	3	-	-	-	-
Southern School Whiting, *Sillago bassensis* (Sillaginidae)	55	1	Private	-	2	2	-	-	1
Eastern School Whiting, *Sillago flindersi* (Sillaginidae)	119	1	Early-release	-	1	1	-	-	-
Duskybanded Sole, *Zebrias penescalaris* (Soleidae)	336	1	Early-release	-	2	-	-	-	-
Snapper, *Chrysophrys auratus* (Sparidae)	107	0.9958	FOA681-04	MSF, REC	1	4	-	-	-
Snook, *Sphyraena novaehollandiae* (Sphyraenidae)	373	1	Early-release	MSF, CBF, REC	-	2	-	-	-

Table 3.11. Continued

					[§]**Prevalence** (/total samples):				
		BOLD assignments[‡]			**2014-2015 samples**			**2016 samples**	
[†]**PREY TAXA** (Total = 181 species) (2014/15 = 166 spp; 2016 = 78 spp.)	**OTU**	**Similarity**	**ID**	**Fishery**[#]	**ASL** (32)	**LNFS** (91)	**AFS** (7)	**LNFS** (20)	**ASL** (19)
FISH (Total = 121 species) cont'd						(111 species) cont'd		(53 species) cont'd	
Spotted Pipefish, *Stigmatopora argus* (Syngnathidae)	200	1	Early-release	-	-	-	-	-	1
Western Striped Grunter, *Pelates octolineatus* (Terapontidae)	14	1	Early-release	-	1	1	-	-	5
Smalleye Squaretail, *Tetragonurus cuvieri* (Tetragonuridae)	452	1	MFC209-08	-	-	1	-	-	-
Ringed Toadfish, *Omegophora armilla* (Tetraodontidae)	83	1	GBGCA5176-13	-	6	-	-	-	1
Starry Toadfish, *Arothron firmamentum* (Tetraodontidae)	150	1	Early-release	-	-	-	-	-	1
Western Roughy, *Optivus agrammus* (Trachichthyidae)	311	1	Private	-	1	2	-	-	-
Red Gurnard, *Chelidonichthys kumu* (Triglidae)	457	1	FOA432-04	-	-	1	-	-	-
Spiny Gurnard, *Lepidotrigla papilio* (Triglidae)	190	1	Early-release	-	5	-	-	-	3
Southern Shortfin Gurnard, *Lepidotrigla spinosa* (Triglidae)	196	0.9967	Early-release	-	2	-	-	-	-
Unclassified Fish species (Actinopterygii)	455	0.8487	GBGCA519-10	-	1	-	-	-	-
Unclassified Fish species (Actinopterygii)	476	0.8416	Private	-	2	-	-	-	2
Unclassified Perch species (Labriformes)	92	0.8932	Early-release	-	4	1	-	-	-
Unclassified Perch species (Perciformes)	214	0.877	Early-release	-	1	-	-	-	-
Unclassified Scorpionfish species (Scorpaeniformes)	195	0.8562	Early-release	-	3	-	-	-	-
Unclassified Dragonfish species (Stomiiformes)	22	0.8881	ANGBF8534-12	-	6	6	1	-	-
Common Stargazer, *Kathetostoma laeve* (Uranoscopidae)	294	1	Early-release	-	2	-	-	-	-
CEPHALOPODS (Total = 25 species):						(23 species)		(15 species)	
Southern Argonaut, *Argonauta nodosa* (Enoploteuthidae)	193	1	GBCPH0054-06	-	-	1	-	-	-
Luminous Bay Squid, *Uroteuthis noctiluca* (Loliginidae)	31	1	GBCPH0268-06	-	-	8	-	-	-
Southern Calamari, *Sepioteuthis australis* (Loliginidae)	8	1	GBCPH0102-06	MSF, REC, CBF	16*	43*	-	1	14*
Oceanic Squid, *Lycoteuthis lorigera* (Lycoteuthidae)	202	0.9968	GBCPH1045-10	-	-	1	-	-	-
Unclassified Octopus species, *Callistoctopus* sp. (Octopodidae)	51	0.9871	Early-release	-	7	1	-	-	6
Unclassified Octopus species, *Callistoctopus* sp. (Octopodidae)	109	1	Early-release	-	1	-	-	-	2
Velvet Octopus, *Grimpella thaumastocheir* (Octopodidae)	155	1	GBCPH1511-13	-	3	-	-	-	-
Common Sydney Octopus, *Octopus cf. tetricus* (Octopodidae)	138	1	GBCPH1940-15	-	3	-	-	-	1
Southern Sand Octopus, *Octopus kaurna* (Octopodidae)	91	0.9967	Early-release	-	6	5	-	-	7
Unclassified Octopus species (Octopodidae)	11	0.9179	GBCPH1941-15	-	18*	8	-	2	15*
Unclassified Octopus species (Octopodidae)	21	0.9966	GBCPH1510-13	-	11*	7	-	-	2
Unclassified Octopus species (Octopodidae)	152	0.9524	GBCPH1510-13	-	3	1	-	-	2
Unclassified Octopus species (Octopodidae)	212	0.9211	GBCPH0014-06	-	-	-	-	-	3
Unclassified Octopus species (Octopodidae)	366	0.8978	CANTA059-08	-	-	2	-	-	-
Unclassified Octopus species (Octopodidae)	186	0.8652	GBCPH0008-06	-	-	2	-	-	-
Red Arrow Squid, *Nototodarus gouldi* (Ommastrephidae)	25	1	Early-release	-	1	47*	2	2	6
Unclassified Flying Squid species, *Ommastrephes* sp. (Ommastrephidae)	175	0.984	GBCPH1199-13	-	-	4	-	-	-
Southern Dumpling Squid, *Euprymna tasmanica* (Sepiidae)	65	0.9935	GBCPH719-07	-	3	8	1	-	5
Giant Australian Cuttlefish, *Sepia apama* (Sepiidae)	12	1	GBCPH1210-13	ECO	13*	15*	2	-	1
Unclassified Cuttlefish species (Sepiida)	56	0.8906	ANGEN050-15	-	14*	2	-	-	4

Table 3.11. Continued

					[§]**Prevalence** (/total samples):				
		BOLD assignments[‡]			**2014-2015 samples**			**2016 samples**	
[†]**PREY TAXA** (Total = 181 species) (2014/15 = 166 spp; 2016 = 78 spp.)	**OTU**	**Similarity**	**ID**	**Fishery**[#]	**ASL** (32)	**LNFS** (91)	**AFS** (7)	**LNFS** (20)	**ASL** (19)
CEPHALOPODS (Total = 25 species) cont'd						(23 species) cont'd		(15 species) cont'd	
Unclassified Cuttlefish species (Sepiida)	310	0.8713	GBCPH1408-13	-	-	2	-	-	-
Striped Pyjama Squid, *Sepioloidea lineolata* (Sepiolidae)	123	0.9935	GBCPH0089-06	-	4	-	-	-	2
Unclassified Squid species (Oegopsida)	292	0.8611	GBCPH1111-13	-	-	4	-	-	-
Unclassified Cephalopod species (Cephalopoda)	181	0.8474	GBCPH0288-06	-	1	-	-	-	-
Unclassified Cephalopod species (Cephalopoda)	266	0.8479	GBCPH0361-06	-	-	-	-	-	1
CRUSTACEA (Total = 14 species)						(14 species)		(5 species)	
Western King Prawn, *Melicertus latisulcatus* (Penaeidae)	208	0.9968	Early-release	PF	4	1	-	-	-
Eastern King Prawn, *Melicertus plebejus* (Penaeidae)	81	1	Early-release	-	5	3	-	-	6
Unclassified Swimming Crab species (Polybiidae)	146	0.9515	GBCDA2238-12	-	3	4	1	-	-
Common Sand Crab, *Ovalipes australiensis* (Polybiidae)	121	0.9968	Early-release	MSF, REC	2	-	-	-	2
Unclassified Sand Crab species, *Ovalipes* sp. (Polybiidae)	90	0.9673	Early-release	-	7	7	-	-	3
Rough Rock Crab, *Nectocarcinus integrifrons* (Portunidae)	41	1	Early-release	-	5	5	-	1	4
Unclassified Rock Crab species (Portunidae)	424	0.9346	Early-release	-	-	1	1	-	-
Unclassified Decapod species (Decapoda)	69	0.8495	GBCMD9032-13	-	-	1	-	-	-
Unclassified Decapod species (Decapoda)[¶]	133	0.8544	Private	-	1	2	-	-	-
Unclassified Decapod species (Decapoda)	300	0.8584	GBCMD9517-13	-	1	-	-	-	-
Unclassified Decapod species (Decapoda)	312	0.8562	Early-release	-	5	-	-	-	1
Unclassified Decapod species (Decapoda)[¶]	491	0.8673	GBCMD0197-06	-	1	-	-	-	-
Unclassified Decapod species (Decapoda)	497	0.8725	Private	-	1	1	-	-	-
Unclassified Decapod species (Decapoda)	604	0.8627	Private	-	-	1	-	-	-
SHARKS/RAYS (Total = 13 species)						(12 species)		(1 species)	
Port Jackson Shark, *Heterodontus portusjacksoni* (Heterodontidae)	215	1	FOAMP001-06	-	2	1	-	-	-
Great White Shark, *Carcharodon carcharias* (Lamnidae)	116	1	MFC051-08	-	-	-	-	2	-
Collar Carpetshark, *Parascyllium collare* (Parascylliidae)	60	0.9968	Early-release	-	2	1	-	-	-
Thornback Skate, *Dentiraja lemprieri* (Rajidae)	20	0.9967	Early-release	-	3	3	-	-	-
Melbourne Skate, *Dipturus whitleyi* (Rajidae)	216	1	FOA201-04	-	1	-	-	-	-
Grey Spotted Catshark, *Asymbolus analis* (Scyliorhinidae)	273	0.9731	Early-release	-	1	-	-	-	-
Dwarf Catshark, *Asymbolus parvus* (Scyliorhinidae)	167	0.9838	FOAF200-07	-	-	-	1	-	-
Spikey Dogfish, *Squalus megalops* (Squalidae)	129	1	FOA089-04	-	-	-	1	-	-
Australian Angelshark, *Squatina australis* (Squatinidae)	265	1	GBGC9565-09	-	2	-	-	-	-
Unclassified Stingaree species, *Urolophus* sp. (Urolophidae)	307	0.9508	FOAD366-05	-	2	-	-	-	-
Unclassified Stingaree species, *Urolophus* sp. (Urolophidae)	384	0.9647	Private	-	2	-	-	-	-
Coastal Stingaree, *Urolophus orarius* (Urolophidae)	283	1	Private	-	3	-	-	-	-
Sparsely-spotted Stingaree, *Urolophus paucimaculatus* (Urolophidae)	77	1	FOA253-04	-	7	1	-	-	-
BIRDS (Total = 6 species)						(6 species)		(2 species)	
Band-tailed Gull, *Larus belcheri* (Laridae)[Δ]	291	0.9936	BROM592-07	-	-	-	1	-	-
Silver Gull, *Larus novaehollandiae* (Laridae)	74	1	BWA044-06	-	1	2	-	-	2

Table 3.11. Continued

					[§]**Prevalence** (/total samples):				
		BOLD assignments[‡]			**2014-2015 samples**			**2016 samples**	
[†]**PREY TAXA** (Total = 181 species) (2014/15 = 166 spp; 2016 = 78 spp.)	**OTU**	**Similarity**	**ID**	**Fishery**[#]	**ASL** (32)	**LNFS** (91)	**AFS** (7)	**LNFS** (20)	**ASL** (19)
BIRDS (Total = 6 species) cont'd						(6 species) cont'd		(2 species) cont'd	
Black-faced Cormorant, *Phalacrocorax fuscescens* (Phalacrocoracidae)	183	0.9968	GBIR5640-15	-	-	3	-	-	3
Short-tailed shearwater, *Puffinus tenuirostris* (Procellariidae)	635	1	KBNA957-04	-	-	1	-	-	-
Unclassified Parrot species, *Neophema* sp. (Psittaculidae)	290	0.9579	USNMB083-10	-	1	-	-	-	-
Little Penguin, *Eudyptula minor* (Spheniscidae)	75	1	BWA004-06	-	-	9	-	-	-
OTHER TAXA (Total = 2 species)						(0 species)		(2 species)	
Unclassified Gastropod species (Gastropoda)	156	0.8252	Private	-	-	-	-	-	1
Unclassified Bivalve species (Bivalvia)	445	0.7508	GBMBM909-13	-	-	-	-	-	1

Prevalence scale:	> 50%	25-50%	10-25%	<10%

[†] Prey taxa were identified by interrogation of the BOLD reference database (http://boldsystems.org/), with the common and scientific names assigned at the lowest possible level (based on % identity). Species distributions were checked within the Atlas of Living Australia (http://www.ala.org.au/) to verify the positive detections from seals in South Australian Waters.

[‡] Corresponds to the closest match for each OTU sequence within the BOLD reference database; Taxonomic affiliations were assigned based on sequence identity values of >99% (Species), 95-99% (Genus), 90-95% (Family), 85-90% (Order) and 80-85% (Class).

[#] MSF - Marine Scalefish Fishery; REC - Recreational; CBF - Charter Boat Fishery; LC - Lakes and Coorong Fishery; PF - Prawn Fishery; GABTF - GAB Trawl Fishery; SASF - South Australian Sardine Fishery; SBT - Southern Bluefin Tuna Fishery; CTF - Commonwealth Trawl Fishery; ECO - Ecotourism.

[§] The prevalence of each prey taxa is reported for ASL and LNFS only due to limited sample size (7 scats) for AFS.

[¶] These species may not be considered a typical prey item of seals due to the small size of the nearest taxa (i.e. Alpheids).

[Δ] Non-endemic species, may represent another closely related taxa.

The prey composition of scat samples

In analysing the 165 scat samples, fish accounted for the majority (~67%, 121/181) of all prey taxa detected, followed by cephalopods (~14%, 25/181), Crustacea (~8%, 14/181), sharks/rays (~7%, 13/181), birds (3%, 6/181), and other taxa (1%, 2/181). Accordingly, fish was the predominant prey group (accounting for ~60-80% of all prey taxa) across all three seal species, with cephalopods the next most important (Figures 3.1 and 3.2). Furthermore, in evaluating the prevalence (or frequency of detection/occurrence) of the individual prey taxa across all scat samples for each seal species (Figures 3.3 - 3.10), particular species of both fish and cephalopods (including some pertinent to the commercial fisheries sector) accounted for the top most frequently detected prey, with some occurring in >25%, or even as many as >50%, of the samples. These included for ASL: 9 Fish (Red Mullet [59% 2014/15, 63% 2016]; Degens Leatherjacket [44% 2014/15, 63% 2016]; Toothbrush Leatherjacket [53% 2014/15, 32% 2016]; Rough Leatherjacket [28% 2014/15, 0% 2016]; Southern Sand Flathead [38% 2014/15, 21% 2016]; Silverbelly [16% 2014/15, 53% 2016]; Bridled Leatherjacket [13% 2014/15, 47% 2016]; Skipjack Trevally [3% 2014/15, 47% 2016]; Yellowtail Kingfish [0% 2014/15, 47% 2016]); and 5 cephalopods (Unclassified Octopus sp._OTU 11 [56% 2014/15, 79% 2016]; Southern Calamari [50% 2014/15, 74% 2016]; Unclassified Cuttlefish sp._OTU 56 [44% 2014/15, 21% 2016]; Giant Australian Cuttlefish [41% 2014/15, 5% 2016]; Unclassified Octopus sp._OTU 21 [34% 2014/15, 11% 2016]). For LNFS, it included: 5 fish (Southern Garfish [40% 2014/15, 5% 2016]; Barracouta [29% 2014/15, 0% 2016]; Yellowtail Scad [14% 2014/15, 50% 2016]; Common Jack Mackerel [9% 2014/15, 45% 2016]; Yellowtail Kingfish [0% 2014/15, 50% 2016]; and only 2 cephalopods (Red Arrow Squid [52% 2014/15, 10% 2016] and Southern Calamari [47% 2014/15, 5% 2016]). Too few samples were available from AFS to report (with confidence) on the frequency of detection of any single prey species, though species identified previously as being prevalent in the diets of AFS like the carangids (e.g., Jack Mackerel, *Trachurus declivis*) (Deagle *et al.* 2009) were also detected along with other species of Fish, Sharks/Rays, Crustacea, Birds and relevant cephalopods. The importance of fish and cephalopods in the diets of seals, particularly over other taxa (perhaps with the exception of Little Penguins in LNFS) has been reported previously (Page *et al.* 2005a, Peters *et al.* 2014). Of course, as discussed above, variation in prey sequence read abundance may be confounded by various biological factors (e.g. prey digestion efficiency or DNA sample integrity), thus some level of caution should be taken when attributing sequence reads to prey abundance. Instead, as recommended elsewhere, such data should be considered with the broader feeding ecology of the animal through parallel alternate dietary analyses (e.g. hard part assessment) (Pompanon *et al*. 2012).

Key finding 9: Prey detected from scats included fish, cephalopods, sharks/rays, crustacea, birds and other taxa; fish and cephalopods were primary components.

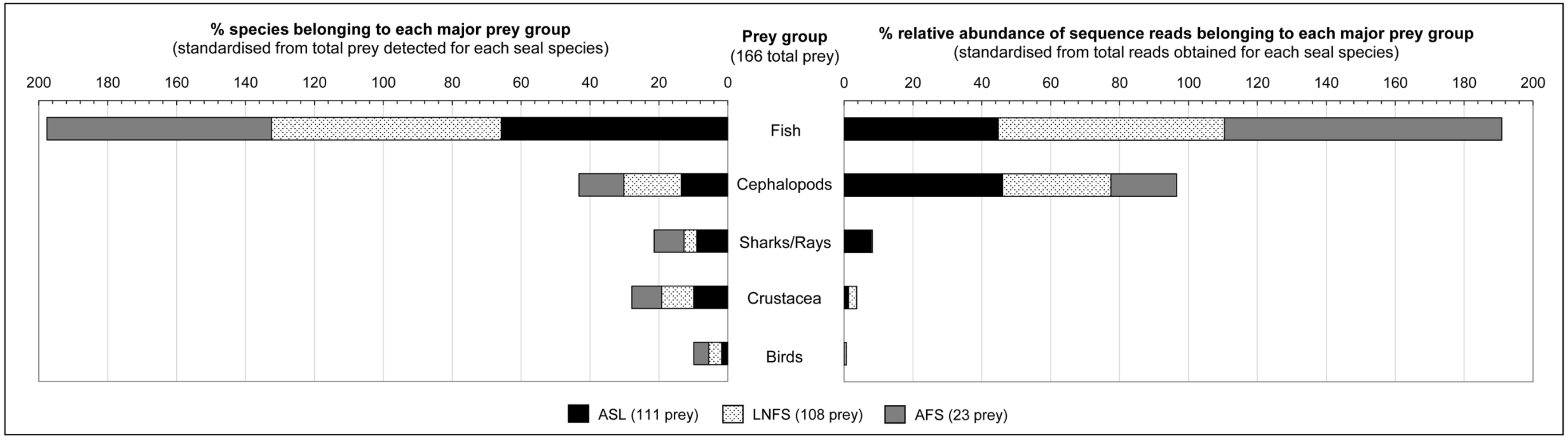


Figure 3.1. Relative abundance of sequences and their contribution to the total species detected for each major prey group from scats collected from Australian Sea Lion, Long-nosed Fur Seal and Australian Fur Seal in 2014/15.

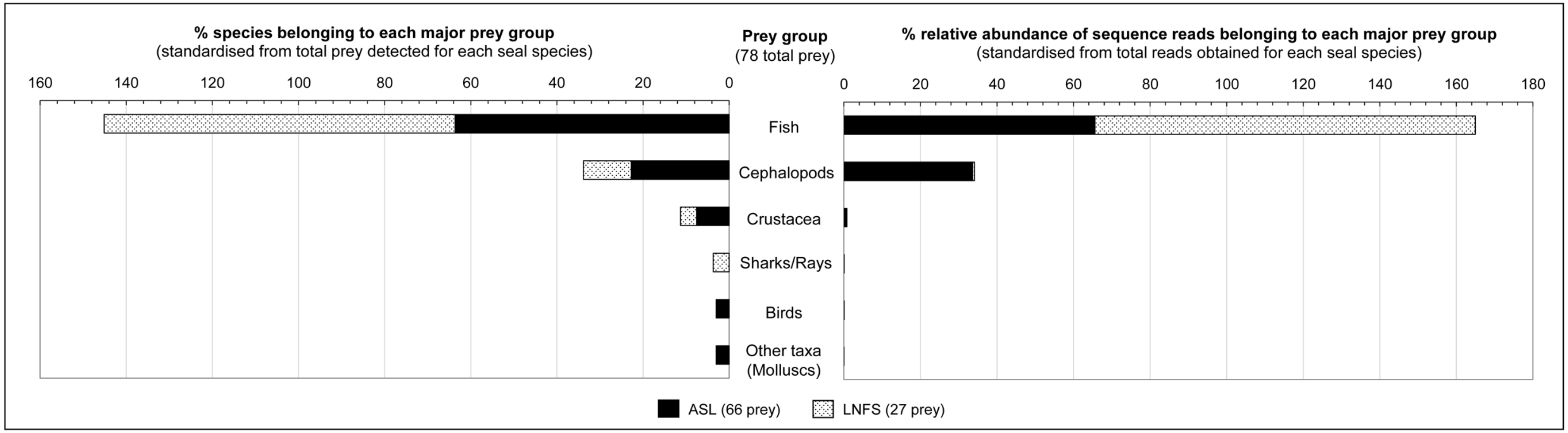


Figure 3.2. Relative abundance of sequences and their contribution to the total species detected for each major prey group from scats collected from Australian Sea Lion (ASL) and Long-nosed Fur Seal (LNFS) in 2016.

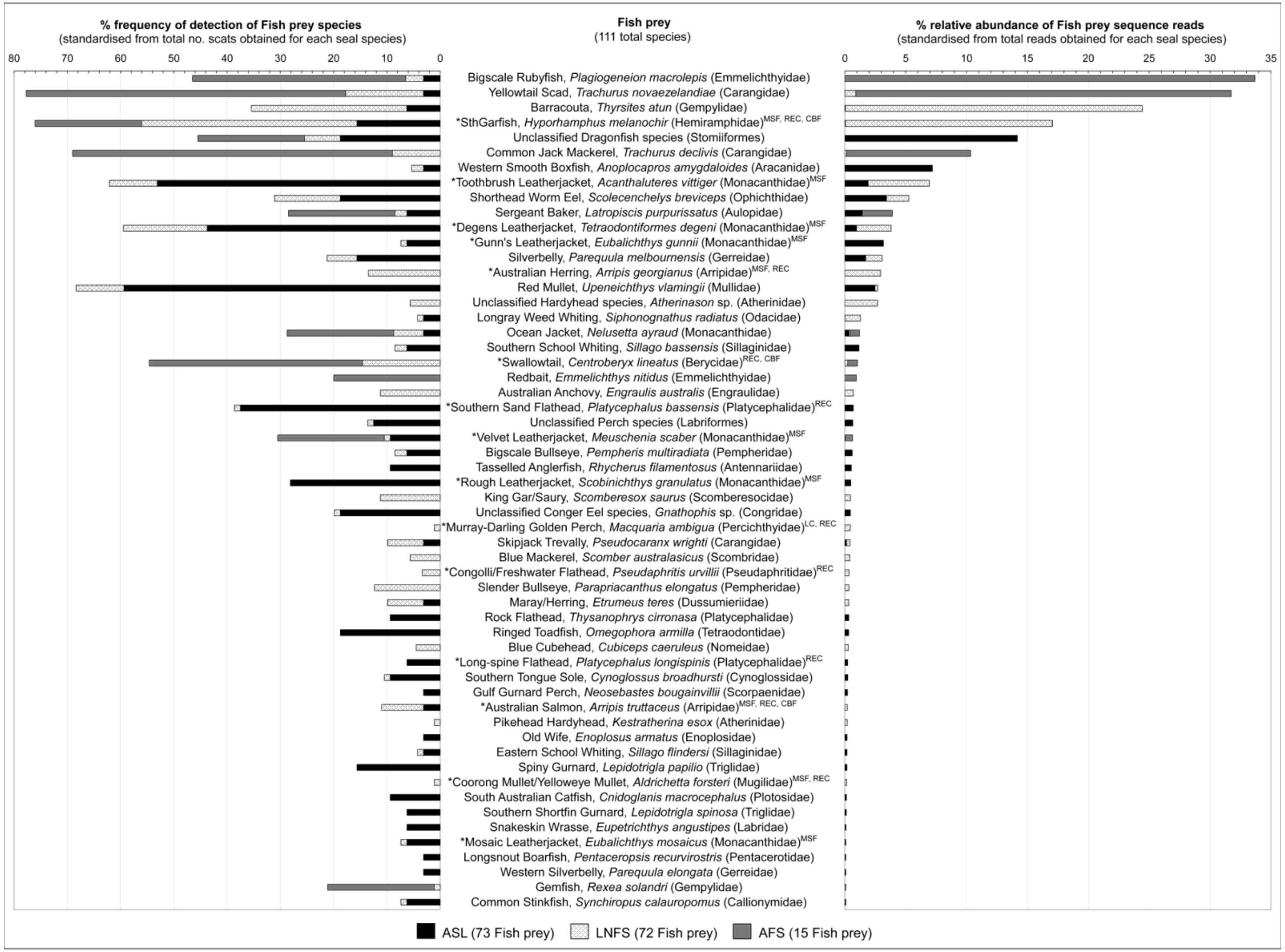


Figure 3.3. Relative abundance of Fish prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) in 2014/15.

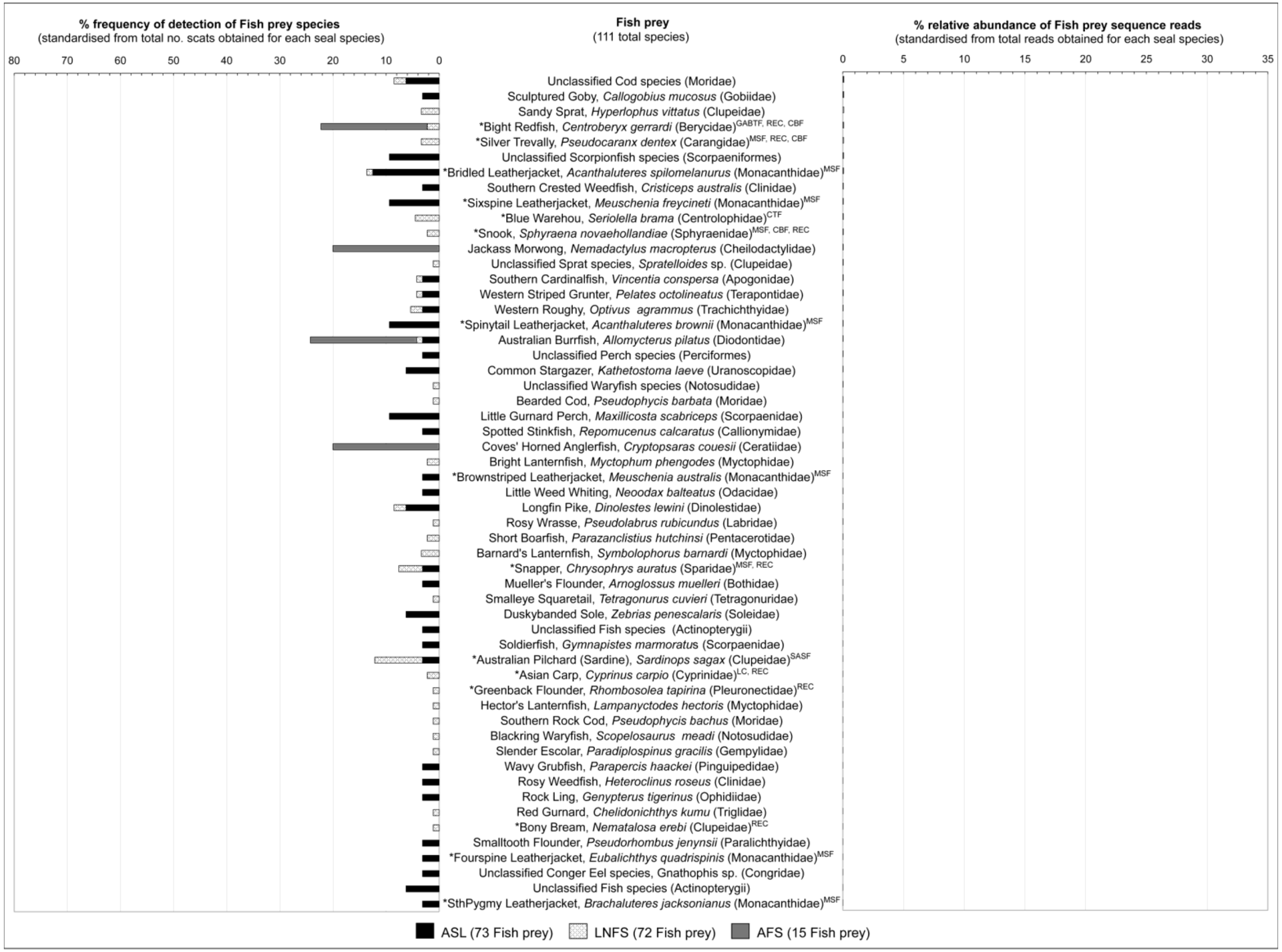


Figure 3.3. Continued

*Key commercial species corresponding to: MSF - Marine Scalefish Fishery; REC - Recreational; CBF - Charter Boat Fishery; LC - Lakes and Coorong Fishery; GABTF - GAB Trawl Fishery; SASF - South Australian Sardine Fishery; CTF - Commonwealth Trawl Fishery.

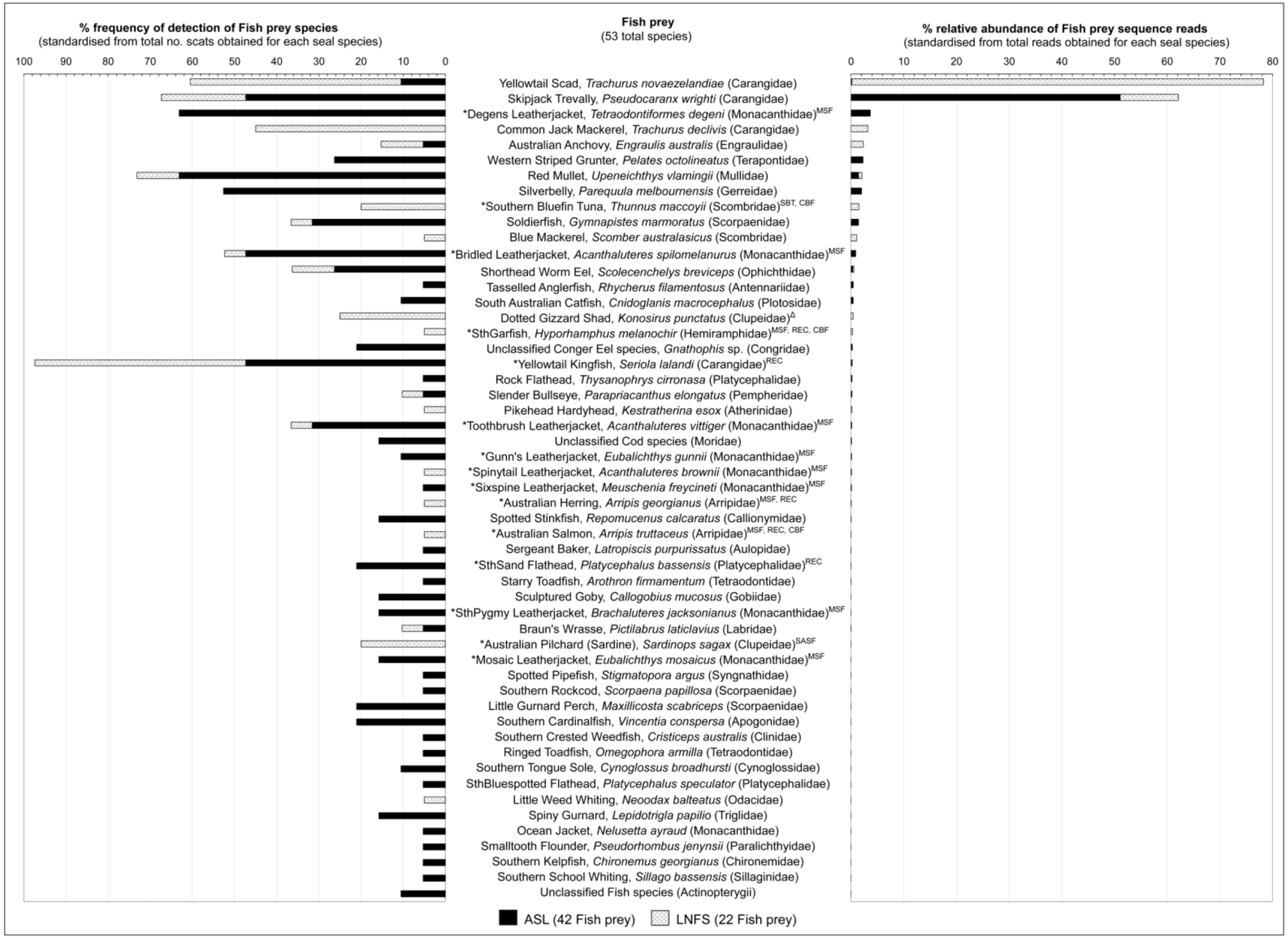


Figure 3.4. Relative abundance of Fish prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL) and Long-nosed Fur Seal (LNFS) in 2016.

*Key commercial species corresponding to: MSF - Marine Scalefish Fishery; REC - Recreational; CBF - Charter Boat Fishery; SASF - South Australian Sardine Fishery; SBT - Southern Bluefin Tuna Fishery. $^{\Delta}$Non-endemic species, may represent another closely related taxa.

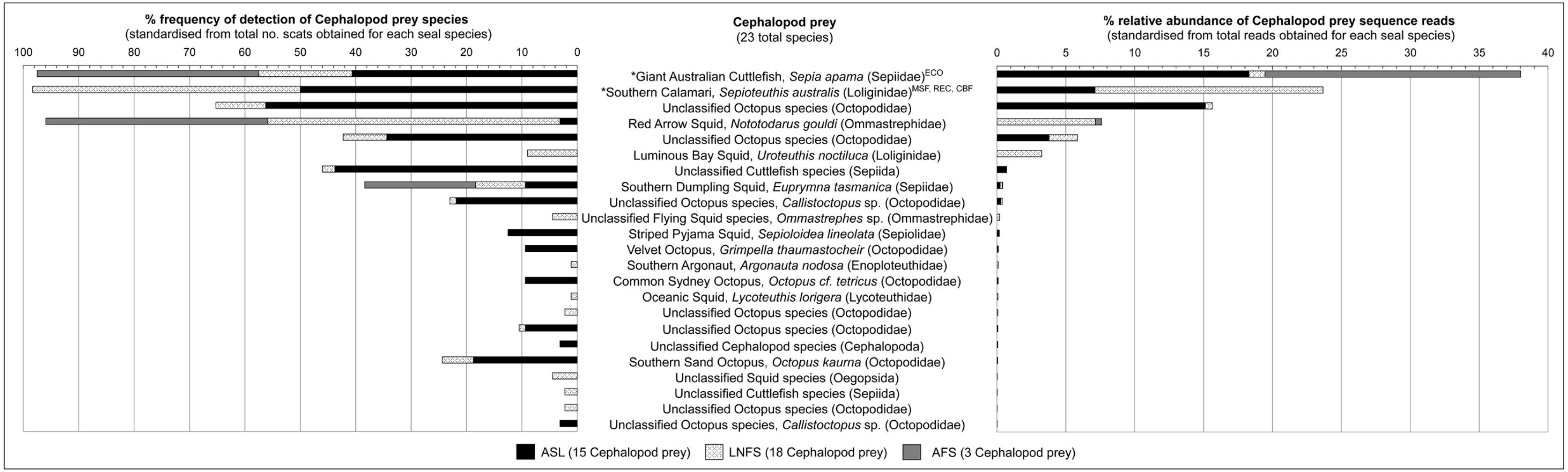


Figure 3.5. Relative abundance of Cephalopod prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) in 2014/15.

*Key commercial species corresponding to: MSF - Marine Scalefish Fishery; REC - Recreational; CBF - Charter Boat Fishery; ECO – Ecotourism.

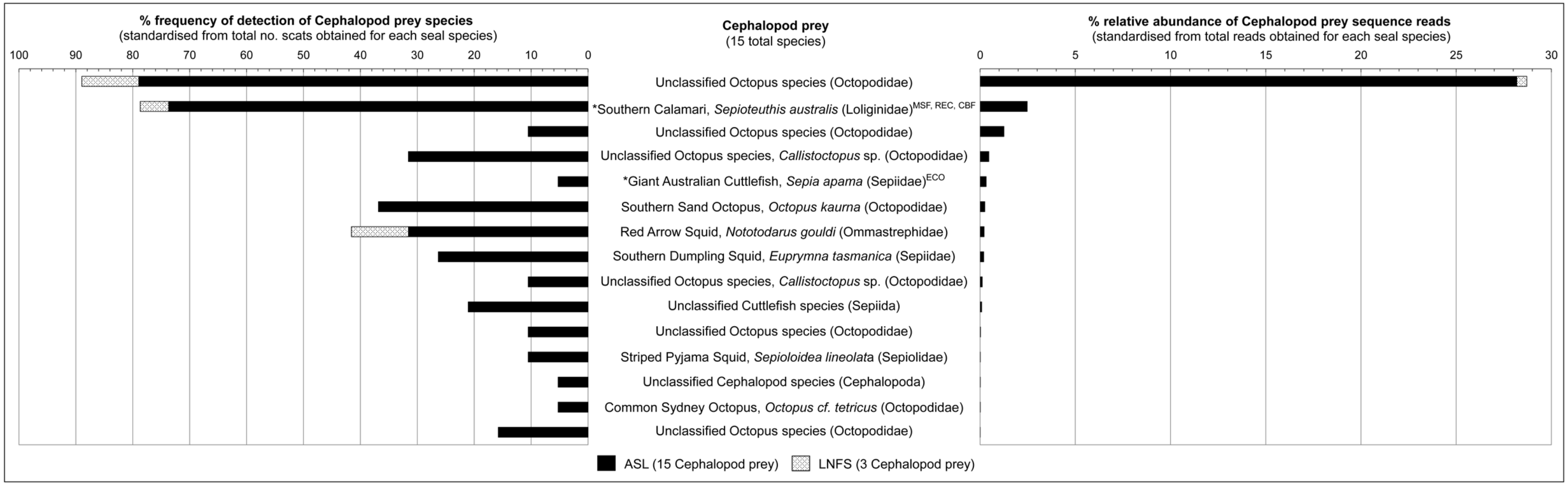


Figure 3.6. Relative abundance of Cephalopod prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL) and Long-nosed Fur Seal (LNFS) in 2016.

*Key commercial species corresponding to: MSF - Marine Scalefish Fishery; REC - Recreational; CBF - Charter Boat Fishery; ECO – Ecotourism.

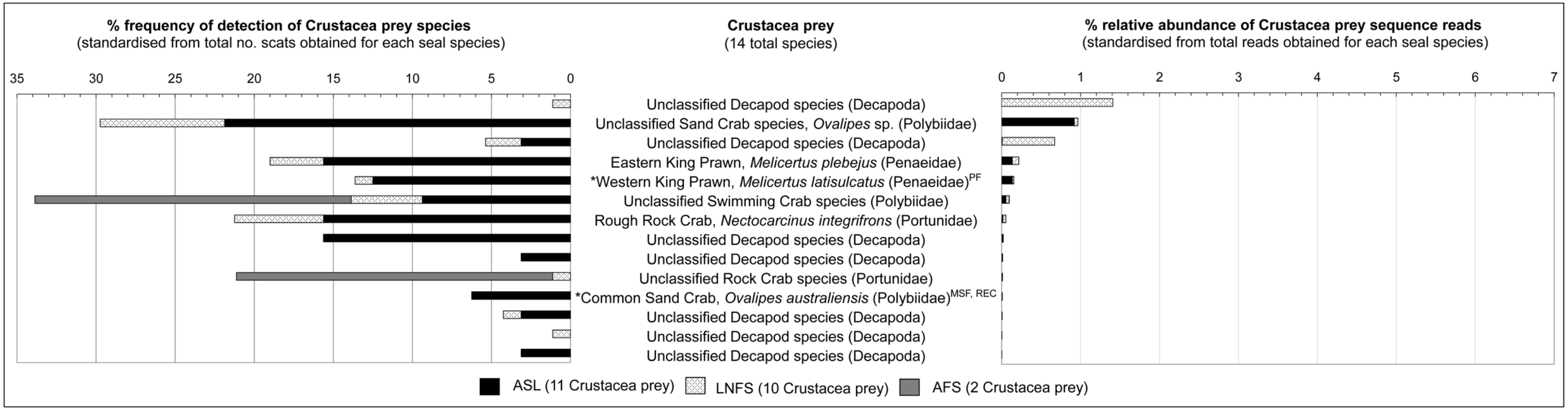


Figure 3.7. Relative abundance of Crustacea prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) in 2014/15.

*Key commercial species corresponding to: MSF - Marine Scalefish Fishery; REC - Recreational; PF - Prawn Fishery.

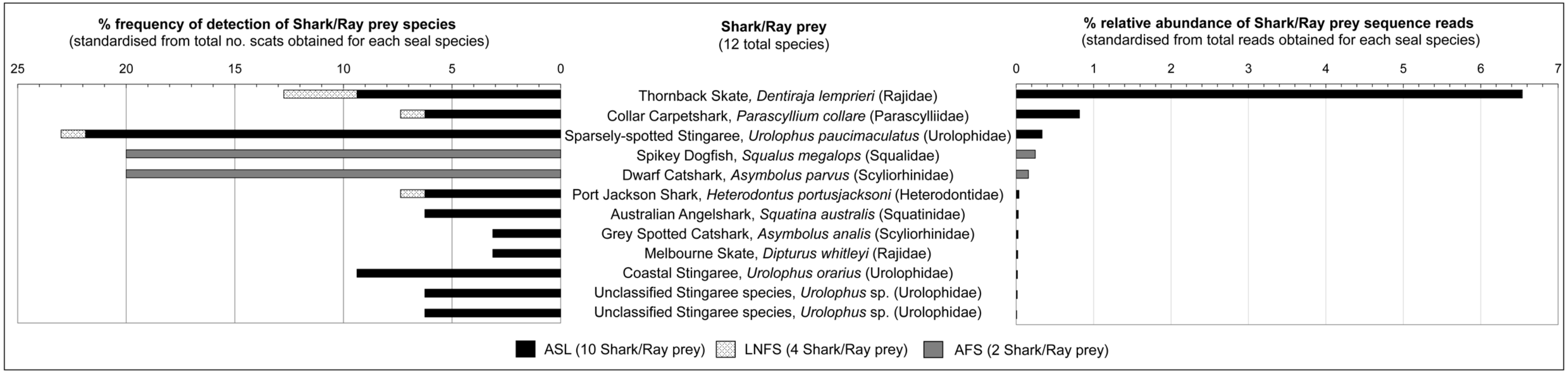


Figure 3.8. Relative abundance of Shark/Ray prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) in 2014/15.

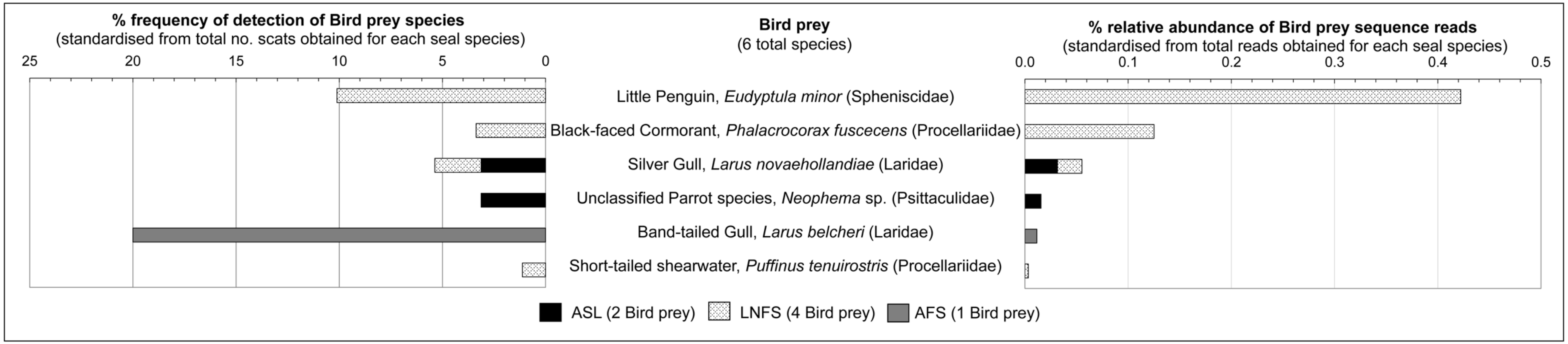


Figure 3.9. Relative abundance of Bird prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) in 2014/15.

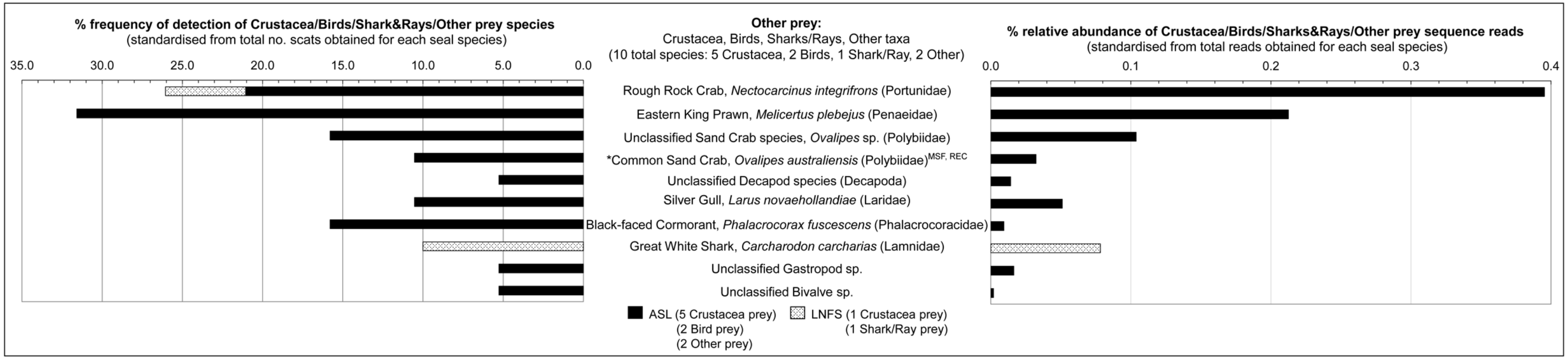


Figure 3.10. Relative abundance of Crustacea/Bird/Shark & Ray/Other prey sequences and the frequency of their detection in scats collected from Australian Sea Lion (ASL) and Long-nosed Fur Seal (LNFS) in 2016.

*Key commercial species corresponding to: MSF - Marine Scalefish Fishery; REC - Recreational.

Overall, 20% (37/181) of the total prey species detected from these animals were relevant to the fisheries sector, with 18-21% of the taxa detected in scats from ASL, 24-37% from LNFS and 26% from AFS representing key commercial species (Table 3.12). Thus, these seals appear to be interacting with a greater diversity of prey beyond those relevant to the commercial sector.

Of particular note, was the detection of sequence reads belonging to Eastern King Prawns (*Melicertus plebejus*), predominantly in scat samples collected from ASL in 2014-2015 and 2016 (Table 3.11). While Eastern King Prawns have been previously observed, albeit rarely, from the Gulfs (see Atlas of Living Australia [ala.org.au] Occurrence Records [invertebrates] J60954 and J60938) and are largely confined to the east coast of Australia (Ruello 1975), Western King Prawns (*Melicertus latisulcatus*) are the common commercial species in the region (McLeay *et al*. 2017, Noel and Hooper 2017). Considering the high level of sequence identity assigned to both the Eastern and Western King Prawn OTUs (i.e. 100 and 99.68% respectively, Table 3.11), this result is surprising and requires further investigation. This is particularly pertinent given that unusual COI gene evolutionary rates may exist for some species of Crustacea, which may contribute to high levels of intraspecific divergence and obscure the ability to accurately delimit the genetic boundaries of a species (da Silva *et al*. 2011). Indeed, for other *Penaeidae* species, COI gene intraspecific divergence rates of 0.24-1.2% may be observed (Quan *et al*. 2004). However, with only partial COI gene sequences used here to assign species identity, further clarification based on near complete COI and/or other phylogenetic marker gene sequences (e.g. mt16S rRNA gene) would be required to delineate these assignments. Thus, until further clarification can be attained for these assignments, it would be prudent to ascribe these identifications more broadly as Prawns (*Melicertus* spp.).

Key finding 10: Some of the primary prey species detected from the seal scats are of commercial significance (e.g., Leatherjackets, Southern Garfish and Southern Calamari), though a wider diversity of prey beyond those relevant to fisheries was also evident, indicating broader trophic interactions peripheral to the commercial sector.

Table 3.12. Summary data of the total, median and unique numbers of prey species and measures of taxonomic distinctness (TD) for scat samples obtained from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) in 2014/15, and ASL and LNFS in 2016.

			No. of prey species/scat sample				Taxonomic distinctness (TD)†	
Seal species	No. of scat samples	Total no. of prey species	Median	Range (min - max)	No. of unique prey species /scat sample*	No. of prey representing key commercial species	Average TD (delta+)	Variation TD (lambda+)
2014/15								
ASL	32	111	11	1 - 27	3.5	23	83.1	375.5
LNFS	89	108	5	1 - 14	1.2	26	83.3	277.8
AFS	5	23	6	1 - 15	4.6	6	78.6	271.3
2016								
ASL	19	66	14	2 - 24	3.5	12	82.5	365.9
LNFS	20	27	3	1 - 12	1.4	10	63.3	195.4

*As calculated from the total no. prey species detected/no. of scat samples.

†Detailed explanation of these metrics and their calculation are described in the Methods.

To specifically assess whether ASL and LNFS scat samples have very different prey profiles, ordination (principal co-ordinate analysis) using prey species presence/absence data across all samples was performed (Figures 3.11 and 3.12). Figure 3.11a revealed that ASL and LNFS scats clustered independently of each other, irrespective that the 2014/15 dataset comprised samples from different locations/seasons, clearly indicating that seal species indeed have an overall preference for different prey species. This was confirmed statistically by PERMANOVA (Pseudo F=6.3, p =0.0001, Figure 3.11a). However, to remove any confounding factors associated with comparison of samples across different locations and seasons, only those ASL and LNFS scat samples collected at Southern SG sites during winter-spring in 2014/15 were further compared. This was repeated for those samples collected in the SG during winter of 2016. Again at both sampling periods, ASL and LNFS scat samples clustered independently (Figure 3.11b, 3.19) and were significantly different (PERMANOVA p= 0.0001). While octopus and leatherjacket species were prevalent in ASL samples during both collection periods, LNFS samples from southern SG in 2014/15 largely comprised Barracouta and Red Arrow Squid, and in SG in 2016, Yellowtail Scad and Common Jack Mackerel. This likely reflects the individual preferences of different seal species for particular prey groups and may be indicative of the sympatric partitioning of dietary resources as reported previously between LNFS and ASL (Page *et al.* 2005a).

Leatherjackets (Monocanthidae), Red Mullet (*Upeneichthys vlamingii*), Trevally (Carangidae), octopus (Octopodidae), Southern Calamari Squid (*Sepioteuthis australis*), and Cuttlefish (Sepiidae), among others, all appear to be particularly relevant prey items targeted by ASL (Table 3.11, Figures 3.3-3.6, 3.11b, 3.12b) which is consistent with earlier reports using comparable molecular approaches (Peters *et al.* 2014). On the other hand, Southern Garfish (*Hyporhamphus melanochir*), Barracouta (*Thyrsites atun*), Trevally (Carangidae), Red Arrow Squid (*Nototodarus gouldi*) and Southern Calamari Squid (*Sepioteuthis australis*) among others, appear to be relevant for LNFS (Table 3.11, Figures 3.3-6, 3.11b, 3.12b). This is consistent, in part, with earlier reports for LNFS based on hard-part identifications (Boren 2010, Green *et al.* 1990, Page *et al.* 2005a), where Barracouta, Octopus and Squid (especially Arrow Squid) have been indicated as important prey items (Green *et al.* 1990, Street 1964, Tate 1981). The finding that these two seal species have little overlap in the top prey taxa detected in the scats (except for species such as Trevally and Calamari squid), was also reflected in the lesser detected prey taxa. For example, in the birds prey group, Little Penguins (*Eudyptula minor*) were only only detected in LNFS scats; these penguins are a well recognised prey species specifically targeted by LNFS (Bool *et al.* 2007, Page *et al.* 2005a). Furthermore, more shark/ray species were detected in the scats from ASL than from LNFS (Table 3.11, Figures 3.1-2, 3.8, 3.10), a finding that contradicts Emami-Khoyi *et al*. (2016) who used molecular (NGS) approaches to reveal that cartilaginous prey such as Sharks/Rays may also be an important component of the diet of LNFS. Interestingly, the only Shark/Ray species detected in LNFS scats was from Great White Sharks (2/20 scats). Whilst interactions between these two species are well documented, whether this shark species represents a legitimate prey item is not clear. There may have been under-representation of certain prey species like Lanternfish (Myctophidae) which were previously reported as a predominant prey group in LNFS based on the recovery and identification of hard-parts (Boren 2010, Carey 1992, Page *et al.* 2005a) and likely reflects the loss of DNA resulting from defecation of the soft remains during transit between the pelagic foraging waters off the shelf-break and the haul-out sites. In this regard, combining DNA and hard-part analyses may improve estimates of prey diversity, and has been recommended elsewhere (Tollit *et al.* 2009).

Key finding 11: Preferences for different prey is evident between seal species even when they share the same sites; Leatherjackets, Red Mullet, Trevally, Octopus, Southern Calamari and Cuttlefish were particularly prevalent in scats from ASL, and Southern Garfish, Barracouta, Trevally, Red Arrow Squid, Southern Calamari and Little Penguins (to a lesser extent) were prevalent in scats from LNFS; this supports the concept of dietary resource partitioning in these animals.

Key finding 12: Under-representation of certain prey species (particularly those likely to be foraged in off-shore pelagic waters, such as the Myctophids) may arise from the differential recovery of DNA from these species, and is likely a result of the defecation of soft tissue remains prior to hauling-out. Combining DNA with hard-part analysis is recommended to improve estimates of prey diversity in this regard.

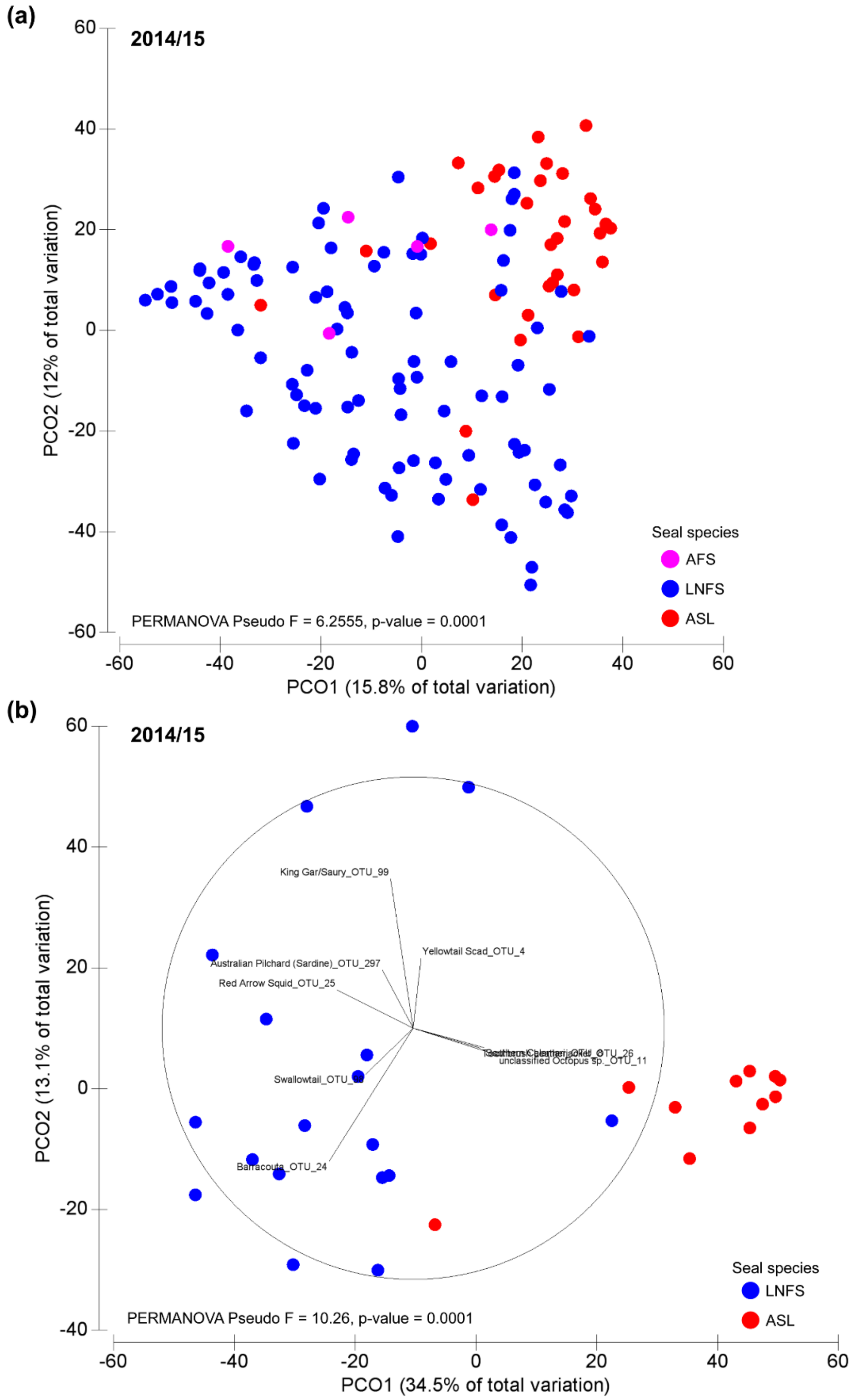


Figure 3.11. Principal Coordinate Analysis (PCoA) ordination plot representing differences in the global prey species compositions obtained from the deep-sequencing of the COI-5P region from scat samples collected in 2014/15. Charts plot (a) all 126 scat samples (32 Australian Sea Lion ASL, 89 Long-nosed Fur Seal LNFS and 5 Australian Fur Seal AFS), where PCO1 and PCO2 account for 27.8% of the total variation between scats; and (b) those sampled from Southern Spencer Gulf during Winter-Spring (17 LNFS and 11 ASL) overlaid with vectors to denote strongly correlating prey species, where PCO1 and PCO2 account for 47.6% of the total variation between scats.

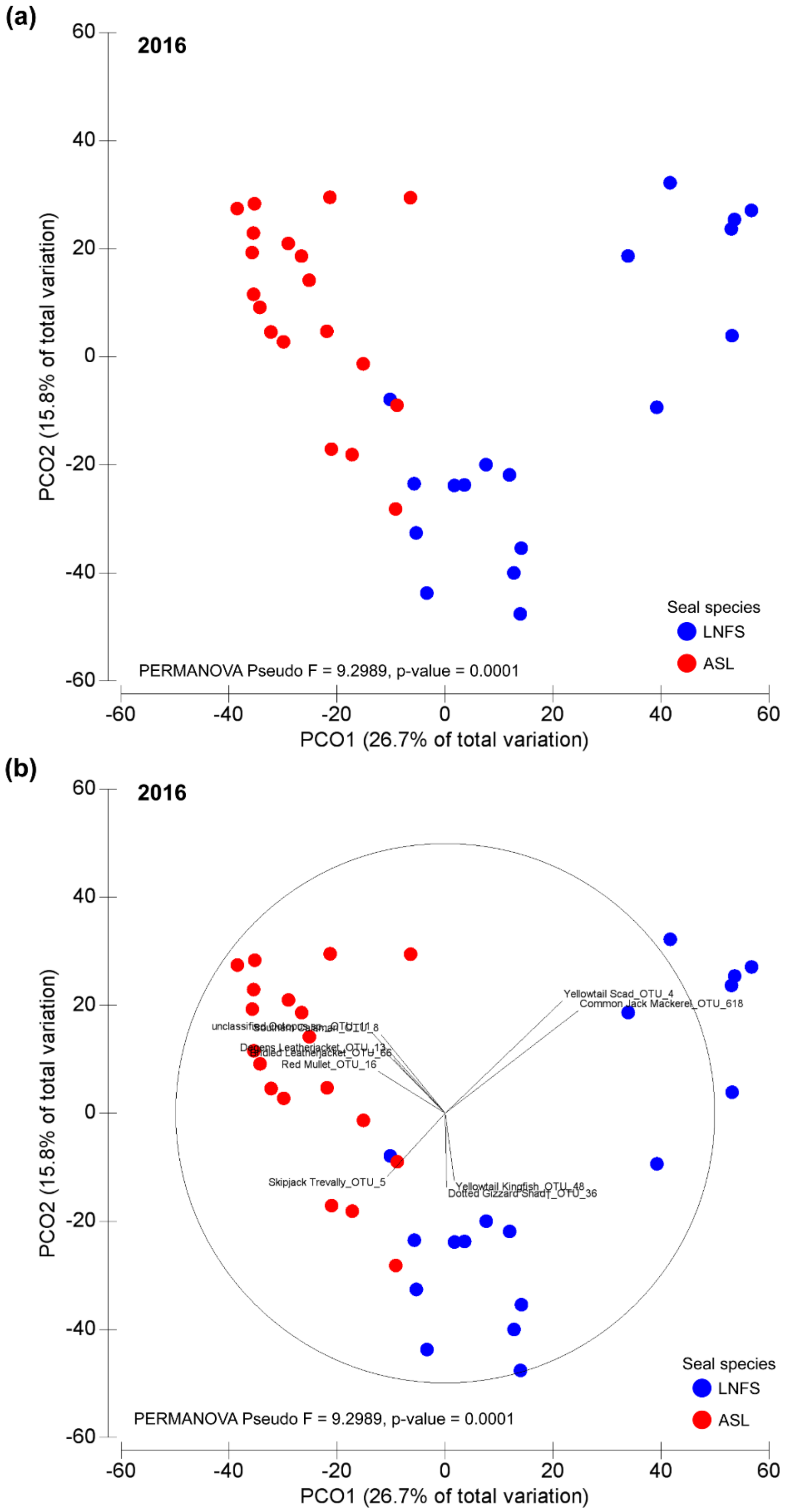


Figure 3.12. Principal Coordinate Analysis (PCoA) ordination plot representing differences in the global prey species compositions obtained from the deep-sequencing of the COI-5P region from scat samples collected in 2016, where PCO1 and PCO2 account for 42.5% of the total variation between scats. Charts plot (a) 39 scat samples (19 Australian Sea Lion ASL and 20 Long-nosed Fur Seal LNFS) and (b) the same plot overlaid with vectors to denote strongly correlating prey species.

Comparing the number of different prey species within scat samples belonging to the different seal species revealed further insights. Prey species richness was significantly higher in both ASL groups (i.e., those sampled in 2014/15 and 2016) compared with the LNFS groups (Mann Whitney U test, $p<0.0001$), with ASL scat samples containing between 1 and 27 prey species, a median of ≥11 prey species/scat and the addition of ≥3 unique prey species to the dataset for every scat sampled. This is in stark contrast to the LNFS groups where a much lower prey species richness was observed, with between 1 and 14 prey species, a median of ≤5 prey species/scat and the addition of only 1 unique prey species to the dataset for every scat sampled (Figure 3.13, Table 3.12). This begs the question of whether those scat samples that comprised greater taxonomic breadth. That is, for those seal groups that consume more prey species, are they consuming a greater variety of species across the major prey groups? To specifically answer this question, taxonomic diversity was measured using taxonomic distinctness (TD) which reports on the relatedness between pairs of prey OTUs within each sample. While such analyses were performed for both the 2014/15 and 2016 datasets (Figure 3.14 and 3.15), only the ASL and LNFS groups from 2016 were formally compared because they comprised samples collected from the same region during the same season and had equal numbers of samples from each seal group. Funnel plots, plotting the number of prey species as a function of average taxonomic distinctness (avTD, or delta+) or taxonomic evenness (varTD, or lambda+) within each sample revealed that ASL scats separate independently from LNFS scats both along the x-axis (depicting an increase in the number of prey species) and along the y-axis depicting greater taxonomic diversity (Figure 3.15a) and in taxonomic unevenness (Figure 3.15b). This indicates that ASL are not only targeting more prey species overall, but also a greater spectrum of prey. This is confirmed by the Mann Whitney U test where there was a significant difference between the measures of both delta+ (p-value = 0.0009) and lambda+ (p-value = 0.0186) (Table 3.12). This trend supports the observed variation in the frequency of detection across and within the major groups of prey (see Figures 3.3 to 3.10).

Locational and seasonal differences in prey composition of scat samples

Finally, to explore the utility of this molecular metabarcoding approach to resolve spatiotemporal variations in prey compositions, the 2014/15 dataset which contains scat samples from a range of locations and across different seasons was further evaluated. More specifically, to assess whether LNFS scat samples comprise different prey profiles dependent upon location, ordination (principal co-ordinate analysis) was performed using prey species presence/absence data across different seasons (Figures 3.16a, b, c). The prey profiles of LNFS scat samples collected during spring-summer from Gulf St Vincent (GSV) clustered out independently and significantly different to those from southern SG (PERMANOVA p =0.0001). Red Arrow Squid was prevalent among scat samples from Southern SG, while Southern Garfish and Southern Calamari were prevalent among samples from GSV, as denoted by the length and direction of the vectors (Figure 3.16a). The prey profiles of scats collected during autumn-winter revealed that Southern SG samples clustered independently and significantly from SG (PERMANOVA p =0.0001). While Red Arrow Squid was prevalent among both locations, Barracouta and Swallowtail were prevalent among samples from Southern SG and Southern Calamari, Shorthead Worm Eel and Southern Garfish in the rest of SG samples (Figure 3.16b). The prey profiles of scats collected during winter-spring revealed that while variation between Kangaroo Island samples was high, there was still a significant difference between these and those collected from the Fleurieu Peninsula (PERMANOVA p =0.0001). While Southern Calamari and Southern Garfish were equally prevalent in both locations, Red Arrow Squid and Degens Leatherjacket were more prevalent in Kangaroo Island and Little Penguin and Luminous Bay Squid were exclusive to samples from the Fleurieu Peninsula (PERMANOVA p =0.0001, Figure 3.16c). The prey profiles of ASL scat samples collected during autumn-winter from Southern SG clustered independently to those from Kangaroo Island. Although there was a significant difference between the prey profiles of scats from these two locations (PERMANOVA p =0.0166), the most prevalent prey species were equally prevalent at both locations as indicated by the equal length of the vectors (Figure 3.17). Locational variations in diet of these animals have been reported previously (Hume *et al.* 2004) and may be indicative of differences in the types of prey in the regions (e.g., due to endemism or changing availabilities), or even the occurrence of different seal cohorts (e.g., age/sex related differences associated with haul-out or breeding sites) (Page *et al.* 2005a) and requires further elucidation. Complementary DNA-based approaches which can discriminate the sex and individual identity of the animal from which the scat originated (Reed *et al.* 1997) would be useful in this regard.

In respect to differences between seasons, there were only enough LNFS scat samples to compare spring-summer with autumn-winter within Southern SG (Figure 3.18). The prey profiles clustered independently by season and were significantly different (PERMANOVA p =0.0015). Most LNFS samples comprised Red Arrow Squid in spring-summer and Barracouta in autumn-winter (as denoted by the length of the vectors in Figure 3.18), although Red Arrow Squid was still consumed by some individuals in autumn-winter. Interestingly, variability in the biomass cycles of these species (and thus their variable availability to seals as a prey item) is typically seasonal, with regionally-specific annual or bi-annual peaks in Arrow Squid populations in response to local environmental conditions (Stark 2008, Virtue *et al.* 2011), and natural annual fluctuations of Barracouta occurring with migrations into Southern Australian waters in autumn-winter (Blackburn and Gartner 1954). The influence of seasonal availability on the consumption of such prey species is thus likely in LNFS and supports earlier findings, whereby Arrow Squid dominant in summer and autumn, was replaced by a combination of Barracouta, Mackerel (*Trachurus* sp.) and New Zealand Octopus (*Octopus maorum*) in winter and spring (Fea *et al.* 1999).

Key finding 13: Spatiotemporal patterns in the prey profiles from seals were evident and highlight the sensitivity of this new molecular (metabarcoding) approach for yielding biologically informative insights into the diets of seals.

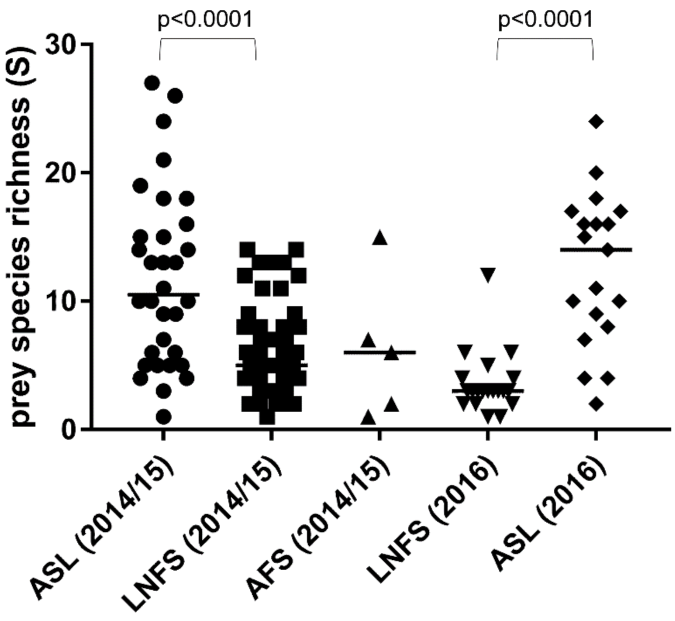


Figure 3.13. Prey species richness of scat samples grouped by seal species for the 2014/15 and the 2016 collection periods. Statistical significance was derived from the Mann-Whitney U test comparing Long-nosed Fur Seal (LNFS) and Australian Sea Lion (ASL) groups only, where alpha was set at 0.05.

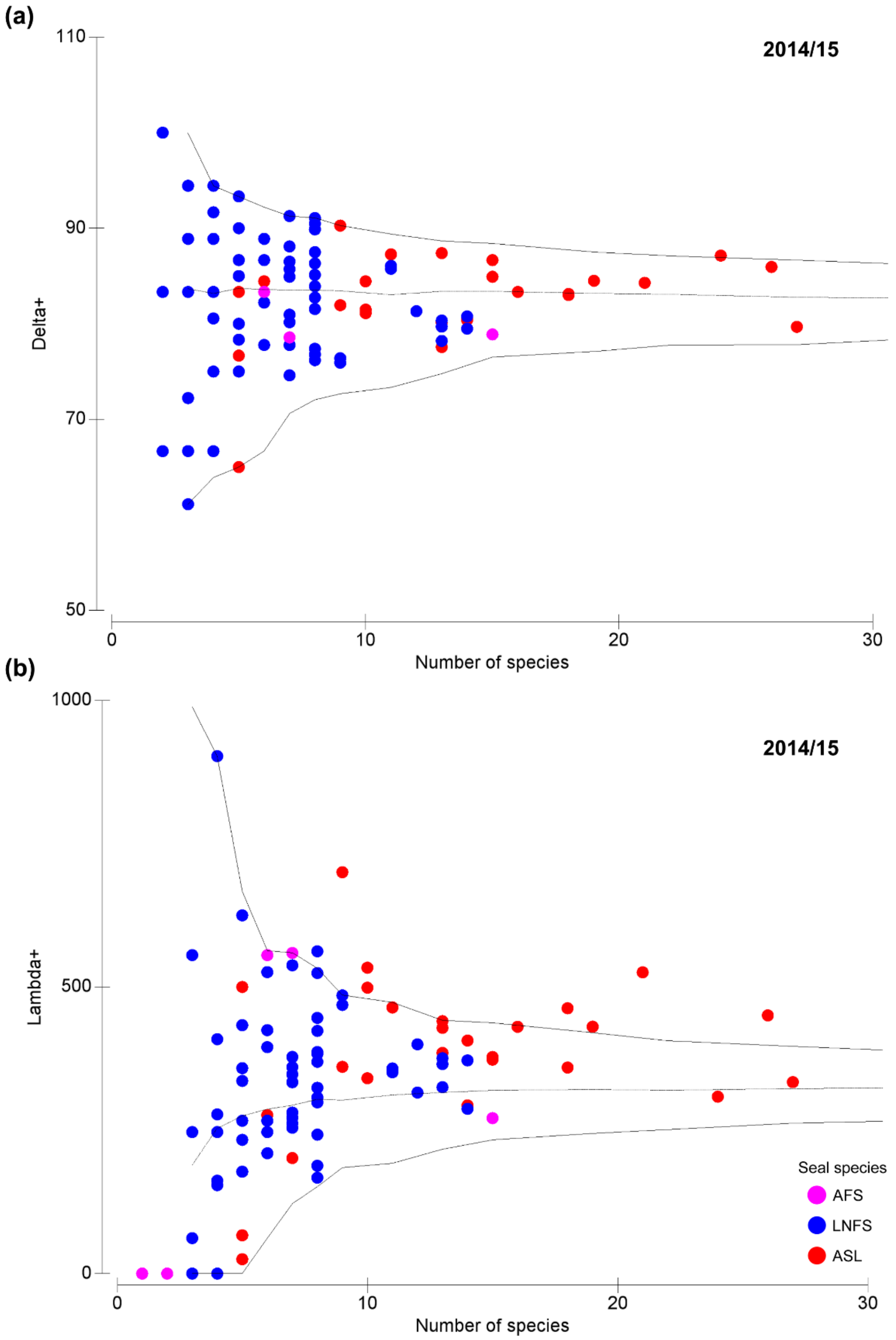


Figure 3.14. Taxonomic distinctness (TD) measures of prey species compositions from Australian Sea Lion (ASL), Long-nosed Fur Seal (LNFS) and Australian Fur Seal (AFS) scat samples collected in 2014/15. Plots chart (a) average taxonomic distinctness (avTD, delta+) and (b) variation in taxonomic distinctness (varTD, lambda+) against prey species (OTU) richness.

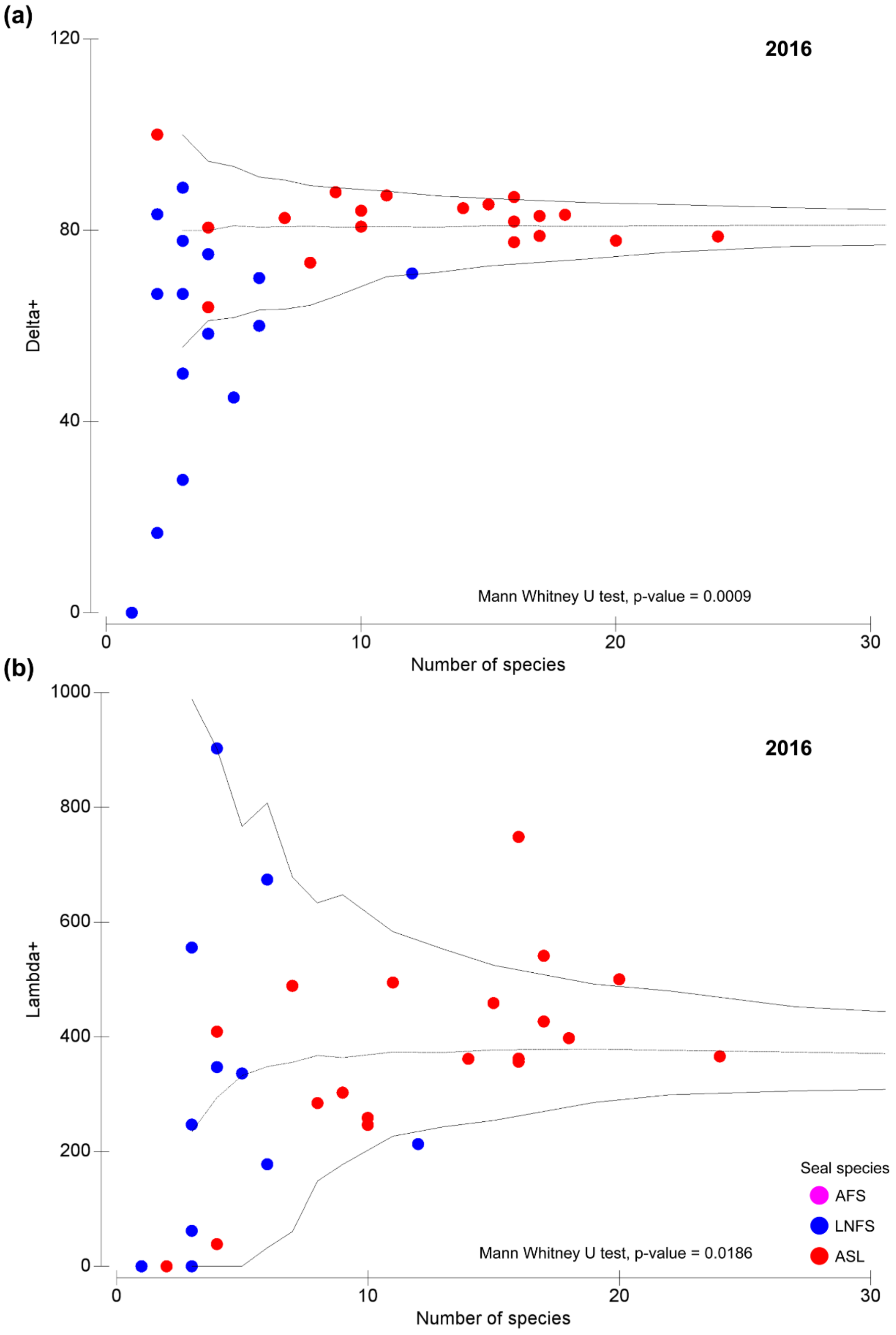


Figure 3.15. Taxonomic distinctness (TD) measures of prey species compositions from Australian Sea Lion (ASL) and Long-nosed Fur Seal (LNFS) scat samples collected in 2016. Plots chart (a) average taxonomic distinctness (avTD, delta+) and (b) variation in taxonomic distinctness (varTD, lambda+) against prey species (OTU) richness.

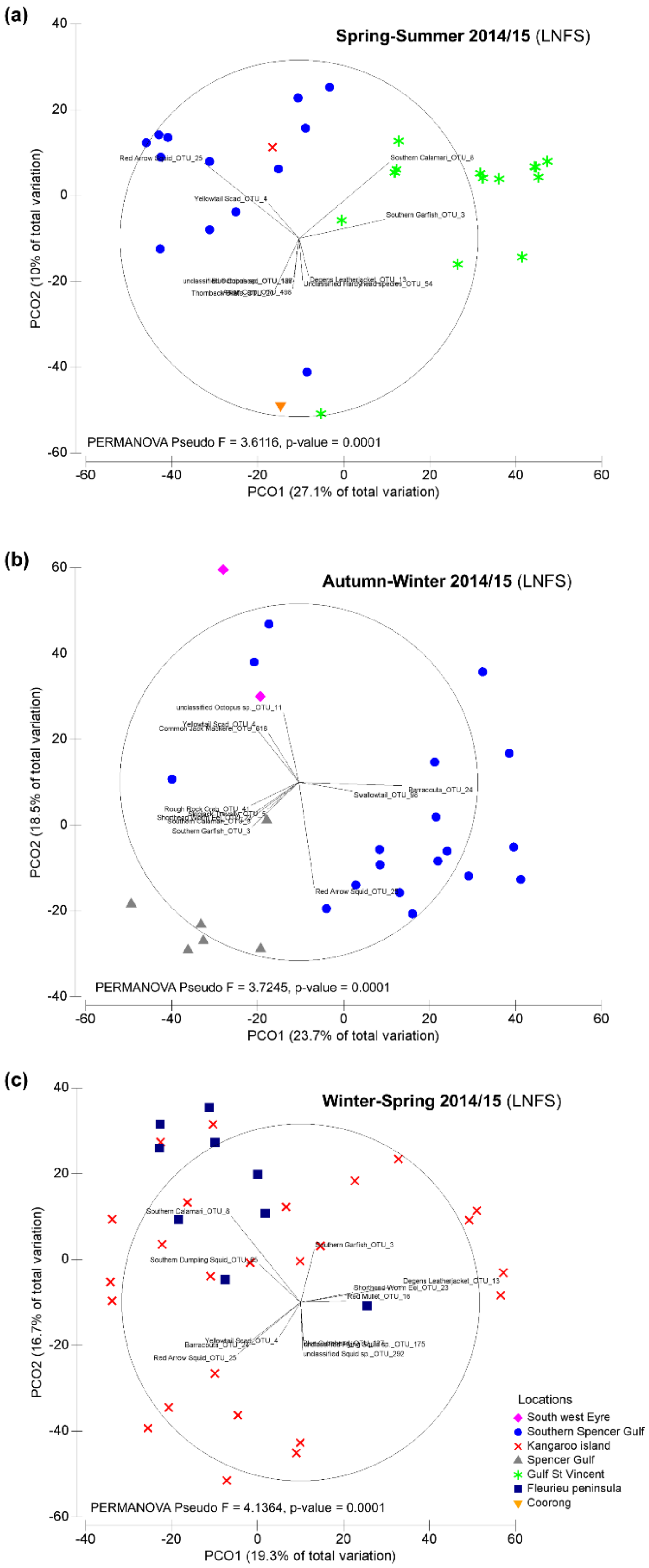


Figure 3.16. Principal Coordinate Analysis (PCoA) ordination plot representing differences in the global prey species compositions obtained from the deep-sequencing of the COI-5P region from Long-nosed Fur Seal (LNFS) scat samples collected in 2014/15 from different seasons, where PCO1 and PCO2 account for between 36-42.2% of the total variation between scats. Plots represent samples collected during (a) Spring-Summer, (b) Autumn-Winter and (c) Winter-Spring, and are overlaid with vectors to denote strongly correlating prey species.

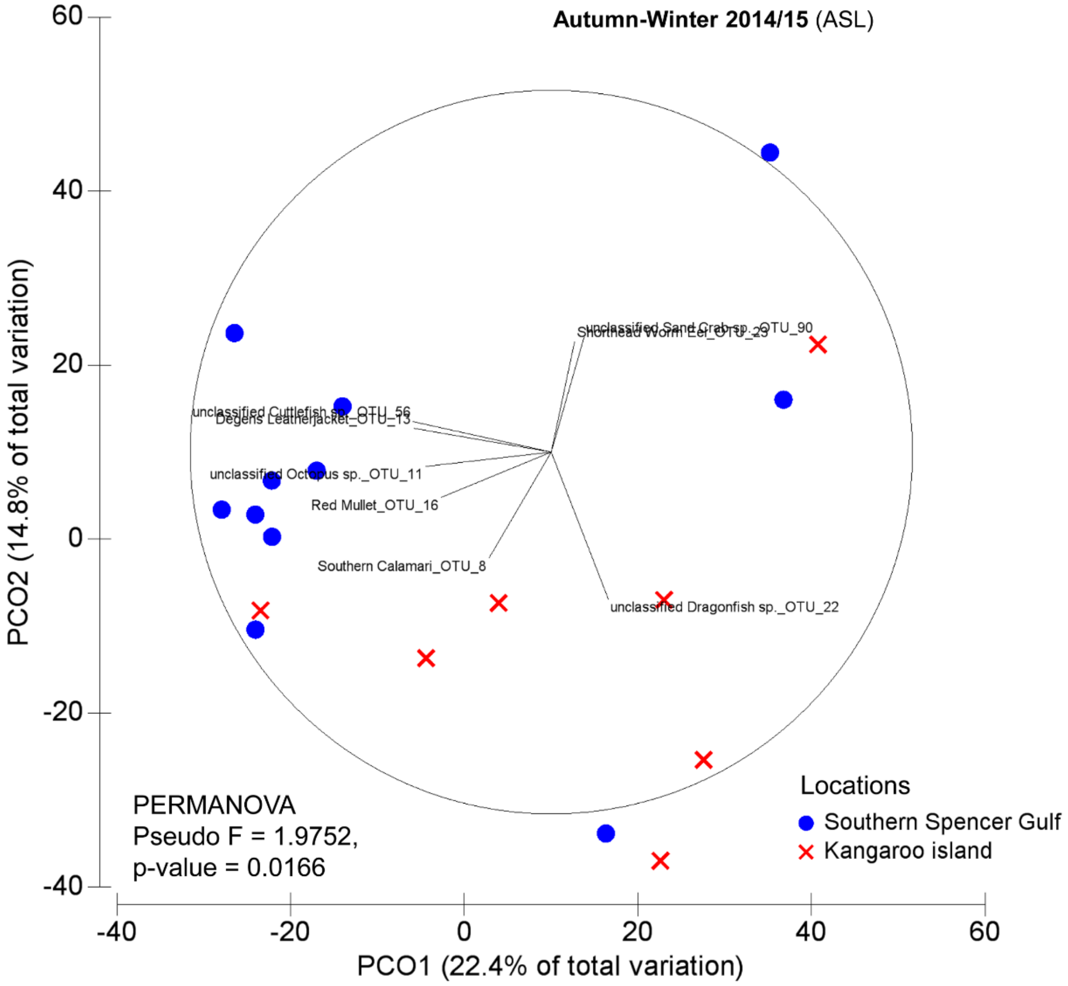


Figure 3.17. Principal Coordinate Analysis (PCoA) ordination plot representing differences in the global prey species compositions obtained from the deep-sequencing of the COI-5P region from Australian Sea Lion (ASL) scat samples collected in 2014/15 during Autumn-Winter, where PCO1 and PCO2 account for between 37.2% of the total variation between scats. The plot is overlaid with vectors to denote strongly correlating prey species.

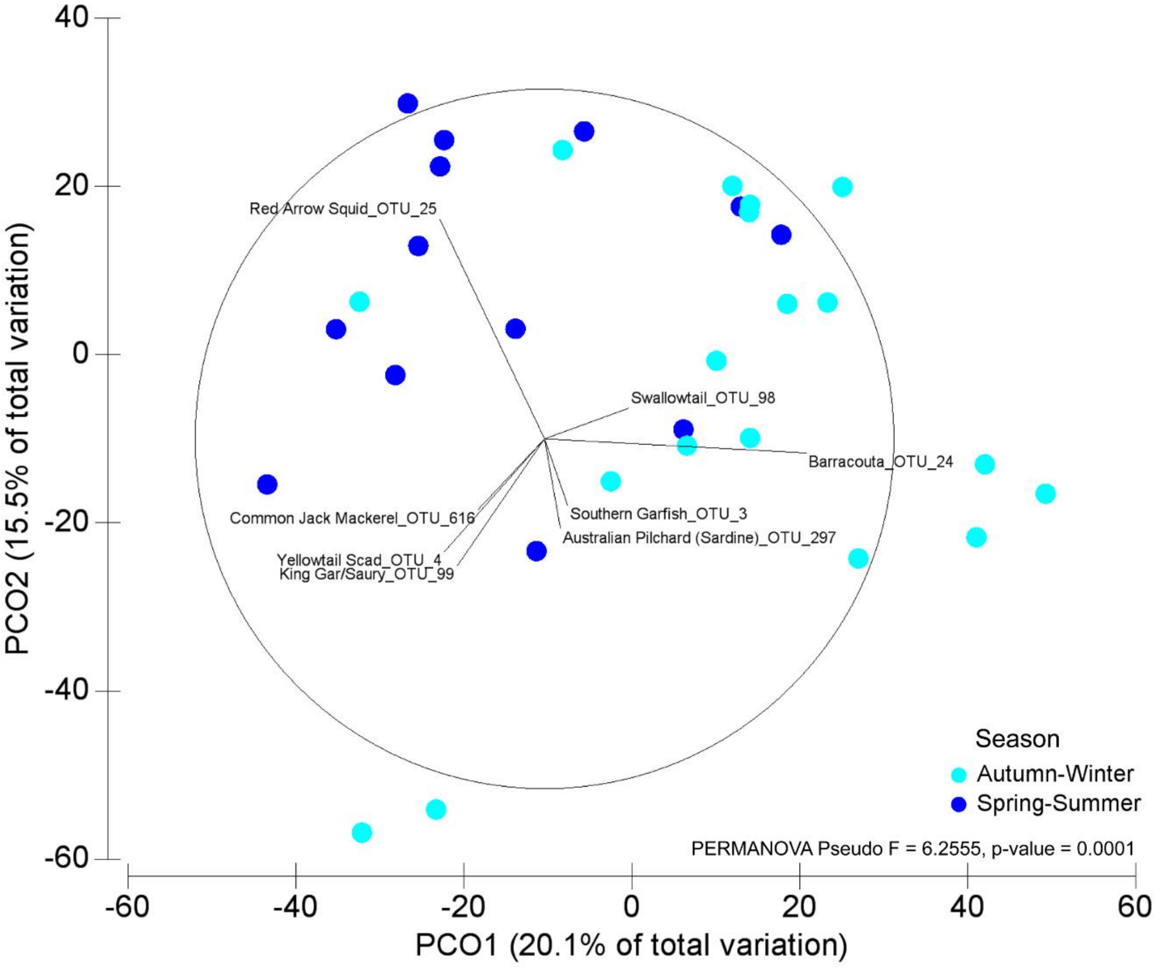


Figure 3.18. Principal Coordinate Analysis (PCoA) ordination plot representing differences in the global prey species compositions obtained from the deep-sequencing of the COI-5P region from Long-nosed Fur Seal (LNFS) scat samples collected in 2014/15 from Southern Spencer Gulf during Spring-Summer and Autumn-Winter, where PCO1 and PCO2 account for between 35.6% of the total variation between scats The plot is overlaid with vectors to denote strongly correlating prey species.

3.4 Conclusion

A new next-generation sequencing (NGS) metabarcoding approach based on the mitochondrial COI gene as a universal marker was established and validated for assessing the diets of ASL, AFS and LNFS. Its success depended on creating a reference database of relevant tissue samples and developing complementary methods for dealing with the predominance of predator (seal) DNA in the samples (i.e. with the establishment of blocking primers). Alongside the development of the laboratory protocol itself, important factors for the downstream analysis were considered; i.e. species identification of prey sequences, verification of the scat samples, sequencing depth and data handling. In doing so, a broad range of prey species was identified further extending the range already reported from these animals. Key prey important for each of the seal species were identified, with some having commercial significance, though a wider diversity of prey beyond those relevant to the fisheries sector was also evident. Seal species-specific prey preferences and spatiotemporal variations in prey compositions were also revealed, highlighting the sensitivity of this new metabarcoding approach for yielding biologically informative insights that can be used to support the broader evaluation of their feeding ecology and impacts on the seafood industry in the South Australian region.

Appendix 3.1. Data supporting the methodology used in the design of oligonucleotide primers for the dietary NGS assays

Appendix 3.1, Table 1. Universal marine metazoan COI-5P forward (mlCOIintF) and reverse (jgHCO2198) primers (Leray *et al.* 2013a)and their corresponding target sequences from seals and other marine taxa. Nucleotide matches are denoted in RED cells and mismatches in BLUE cells. [†]Representative seal prey species (based on findings from earlier molecular and hard-part studies[*]) were included, where available, from the BOLD database and the corresponding barcode index numbers (BINs) and NCBI Genbank accessions listed. Sequences from related species and other marine taxa not reported as prey were also included to assess the broader coverage of the COI gene primers, with the consensus sequences given for each rimer at bottom of the table. The total and mean numbers of mismatches are indicated for each taxa. [Δ]DNA extracts from these species were used in downstream molecular assays for validating the COI gene primers.

Forward primer: mlCOIintF (5'-3')			G	G	W	A	C	W	G	G	W	T	G	A	A	C	W	G	T	W	T	A	Y	C	C	Y	C	C	Total mismatches (mlCOIintF)
Degenerate base pos. no.					1			2			3						4			5			6			7			
Corresponding base					A/T			A/T			A/T						A/T			A/T			C/T			C/T			
Taxa (Total of 121 species)	**Genbank no.**	**BOLD BIN no.**																											
Seals (3 species)																													
Otariidae																													
Australian Fur Seal, *Arctocephalus pusillus* [Δ]	AM181018	BOLD:AAJ1798	G	G	T	A	C	**C**	G	G	A	T	G	A	A	C	**G**	G	T	T	T	A	C	C	C	T	C	C	2
Australian Sea Lion, *Neophoca cinerea* [Δ]	AM181020	BOLD:AAG5619	G	G	T	A	C	**C**	G	G	A	T	G	A	A	C	**G**	G	T	T	T	A	C	C	C	T	C	C	2
Long-nosed Fur Seal, *Arctocephalus forsteri* [Δ]	NC_004023	BOLD:ACC8434	G	G	T	A	C	**C**	G	G	A	T	G	A	A	C	A	G	T	T	T	A	C	C	C	T	C	C	1
mlCOIintF mean no. base mismatches (Seals); min and max																													**2 (min = 1, max = 2)**
Fish (69 species)																													
Argentinidae [†]																													
Smallmouth Hardyhead, *Argentina striata*	FJ918913	BOLD:AAD8991	G	G	A	A	C	T	G	G	T	T	G	A	A	C	**C**	G	T	T	T	A	C	C	C	C	C	C	1
Atherinidae [†]																													
Smelt/Argentine, *Atherinosoma microstoma*	KJ669394	BOLD:AAE0442	G	G	A	A	C	T	G	G	T	T	G	A	A	C	**C**	G	T	T	T	A	C	C	C	C	C	C	1
Arripidae [†Δ]																													
Australian Salmon, *Arripis trutta* [†Δ]	AP006810	BOLD:AAC2505	G	G	A	A	C	T	G	G	**C**	T	G	A	A	C	**C**	G	T	T	T	A	C	C	C	C	C	C	2
Berycidae [†Δ]																													
Bight Redfish, *Centroberyx gerrardi* [†Δ]	EF609315	BOLD:AAE4174	G	G	A	A	C	A	G	G	**G**	T	G	A	A	C	**G**	G	T	T	T	A	C	C	C	**A**	C	C	3
Imperador, *Beryx decadactylus* [†]	NC_004393	-	G	G	A	A	C	A	G	G	**G**	T	G	A	A	C	T	G	T	A	T	A	C	C	C	**A**	C	C	2
Splendid Alfonsino, *Beryx splendens*	DQ996312	BOLD:AAB1622	G	G	**G**	A	C	**C**	G	G	A	T	G	A	A	C	T	G	T	A	T	A	C	C	C	**A**	C	C	3
Carangidae [†Δ]																													
Jack Mackerel, *Trachurus declivis* [†Δ]	-	BOLD:AAA8614	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	**C**	T	A	T	C	C	C	C	C	1
Yellowtail Scad, *Trachurus novaezelandiae* [†]	EU182976	BOLD:AAA8614	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	**C**	T	A	T	C	C	C	C	C	1
Silver Trevally, *Pseudocaranx dentex* [†Δ]	EF609442	BOLD:AAB9929	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	A	T	A	T	C	C	C	C	C	0
Skipjack Trevally, *Pseudocaranx wrighti* [†]	EF609443	BOLD:AAC9281	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	**C**	T	A	C	C	C	C	C	C	1
Samson Fish, *Seriola hippos*	EF609459	BOLD:AAE9597	G	G	A	A	C	**G**	G	G	T	T	G	A	A	C	A	G	T	**C**	T	A	C	C	C	**G**	C	C	3
Centrolophidae [†]																													
Spotted Warehou, *Seriolella punctata* [†]	AB205440	BOLD:AAB7118	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	A	T	A	C	C	C	**G**	C	C	1
Blue Warehou, *Seriolella brama* [†]	HM007734	BOLD:AAB8496	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	A	T	A	C	C	C	**G**	C	C	1
Cheilodactylidae [†]																													
Blue Morwong (NSW spp.), *Nemadactylus douglasii*	AF136267	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jackass Morwong, *Nemadactylus macropterus* [†]	KX81853	BOLD:AAB8848	G	G	**G**	A	C	**C**	G	G	T	T	G	A	A	C	T	G	T	T	T	A	C	C	C	**G**	C	C	3
Clupeidae [†Δ]																													
Australian Pilchard (Sardine), *Sardinops sagax* [†Δ]	HQ611132	BOLD:AAB6180	G	G	**G**	A	C	**C**	G	G	A	T	G	A	A	C	T	G	T	**C**	T	A	C	C	C	C	C	C	3
Sandy Sprat, *Hyperlophus vittatus*	NC_016671	-	G	G	**G**	A	C	**C**	G	G	A	T	G	A	A	C	T	G	T	**G**	T	A	T	C	C	C	C	C	3
Diodontidae [†]																													
Australian Burrfish, *Allomycterus pilatus* [†]	JQ681753	BOLD:AAF2559	G	G	**G**	A	C	A	G	G	A	T	G	A	A	C	A	G	T	**C**	T	A	C	C	C	**G**	C	C	3
Emmelichthyidae [†]																													
Redbait, *Emmelichthys nitidus* [†]	-	BOLD:AAB8696	G	G	T	A	C	T	G	G	**G**	T	G	A	A	C	A	G	T	**C**	T	A	C	C	C	C	C	C	2
Engraulidae [†]																													
Australian Anchovy, *Engraulis australis* [†]	HQ167626	BOLD:AAB2317	G	G	**G**	A	C	A	G	G	A	T	G	A	A	C	A	G	T	**C**	T	A	C	C	C	C	C	C	2
Enoplosidae [†]																													
Old Wife Fish, *Enoplosus armatus* [†]	NC_013181	BOLD:ACM7266	G	G	A	A	C	**G**	G	G	**C**	T	G	A	A	C	**C**	G	T	**C**	T	A	C	C	C	T	C	C	4
Epigonidae																													
Cardinalfish, *Epigonus telescopus*	HM007702	BOLD:AAB5843	G	G	**C**	A	C	**C**	G	G	A	T	G	A	A	C	**G**	G	T	T	T	A	C	C	C	T	C	C	3
Gempylidae [†]																													
Barracouta, *Thyrsites atun* [†]	EU263814	BOLD:AAB5033	G	G	**G**	A	C	T	G	G	A	T	G	A	A	C	**C**	G	T	T	T	A	T	C	C	C	C	C	2
Western Gemfish, *Rexea solandri* [†]	EU263803	BOLD:AAB5033	G	G	A	A	C	T	G	G	**G**	T	G	A	A	C	A	G	T	T	T	A	C	C	C	T	C	C	1
Gerreidae [†]																													
Silver Biddy (Sth African spp.), *Gerres methueni*	-	BOLD:AAF8786	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiramphidae [†]																													
Longtail Garfish (Nth Australian spp.), *Hyporhamphus quoyi*	EF609376	BOLD:AAC4256	G	G	A	A	C	A	G	G	**C**	T	G	A	A	C	A	G	T	T	T	A	T	C	C	T	C	C	1
Kyphosidae [†Δ]																													
Mado, *Atypichthys strigatus* [†Δ]	DQ107778	BOLD:AAC9869	G	G	**C**	A	C	T	G	G	T	T	G	A	A	C	**C**	G	T	**C**	T	A	C	C	C	T	C	C	3
Sweep, *Scorpis lineolata* [Δ]	AP011063	BOLD:AAD9146	G	G	T	A	C	T	G	G	**C**	T	G	A	A	C	T	G	T	**C**	T	A	C	C	C	C	C	C	2
Labridae [†Δ]																													
Bluethroat Wrasse, *Notolabrus tetricus* [†Δ]	EF609419	BOLD:AAF2693	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	G	T	T	T	A	C	C	C	T	C	C	0
Crimsonband wrasse, *Notolabrus gymnogensis*	EF609419	BOLD:AAE2123	G	G	**G**	A	C	T	G	G	T	T	G	A	A	C	A	G	T	**C**	T	A	C	C	C	C	C	C	2

Reverse primer: jgHCO2198 (5'-3')	T	A	I	A	C	Y	T	C	I	G	G	R	T	G	I	C	C	R	A	A	R	A	A	Y	C	A	Total mismatches (jgHCO2198)
Reverse primer (reverse comp.): jgHCO2198 (5'-3')	T	G	R	T	T	Y	T	T	Y	G	G	I	C	A	Y	C	C	I	G	A	R	G	T	I	T	A	
Degenerate base pos. no.			1			2			3			4			5			6			7			8			
Corresponding base (reverse comp. sequence)			A/G			C/T			C/T			N			C/T			N			A/G			N			
Seals (3 species)																											
Otariidae																											
Australian Fur Seal, *Arctocephalus pusillus* [Δ]	T	G	A	T	T	C	T	T	C	G	G	A	C	A	C	C	C	A	G	A	A	G	T	A	T	A	0
Australian Sea Lion, *Neophoca cinerea* [Δ]	T	G	A	T	T	C	T	T	C	G	G	A	C	A	T	C	C	A	G	A	A	G	T	A	T	A	0
Long-nosed Fur Seal, *Arctocephalus forsteri* [Δ]	T	G	A	T	T	C	T	T	C	G	G	A	C	A	C	C	C	A	G	A	A	G	T	G	T	A	0
jgHCO2198 mean no. base mismatches (Seals)																											**0**
Fish (69 species)																											
Argentinidae [†]																											
Smallmouth Hardyhead, *Argentina striata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atherinidae [†]																											
Smelt/Argentine, *Atherinosoma microstoma*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arripidae [†Δ]																											
Australian Salmon, *Arripis trutta* [†Δ]	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	A	G	A	A	G	T	T	T	A	0
Berycidae [†Δ]																											
Bight Redfish, *Centroberyx gerrardi* [†Δ]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Imperador, *Beryx decadactylus* [†]	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Splendid Alfonsino, *Beryx splendens*	T	G	A	T	T	C	T	T	T	G	G	C	C	A	T	C	C	A	G	A	A	G	T	T	T	A	0
Carangidae [†Δ]																											
Jack Mackerel, *Trachurus declivis* [†Δ]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yellowtail Scad, *Trachurus novaezelandiae* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver Trevally, *Pseudocaranx dentex* [†Δ]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skipjack Trevally, *Pseudocaranx wrighti* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Samson Fish, *Seriola hippos*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrolophidae [†]																											
Spotted Warehou, *Seriolella punctata* [†]	T	G	A	T	T	C	T	T	C	G	G	A	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Blue Warehou, *Seriolella brama* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cheilodactylidae [†]																											
Blue Morwong (NSW spp.), *Nemadactylus douglasii*	T	G	G	T	T	C	T	T	T	G	G	C	C	A	T	C	C	T	G	A	A	G	T	G	T	A	0
Jackass Morwong, *Nemadactylus macropterus* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clupeidae [†Δ]																											
Australian Pilchard (Sardine), *Sardinops sagax* [†Δ]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sandy Sprat, *Hyperlophus vittatus*	T	G	G	T	T	C	T	T	C	G	G	C	C	A	C	C	C	C	G	A	A	G	T	C	T	A	0
Diodontidae [†]																											
Australian Burrfish, *Allomycterus pilatus* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Emmelichthyidae [†]																											
Redbait, *Emmelichthys nitidus* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Engraulidae [†]																											
Australian Anchovy, *Engraulis australis* [†]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enoplosidae [†]																											
Old Wife Fish, *Enoplosus armatus* [†]	T	G	A	T	T	T	T	T	T	G	G	A	C	A	T	C	C	A	G	A	A	G	T	C	T	A	0
Epigonidae																											
Cardinalfish, *Epigonus telescopus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gempylidae [†]																											
Barracouta, *Thyrsites atun* [†]	T	G	A	T	T	T	T	T	T	G	G	C	C	A	C	C	C	C	G	A	A	G	T	C	T	A	0
Western Gemfish, *Rexea solandri* [†]	T	G	A	T	T	T	T	T	T	G	G	C	C	A	C	C	C	C	G	A	A	G	T	C	T	A	0
Gerreidae [†]																											
Silver Biddy (Sth African spp.), *Gerres methueni*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiramphidae [†]																											
Longtail Garfish (Nth Australian spp.), *Hyporhamphus quoyi*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kyphosidae [†Δ]																											
Mado, *Atypichthys strigatus* [†Δ]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sweep, *Scorpis lineolata* [Δ]	T	G	A	T	T	C	T	T	C	G	G	C	C	A	T	C	C	C	G	A	A	G	T	T	T	A	0
Labridae [†Δ]																											
Bluethroat Wrasse, *Notolabrus tetricus* [†Δ]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crimsonband wrasse, *Notolabrus gymnogensis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 3.1 Table 1. Continued

Forward primer: mICOlintF (5'-3')			G	G	W	A	C	W	G	G	W	T	G	A	A	C	W	G	T	W	T	A	Y	C	C	Y	C	C	**Total mismatches (mICOlintF)**
Degenerate base pos. no.					1			2			3						4			5			6			7			
Corresponding base					A/T			A/T			A/T						A/T			A/T			C/T			C/T			
Taxa (Total of 121 species)	**Genbank no.**	**BOLD BIN no.**																											
Fish (69 species) cont'd																													
Latridae †																													
Stripey Trumpeter, *Latris lineata*	AF156246	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microstomatidae †																													
Pencil Smelt, *Nansenia antarctica*	JN640707	BOLD:AAG7094	G	G	A	A	C	G	G	G	C	T	G	A	A	C	A	G	T	A	T	A	C	C	C	A	C	C	3
Monacanthidae †Δ																													
Sixspine Leatherjacket, *Meuschenia freycineti* †Δ	KF025707	BOLD:AAC5090	G	G	A	A	C	C	G	G	C	T	G	G	A	C	C	G	T	T	T	A	T	C	C	C	C	C	4
Yellowfin Leatherjacket, *Meuschenia trachylepis* †	KF025709	BOLD:AAC5092	G	G	G	A	C	C	G	G	G	T	G	A	A	C	C	G	T	T	T	A	T	C	C	C	C	C	4
Spinytail Leatherjacket, *Acanthaluteres brownii* †	NC_011947	BOLD:AAD7305	G	G	G	A	C	C	G	G	A	T	G	A	A	C	T	G	T	T	T	A	T	C	C	C	C	C	2
Toothbrush Leatherjacket, *Acanthaluteres vittiger* †	KF025694	BOLD:AAC1015	G	G	G	A	C	C	G	G	A	T	G	A	A	C	C	G	T	T	T	A	T	C	C	C	C	C	3
Moridae †																													
Red Cod, *Pseudophycis bachus* †	EF609444	BOLD:AAB8051	G	G	G	A	C	A	G	G	A	T	G	A	A	C	T	G	T	C	T	A	C	C	C	T	C	C	2
Beardie, *Lotella rhacina* †	EF609392	BOLD:AAD7850	G	G	G	A	C	A	G	G	T	T	G	A	A	C	T	G	T	T	T	A	C	C	C	C	C	C	1
Mugilidae †																													
Yellow-eyed Mullet, *Aldrichetta forsteri*	NC_017879	-	G	G	A	A	C	A	G	G	A	T	G	A	A	C	C	G	T	T	T	A	C	C	C	T	C	C	1
Red Mullet, *Upeneichthys vlamingii* †	DQ107791	-	G	G	G	A	C	T	G	G	A	T	G	A	A	C	T	G	T	G	T	A	C	C	C	C	C	C	2
Mullidae †																													
Blue-spotted Goatfish, *Upeneichthys vlamingii* †	DQ107791	BOLD:AAC2007	G	G	G	A	C	T	G	G	A	T	G	A	A	C	T	G	T	G	T	A	C	C	C	C	C	C	2
Myctophidae †																													
False-midas Lanternfish, *Gymnoscopelus hintonoides* †	JN640969	BOLD:AAC0459	G	G	A	A	C	T	G	G	C	T	G	A	A	C	A	G	T	C	T	A	C	C	C	T	C	C	2
Southern Blacktip Lanternfish, *Gymnoscopelus piabilis* †	JN640704	BOLD:AAC0459	G	G	T	A	C	T	G	G	T	T	G	A	A	C	T	G	T	T	T	A	T	C	C	G	C	C	1
Evermann's Lanternfish, *Symbolophorus evermanni* †	GU440540	BOLD:AAD4625	G	G	T	A	C	T	G	G	T	T	G	A	A	C	T	G	T	T	T	A	T	C	C	G	C	C	1
Neosebastidae †																													
Incised Gurnard Perch, *Neosebastes incisipinnis*	DQ108058	BOLD:AAE1385	G	G	A	A	C	C	G	G	G	T	G	A	A	C	G	G	T	C	T	A	C	C	C	A	C	C	5
Odacidae †																													
Blue Weed Whiting, *Haletta semifasciata*	EF609368	BOLD:AAC1176	G	G	C	A	C	G	G	G	A	T	G	A	A	C	A	G	T	C	T	A	C	C	C	G	C	C	4
Ophidiidae †Δ																													
Pink Ling, *Genypterus blacodes* †	EF609354	BOLD:AAB2203	G	G	A	A	C	C	G	G	T	T	G	A	A	C	C	G	T	T	T	A	C	C	C	G	C	C	3
Pempheridae †																													
Sweeper (Sth African spp.), *Pempheris schwenkii*	HQ561454	BOLD:AAF8820	G	G	C	A	C	T	G	G	T	T	G	A	A	C	C	G	T	T	T	A	C	C	C	A	C	C	3
Pinguipedidae †																													
Barred Grubfish, *Parapercis allporti* †	KJ817172	BOLD:AAE6842	G	G	G	A	C	C	G	G	C	T	G	A	A	C	A	G	T	C	T	A	T	C	C	T	C	C	4
Platycephalidae †Δ																													
Tiger Flathead, *Platycephalus richardsoni* †Δ	JX488214	BOLD:AAG9505	G	G	A	A	C	C	G	G	C	T	G	A	A	C	A	G	T	C	T	A	C	C	C	A	C	C	3
Pleuronectidae †																													
Greenback Flounder, *Rhombosolea tapirina*	EF609448	BOLD:AAC7814	G	G	A	A	C	C	G	G	T	T	G	A	A	C	C	G	T	G	T	A	C	C	C	C	C	C	3
Long-snouted Flounder, *Ammotretis rostratus*	EF609281	BOLD:AAD5520	G	G	C	A	C	T	G	G	T	T	G	A	A	C	A	G	T	C	T	A	C	C	C	C	C	C	2
Scomberesocidae †																													
King Gar, *Scomberesox saurus* †	-	BOLD:ACY2657	G	G	A	A	C	C	G	G	A	T	G	A	A	C	T	G	T	T	T	A	C	C	C	A	C	C	2
Scombridae †Δ																													
Blue Mackerel, *Scomber australasicus* †	JF952849	BOLD:AAA5957	G	G	A	A	C	T	G	G	C	T	G	A	A	C	A	G	T	T	T	A	T	C	C	T	C	C	1
Yellowfin Tuna, *Thunnus albacares*	JN086153	-	G	G	A	A	C	C	G	G	T	T	G	A	A	C	A	G	T	C	T	A	C	C	C	T	C	C	2
Southern Bluefin Tuna, *Thunnus maccoyii* Δ	JN086150	-	G	G	A	A	C	C	G	G	T	T	G	A	A	C	A	G	T	C	T	A	T	C	C	T	C	C	2
Scorpaenidae †																													
Rock Cod (Nth Australian spp.), *Scorpaena sp.*	UG0632	BOLD:AAE9847	G	G	G	A	C	A	G	G	T	T	G	A	A	C	C	G	T	G	T	A	C	C	C	C	C	C	3
Ocean Perch, *Helicolenus barathri* †	EF609370	BOLD:AAA9248	G	G	A	A	C	C	G	G	T	T	G	A	A	C	A	G	T	G	T	A	T	C	C	A	C	C	3
Sebastidae †																													
(Asian spp.) *Helicolenus hilgendorfi*	AP002948	BOLD:AAA9248	G	G	A	A	C	C	G	G	T	T	G	A	A	C	A	G	T	G	T	A	T	C	C	A	C	C	3
Red Gurnard Perch, *Helicolenus percoides* †	DQ108056	BOLD:AAA9248	G	G	A	A	C	C	G	G	T	T	G	A	A	C	A	G	T	G	T	A	T	C	C	A	C	C	3
Serranidae †																													
Longfin Perch, *Caprodon longimanus*	DQ107893	BOLD:AAB0653	G	G	C	A	C	C	G	G	G	T	G	A	A	C	G	G	T	G	T	A	T	C	C	G	C	C	6
Sillaginidae †Δ																													
Eastern School Whiting, *Sillago flindersi* †	EF609468	BOLD:AAC4203	G	G	T	A	C	T	G	G	A	T	G	A	A	C	C	G	T	A	T	A	C	C	C	C	C	C	1
King George Whiting, *Sillaginodes punctatus* † Δ	EF609465	BOLD:AAC4968	G	G	G	A	C	C	G	G	G	T	G	A	A	C	A	G	T	A	T	A	T	C	C	G	C	C	4
Silver Whiting, *Sillago bassensis* †	EF609466	BOLD:AAD0981	G	G	A	A	C	T	G	G	A	T	G	A	A	C	C	G	T	G	T	A	C	C	C	C	C	C	2
Sparidae †																													
Snapper, *Chrysophrys auratus* †	DQ107841	BOLD:AAC0553	G	G	C	A	C	T	G	G	G	T	G	A	A	C	A	G	T	T	T	A	T	C	C	A	C	C	3
Triglidae †																													
Rough-snouted Gurnard, *Lepidotrigla mulhalli*	DQ108031	BOLD:AAD1873	G	G	G	A	C	A	G	G	A	T	G	A	A	C	T	G	T	T	T	A	C	C	C	T	C	C	1
Uranoscopidae †																													
Giant Star Gazer (New Zealand spp.), *Kathestostoma giganteum*	EU854573	BOLD:ACE5830	G	G	T	A	C	C	G	G	C	T	G	A	A	C	A	G	T	T	T	A	T	C	C	G	C	C	3
Zeidae †																													
Silver Dory, *Cyttus australis* †	EF609340	BOLD:AAC9507	G	G	T	A	C	T	G	G	A	T	G	A	A	C	A	G	T	T	T	A	C	C	C	C	C	C	0
John Dory, *Zeus faber* †	EU869848	BOLD:AAA7904	G	G	G	A	C	A	G	G	A	T	G	A	A	C	A	G	T	C	T	A	C	C	C	C	C	C	2
mICOlintF mean no. base mismatches (Fish) ± SD; min and max																													**2 ± 1 (min = 0, max = 6)**

Reverse primer: jgHCO2198 (5'-3')	T	A	I	A	C	Y	T	C	I	G	G	R	T	G	I	C	C	R	A	A	R	A	A	Y	C	A	**Total mismatches (jgHCO2198)**
Reverse primer (reverse comp.): jgHCO2198 (5'-3')	T	G	R	T	T	Y	T	T	Y	G	G	I	C	A	Y	C	C	I	G	A	R	G	T	I	T	A	
Degenerate base pos. no.			1			2			3			4			5			6			7			8			
Corresponding base (reverse comp. sequence)			A/G			C/T			C/T			N			C/T			N			A/G			N			
Fish (69 species) cont'd																											
Latridae †																											
Stripey Trumpeter, *Latris lineata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microstomatidae †																											
Pencil Smelt, *Nansenia antarctica*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monacanthidae †Δ																											
Sixspine Leatherjacket, *Meuschenia freycineti* †Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yellowfin Leatherjacket, *Meuschenia trachylepis* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spinytail Leatherjacket, *Acanthaluteres brownii* †	T	G	A	T	T	C	T	T	C	G	G	G	C	A	C	C	C	T	G	A	A	G	T	T	T	A	0
Toothbrush Leatherjacket, *Acanthaluteres vittiger* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Moridae †																											
Red Cod, *Pseudophycis bachus* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beardie, *Lotella rhacina* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mugilidae †																											
Yellow-eyed Mullet, *Aldrichetta forsteri*	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	C	G	A	A	G	T	G	T	A	0
Red Mullet, *Upeneichthys vlamingii* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mullidae †																											
Blue-spotted Goatfish, *Upeneichthys vlamingii* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Myctophidae †																											
False-midas Lanternfish, *Gymnoscopelus hintonoides* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southern Blacktip Lanternfish, *Gymnoscopelus piabilis* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Evermann's Lanternfish, *Symbolophorus evermanni* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Neosebastidae †																											
Incised Gurnard Perch, *Neosebastes incisipinnis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Odacidae †																											
Blue Weed Whiting, *Haletta semifasciata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ophidiidae †Δ																											
Pink Ling, *Genypterus blacodes* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pempheridae †																											
Sweeper (Sth African spp.), *Pempheris schwenkii*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinguipedidae †																											
Barred Grubfish, *Parapercis allporti* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platycephalidae †Δ																											
Tiger Flathead, *Platycephalus richardsoni* †Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleuronectidae †																											
Greenback Flounder, *Rhombosolea tapirina*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Long-snouted Flounder, *Ammotretis rostratus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scomberesocidae †																											
King Gar, *Scomberesox saurus* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scombridae †Δ																											
Blue Mackerel, *Scomber australasicus* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yellowfin Tuna, *Thunnus albacares*	T	G	A	T	T	C	T	T	T	G	G	A	C	A	T	C	C	A	G	A	A	G	T	C	T	A	0
Southern Bluefin Tuna, *Thunnus maccoyii* Δ	T	G	A	T	T	C	T	T	T	G	G	G	C	A	T	C	C	A	G	A	A	G	T	C	T	A	0
Scorpaenidae †																											
Rock Cod (Nth Australian spp.), *Scorpaena sp.*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ocean Perch, *Helicolenus barathri* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sebastidae †																											
(Asian spp.) *Helicolenus hilgendorfi*	T	G	A	T	T	C	T	T	T	G	G	A	C	A	C	C	C	A	G	A	A	G	T	A	T	A	0
Red Gurnard Perch, *Helicolenus percoides* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Serranidae †																											
Longfin Perch, *Caprodon longimanus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sillaginidae †Δ																											
Eastern School Whiting, *Sillago flindersi* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
King George Whiting, *Sillaginodes punctatus* † Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver Whiting, *Sillago bassensis* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sparidae †																											
Snapper, *Chrysophrys auratus* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triglidae †																											
Rough-snouted Gurnard, *Lepidotrigla mulhalli*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranoscopidae †																											
Giant Star Gazer (New Zealand spp.), *Kathestostoma giganteum*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zeidae †																											
Silver Dory, *Cyttus australis* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
John Dory, *Zeus faber* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
jgHCO2198 mean no. base mismatches (Fish)																											**0**

Appendix 3.1 Table 1. Continued

Forward primer: mlCOIintF (5'-3')			**G**	**G**	**W**	**A**	**C**	**W**	**G**	**G**	**W**	**T**	**G**	**A**	**A**	**C**	**W**	**G**	**T**	**W**	**T**	**A**	**Y**	**C**	**C**	**Y**	**C**	**C**	**Total mismatches (mlCOIintF)**
Degenerate base pos. no.					1			2			3						4			5			6			7			
Corresponding base					A/T			A/T			A/T						A/T			A/T			C/T			C/T			
Taxa (Total of 121 species)	**Genbank no.**	**BOLD BIN no.**																											
Elasmobranchs (Sharks, Skates and Rays) (12 species)																													
Heterodontidae Δ																													
Port Jackson Shark, *Heterodontus portusjacksoni* Δ	EU398832	BOLD:AAC3066	G	G	A	A	C	T	G	G	C	T	G	A	A	C	A	G	T	T	T	A	C	C	C	C	C	C	1
Orectolobidae †Δ																													
Gulf Wobbegong Shark, *Orectolobus halei* Δ	EU398942	BOLD:ABY7771	G	G	A	A	C	A	G	G	T	T	G	A	A	C	A	G	T	T	T	A	T	C	C	A	C	C	1
Spotted Wobbegong Shark, *Orectolobus maculatus*	EU398953	BOLD:ABY7771	G	G	A	A	C	A	G	G	T	T	G	A	A	C	A	G	T	T	T	A	T	C	C	A	C	C	1
Triakidae Δ																													
Gummy Shark, *Mustelus antarcticus* Δ	DQ108312	BOLD:AAA4344	G	G	T	A	C	T	G	G	T	T	G	A	A	C	A	G	T	T	T	A	C	C	C	A	C	C	1
School Shark, *Galeorhinus galeus* Δ	DQ108320	BOLD:AAB3071	G	G	T	A	C	T	G	G	T	T	G	A	A	C	A	G	T	A	T	A	T	C	C	T	C	C	0
Squalidae Δ																													
Whitespotted Dogfish, *Squalus acanthias* Δ	Y18134	BOLD:AAA1547	G	G	A	A	C	C	G	G	C	T	G	A	A	C	A	G	T	C	T	A	C	C	C	C	C	C	3
Spikey Dogfish, *Squalus megalops*	DQ108268	BOLD:AAA1550	G	G	A	A	C	C	G	G	C	T	G	A	A	C	A	G	T	T	T	A	C	C	C	C	C	C	2
Dasyatidae																													
Smooth Stingray, *Trygonorrhina guanerius*	EF609341	BOLD:AAD0403	G	G	T	A	C	A	G	G	A	T	G	A	A	C	A	G	T	T	T	A	C	C	C	T	C	C	0
Myliobatidae †Δ																													
Southern Eagle Ray, *Myliobatis australis* †Δ	JN184064	BOLD:AAB7920	G	G	A	A	C	T	G	G	G	T	G	A	A	C	A	G	T	T	T	A	C	C	C	C	C	C	1
Rhinobatidae †Δ																													
Southern Fiddler Ray, *Trygonorrhina guanerius* †Δ	JN184081	BOLD:ABC9048	G	G	G	A	C	T	G	G	T	T	G	A	A	C	T	G	T	C	T	A	T	C	C	C	C	C	2
Rajidae †																													
Brown Skate (Sth African spp.), *Raja miraletus*	JF494345	BOLD:AAA4359	G	G	A	A	C	A	G	G	T	T	G	A	A	C	A	G	T	C	T	A	C	C	C	A	C	C	2
Urolophidae Δ																													
Banded Stingaree, *Urolophus cruciatus* Δ	JN184085	BOLD:AAC3932	G	G	A	A	C	C	G	G	A	T	G	A	A	C	C	G	T	A	T	A	T	C	C	C	C	C	2
mlCOIintF mean no. base mismatches (Elasmobranchs) ± SD; min and max																													**1 ± 1 (min = 0, max = 3)**
Cephalopods (Cuttlefish, Octopus and Squid) (10 species)																													
Octopodidae †																													
Common Octopus, *Octopus vulgaris*	AB158363	BOLD:AAB0289	G	G	T	A	C	C	G	G	A	T	G	A	A	C	C	G	T	T	T	A	C	C	C	G	C	C	3
Octopoda sp. (Sth Australian spp.)†	-	BOLD:ABU6719	G	G	A	A	C	C	G	G	T	T	G	A	A	C	C	G	T	T	T	A	T	C	C	T	C	C	2
Sydney Octopus, *Octopus tetricus*	AF000065	BOLD:AAW9989	G	G	T	A	C	C	G	G	A	T	G	A	A	C	C	G	T	T	T	A	T	C	C	A	C	C	3
Enoploteuthidae †																													
Southern Argonaut, *Argonauta nodosa* †	GU000028	BOLD:AAJ8255	G	G	A	A	C	T	G	G	A	T	G	A	A	C	T	G	T	A	T	A	T	C	C	G	C	C	1
Histioteuthidae †																													
Jewel Squid, *Histioteuthis* sp.†	GU220787	BOLD:ACH3185	G	G	A	A	C	A	G	G	A	T	G	A	A	C	A	G	T	A	T	A	C	C	C	T	C	C	0
Loliginidae †Δ																													
Southern Calamari Squid, *Sepioteuthis australis* †Δ	AF000065	BOLD:AAF0818	G	G	T	A	C	T	G	G	G	T	G	A	A	C	T	G	T	A	T	A	C	C	C	C	C	C	1
Ommastrephidae †Δ																													
Red Arrow Squid, *Nototodarus gouldi* †Δ	AB270939	BOLD:AAI2536	G	G	G	A	C	T	G	G	T	T	G	A	A	C	A	G	T	T	T	A	C	C	C	T	C	C	1
Southern Arrow Squid, *Todarodes filippovae* †	AB270935	BOLD:ACB7703	G	G	A	A	C	A	G	G	A	T	G	A	A	C	A	G	T	T	T	A	T	C	C	T	C	C	0
Sepiidae †Δ																													
Giant Australian Cuttlefish, *Sepia apama* †Δ	AB675092	BOLD:ACI2463	G	G	G	A	C	A	G	G	A	T	G	A	A	C	A	G	T	A	T	A	C	C	C	C	C	C	1
Sepiolidae †																													
Southern Dumpling Squid, *Euprymna tasmanica* †	AY293713	BOLD:AAB6392	G	G	T	A	C	A	G	G	G	T	G	A	A	C	T	G	T	A	T	A	C	C	C	T	C	C	1
mlCOIintF mean no. base mismatches (Cephalopods) ± SD; min and max																													**1 ± 1 (min = 0, max = 3)**
Crustacea (Crabs, Prawns, Bugs and Lobsters) (10 species)																													
Menippidae																													
Giant Crab, *Pseudocarcinus gigas*	AY562127	BOLD:AAD5400	G	G	A	A	C	A	G	G	T	T	G	A	A	C	T	G	T	C	T	A	C	C	C	T	C	C	1
Portunidae Δ																													
Three-spot Swimming Crab, *Portunus sanguinolentus*	EU284144	BOLD:ACD2337	G	G	T	A	C	T	G	G	T	T	G	A	A	C	T	G	T	C	T	A	C	C	C	T	C	C	1
Blue Swimmer Crab, *Portunus armatus* Δ	EF661934	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Penaeidae †																													
Caramote Prawn (Atlantic spp.), *Melicertus kerathurus*	-	BOLD:AAB4142	G	G	A	A	C	A	G	G	A	T	G	A	A	C	A	G	T	C	T	A	C	C	C	T	C	C	1
Tiger Prawn (Nth Australian spp.), *Penaeus monodon*	AF217843	BOLD:AAD1869	G	G	A	A	C	T	G	G	A	T	G	A	A	C	A	G	T	A	T	A	C	C	C	T	C	C	0
Scyllaridae Δ																													
Slipper/Velvet Fan Lobster (bug), *Ibacus alticrenatus*	JN701660	BOLD:ACB4208	G	G	A	A	C	A	G	G	A	T	G	A	A	C	T	G	T	A	T	A	T	C	C	T	C	C	0
Balmain Bug, *Ibacus peronei* Δ	HM015458	BOLD:AAC9587	G	G	A	A	C	A	G	G	A	T	G	A	A	C	C	G	T	G	T	A	T	C	C	C	C	C	2
Palinuridae Δ																													
Southern Rock Lobster, *Jasus edwardsii* Δ	FJ174951	BOLD:AAC7900	G	G	A	A	C	A	G	G	T	T	G	G	A	C	A	G	T	A	T	A	C	C	C	T	C	C	1
Cape Rock Lobster (Sth African spp.), *Jasus lalandii*	AF192882	-	G	G	G	A	C	A	G	G	T	T	G	A	A	C	A	G	T	A	T	A	C	C	C	T	C	C	1
St Paul Rock Lobster (Sth Indian ocean spp.), *Jasus paulensis*	JN673754	BOLD:ACI2246	G	G	G	A	C	A	G	G	T	T	G	A	A	C	A	G	T	C	T	A	C	C	C	T	C	C	1
mlCOIintF mean no. base mismatches (Crustacea) ± SD; min and max																													**1 ± 1 (min = 0, max = 2)**
Birds (8 species)																													
Diomedeidae †																													
Albatross, *Thalassarche melanophrys* †	NC_007172	BOLD:AAC7360	G	G	T	A	C	A	G	G	A	T	G	A	A	C	T	G	T	G	T	A	C	C	C	G	C	C	2
Laridae †Δ																													
Kelp Gull, *Larus dominicanus*	AY293619	BOLD:ACE9128	G	G	C	A	C	A	G	G	A	T	G	A	A	C	A	G	T	A	T	A	C	C	C	C	C	C	1
Silver Gull, *Larus novaehollandiae* Δ	JN801453	BOLD:AAB7722	G	G	T	A	C	A	G	G	G	T	G	A	A	C	A	G	T	A	T	A	C	C	C	C	C	C	1

Reverse primer: jgHCO2198 (5'-3')	**T**	**A**	**I**	**A**	**C**	**Y**	**T**	**C**	**I**	**G**	**G**	**R**	**T**	**G**	**I**	**C**	**C**	**R**	**A**	**A**	**R**	**A**	**A**	**Y**	**C**	**A**	**Total mismatches (jgHCO2198)**
Reverse primer (reverse comp.): jgHCO2198 (5'-3')	T	G	R	T	T	Y	T	T	Y	G	G	I	C	A	Y	C	C	I	G	A	R	G	T	I	T	A	
Degenerate base pos. no.			1			2			3			4			5			6			7			8			
Corresponding base (reverse comp. sequence)			A/G			C/T			C/T			N			C/T			N			A/G			N			
Elasmobranchs (Sharks, Skates and Rays) (12 species)																											
Heterodontidae Δ																											
Port Jackson Shark, *Heterodontus portusjacksoni* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Orectolobidae †Δ																											
Gulf Wobbegong Shark, *Orectolobus halei* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spotted Wobbegong Shark, *Orectolobus maculatus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triakidae Δ																											
Gummy Shark, *Mustelus antarcticus* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
School Shark, *Galeorhinus galeus* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Squalidae Δ																											
Whitespotted Dogfish, *Squalus acanthias* Δ	T	G	A	T	T	C	T	T	C	G	G	C	C	A	C	C	C	A	G	A	A	G	T	T	T	A	0
Spikey Dogfish, *Squalus megalops*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dasyatidae																											
Smooth Stingray, *Trygonorrhina guanerius*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Myliobatidae †Δ																											
Southern Eagle Ray, *Myliobatis australis* †Δ	T	G	A	T	T	C	T	T	T	G	G	T	C	A	C	C	C	A	G	A	G	G	T	T	T	A	0
Rhinobatidae †Δ																											
Southern Fiddler Ray, *Trygonorrhina guanerius* †Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rajidae †																											
Brown Skate (Sth African spp.), *Raja miraletus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urolophidae Δ																											
Banded Stingaree, *Urolophus cruciatus* Δ	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	T	G	A	A	G	T	C	T	A	0
jgHCO2198 mean no. base mismatches (Elasmobranchs)																											**0**
Cephalopods (Cuttlefish, Octopus and Squid) (10 species)																											
Octopodidae †																											
Common Octopus, *Octopus vulgaris*	T	G	A	T	T	C	T	T	T	G	G	T	C	A	C	C	C	A	G	A	A	G	T	A	T	A	0
Octopoda sp. (Sth Australian spp.)†	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sydney Octopus, *Octopus tetricus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enoploteuthidae †																											
Southern Argonaut, *Argonauta nodosa* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Histioteuthidae †																											
Jewel Squid, *Histioteuthis* sp.†	T	G	A	T	T	T	T	T	T	G	G	T	C	A	T	C	C	A	G	A	A	G	T	C	T	A	0
Loliginidae †Δ																											
Southern Calamari Squid, *Sepioteuthis australis* †Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ommastrephidae †Δ																											
Red Arrow Squid, *Nototodarus gouldi* †Δ	T	G	A	T	T	C	T	T	T	G	G	G	C	A	C	C	C	A	G	A	G	G	T	G	T	A	0
Southern Arrow Squid, *Todarodes filippovae* †	T	G	A	T	T	T	T	T	T	G	G	A	C	A	C	C	C	A	G	A	A	G	T	A	T	A	0
Sepiidae †Δ																											
Giant Australian Cuttlefish, *Sepia apama* †Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sepiolidae †																											
Southern Dumpling Squid, *Euprymna tasmanica* †	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
jgHCO2198 mean no. base mismatches (Cephalopods)																											**0**
Crustacea (Crabs, Prawns, Bugs and Lobsters) (10 species)																											
Menippidae																											
Giant Crab, *Pseudocarcinus gigas*	T	G	A	T	T	T	T	T	T	G	G	A	C	A	C	C	C	T	G	A	A	G	T	G	T	A	0
Portunidae Δ																											
Three-spot Swimming Crab, *Portunus sanguinolentus*	T	G	A	T	T	T	T	T	T	G	G	T	C	A	C	C	C	T	G	A	A	G	T	T	-	-	0
Blue Swimmer Crab, *Portunus armatus* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	T	C	C	T	G	A	A	G	T	C	T	A	0
Penaeidae †																											
Caramote Prawn (Atlantic spp.), *Melicertus kerathurus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tiger Prawn (Nth Australian spp.), *Penaeus monodon*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scyllaridae Δ																											
Slipper/Velvet Fan Lobster (bug), *Ibacus alticrenatus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Balmain Bug, *Ibacus peronei* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palinuridae Δ																											
Southern Rock Lobster, *Jasus edwardsii* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cape Rock Lobster (Sth African spp.), *Jasus lalandii*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St Paul Rock Lobster (Sth Indian ocean spp.), *Jasus paulensis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
jgHCO2198 mean no. base mismatches (Crustacea)																											**0**
Birds (8 species)																											
Diomedeidae †																											
Albatross, *Thalassarche melanophrys* †	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Laridae †Δ																											
Kelp Gull, *Larus dominicanus*	T	G	A	T	T	C	T	T	C	G	G	C	C	A	C	C	C	A	G	A	A	G	T	A	T	A	0
Silver Gull, *Larus novaehollandiae* Δ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 3.1 Table 1. Continued

Forward primer: mlCOlintF (5'-3')			**G**	**G**	**W**	**A**	**C**	**W**	**G**	**G**	**W**	**T**	**G**	**A**	**A**	**C**	**W**	**G**	**T**	**W**	**T**	**A**	**Y**	**C**	**C**	**Y**	**C**	**C**	**Total mismatches (mlCOlintF)**
Degenerate base pos. no.					1			2			3						4			5			6			7			
Corresponding base					A/T			A/T			A/T						A/T			A/T			C/T			C/T			
Taxa (Total of 121 species)	**Genbank no.**	**BOLD BIN no.**																											
Birds (8 species) cont'd																													
Procellariidae †Δ																													
Fleshy-footed Shearwater, *Ardenna carneipes* †	DQ434025	BOLD:AAD0769	G	G	C	A	C	A	G	G	A	T	G	A	A	C	T	G	T	G	T	A	T	C	C	C	C	C	2
Short-tailed Shearwater, *Puffinus tenuirostris* †Δ	DQ434025	BOLD:AAD0769	G	G	C	A	C	A	G	G	A	T	G	G	A	C	T	G	T	G	T	A	C	C	C	T	C	C	3
Phalacrocoracidae †																													
Comorant/Shag, *Phalacrocorax nivalis*	KM065514	BOLD:AAC0914	G	G	T	A	C	A	G	G	A	T	G	A	A	C	G	G	T	A	T	A	T	C	C	A	C	C	2
Spheniscidae †Δ																													
Little Penguin, *Eudyptula minor* †Δ	EU525350	BOLD:AAA6338	G	G	C	A	C	A	G	G	A	T	G	A	A	C	A	G	T	A	T	A	T	C	C	C	C	C	1
Sulidae †																													
Australasian Gannet, *Morus serrator* †	AY369058	BOLD:AAB6000	G	G	T	A	C	A	G	G	A	T	G	A	A	C	T	G	T	A	T	A	T	C	C	C	C	C	0
mlCOlintF mean no. base mismatches (Birds) ± SD; min and max																													**2 ± 1 (min = 0, max = 3)**
Other taxa (Gastropods/Bivalves/Echinoderms) (9 species)																													
Haliotidae																													
Blacklip Abalone, *Haliotis rubra*	AY588938	-	G	G	G	A	C	A	G	G	A	T	G	A	A	C	A	G	T	C	T	A	C	C	C	C	C	C	2
Greenlip Abalone, *Haliotis laevigata*	DQ146307	BOLD:AAE2882	G	G	G	A	C	A	G	G	A	T	G	A	A	C	A	G	T	C	T	A	C	C	C	C	C	C	2
Turbinidae																													
Military Turban Shell (NSW/QLD spp.), *Turbo militaris*	AM403898	BOLD:AAF6477	G	G	G	A	C	A	G	G	A	T	G	G	A	C	A	G	T	C	T	A	C	C	C	T	C	C	3
Mytilidae																													
Blue Mussel, *Mytilus galloprovincialis*	KC789254	BOLD:AAA2184	G	G	T	G	C	T	G	G	A	T	G	G	A	C	T	A	T	T	T	A	C	C	C	G	C	C	4
Pectinidae																													
Japanese Scallop (Asian spp.), *Chlamys farreri*	FJ595957	BOLD:AAE9030	G	G	A	A	C	T	G	G	T	T	G	A	A	C	A	A	T	A	T	A	C	C	C	T	C	C	1
Veneridae																													
Mud Cockle, *Katelysia scalarina*	DQ184823	BOLD:AAX0279	G	G	T	A	C	T	G	G	T	T	G	A	A	C	T	A	T	T	T	A	T	C	C	T	C	C	1
Mud Cockle, *Katelysia rhytiphora*	DQ184822	BOLD:AAX0278	G	G	T	A	C	T	G	G	T	T	G	A	A	C	T	A	T	T	T	A	T	C	C	T	C	C	1
Asteriidae																													
Eleven-armed Starfish, *Coscinasterias muricata*	EU869903	BOLD:AAA9809	G	G	A	A	C	A	G	G	A	T	G	A	A	C	C	A	T	A	T	A	C	C	C	C	C	C	1
Echinometridae																													
Purple Sea Urchin, *Heliocidaris erythrogramma*	EU869937	BOLD:AAD6250	G	G	G	A	C	T	G	G	T	T	G	A	A	C	T	A	T	T	T	A	T	C	C	G	C	C	3
mlCOlintF mean no. base mismatches (Other taxa) ± SD; min and max																													**2 ± 1 (min = 1, max = 4)**
TOTAL mean no. base mismatches (ALL TAXA) ± SD; min and max (mlCOlintF)																													**2 ± 1 (min = 0, max = 6)**
mlCOlintF CONSENSUS			**G**	**G**	**N**	**A**	**C**	**N**	**G**	**G**	**N**	**T**	**G**	**R**	**A**	**C**	**N**	**R**	**T**	**N**	**T**	**A**	**Y**	**C**	**C**	**N**	**C**	**C**	

Reverse primer: jgHCO2198 (5'-3')	**T**	**A**	**I**	**A**	**C**	**Y**	**T**	**C**	**I**	**G**	**G**	**R**	**T**	**G**	**I**	**C**	**C**	**R**	**A**	**A**	**R**	**A**	**A**	**Y**	**C**	**A**	**Total mismatches (jgHCO2198)**
Reverse primer (reverse comp.): jgHCO2198 (5'-3')	**T**	**G**	**R**	**T**	**T**	**Y**	**T**	**T**	**Y**	**G**	**G**	**I**	**C**	**A**	**Y**	**C**	**C**	**I**	**G**	**A**	**R**	**G**	**T**	**I**	**T**	**A**	
Degenerate base pos. no.			1			2			3			4			5			6			7			8			
Corresponding base (reverse comp. sequence)			A/G			C/T			C/T			N			C/T			N			A/G			N			
Birds (8 species) cont'd																											
Procellariidae †Δ																											
Fleshy-footed Shearwater, *Ardenna carneipes* †	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Short-tailed Shearwater, *Puffinus tenuirostris* †Δ	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Phalacrocoracidae †																											
Comorant/Shag, *Phalacrocorax nivalis*	T	G	A	T	T	C	T	T	C	G	G	C	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Spheniscidae †Δ																											
Little Penguin, *Eudyptula minor* †Δ	T	G	A	T	T	C	T	T	T	G	G	T	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Sulidae †																											
Australasian Gannet, *Morus serrator* †	T	G	A	T	T	C	T	T	C	G	G	C	C	A	T	C	C	A	G	A	A	G	T	C	T	A	0
jgHCO2198 mean no. base mismatches (Birds)																											**0**
Other taxa (Gastropods/Bivalves/Echinoderms) (9 species)																											
Haliotidae																											
Blacklip Abalone, *Haliotis rubra*	T	G	A	T	T	C	T	T	C	G	G	T	C	A	C	C	C	A	G	A	A	G	T	C	T	A	0
Greenlip Abalone, *Haliotis laevigata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbinidae																											
Military Turban Shell (NSW/QLD spp.), *Turbo militaris*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Mytilidae																											
Blue Mussel, *Mytilus galloprovincialis*	T	G	A	T	T	T	T	T	T	G	G	G	C	A	C	C	C	T	G	A	G	G	T	G	T	A	0
Pectinidae																											
Japanese Scallop (Asian spp.), *Chlamys farreri*	T	G	G	T	T	T	T	T	T	G	G	T	C	A	T	C	C	T	G	A	A	G	T	T	T	A	0
Veneridae																											
Mud Cockle, *Katelysia scalarina*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mud Cockle, *Katelysia rhytiphora*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Asteriidae																											
Eleven-armed Starfish, *Coscinasterias muricata*	T	G	A	T	T	C	T	T	T	G	G	C	C	A	C	C	C	A	G	A	A	G	T	A	T	A	0
Echinometridae																											
Purple Sea Urchin, *Heliocidaris erythrogramma*	T	G	A	T	T	C	T	T	C	G	G	A	C	A	C	C	C	A	G	A	A	G	T	G	T	A	0
jgHCO2198 mean no. base mismatches (Other taxa)																											**0**
TOTAL mean no. base mismatches (ALL TAXA) (jgHCO2198)																											**0**
jgHCO2198 CONSENSUS	**T**	**G**	**R**	**T**	**T**	**Y**	**T**	**T**	**Y**	**G**	**G**	**N**	**C**	**A**	**Y**	**C**	**C**	**H**	**G**	**A**	**R**	**G**	**T**	**N**	**T**	**A**	

[*] Seal prey reference sources: Allen and Huveneers, 2005, Deagle *et al*. 2009, Gales and Pemberton, 1994, Page *et al*. 2005, Peters *et al*. 2014.

Appendix 3.1, Table 2. Location and general characteristics of the Dual Priming Oligonucleotide (DPO) predator blocking primers designed and used in this study. A total of four blocking primers (COI5P_DPOblk) were designed, and include one specific primer for each of the three seal species (Australian Fur Seal - AFS, Australian Sea Lion - ASL and Long-nosed Fur Seal - LNFS) as well as a non-specific ("universal seals") primer. The blockers were designed to overlap the universal COI 5P primer (RED), and comprise two priming regions (indicated in BLUE and DARK BLUE) separated by a polydeoxyinosine linker (BLACK) and terminating in a C3 spacer (GOLD). The location of the blocking primers are denoted within the seal COI 5P sequence regions (GREY), with the corresponding regions within the prey taxa given below. Lower case letters indicate mismatches between seal species.

	DPO blocking primer characteristics*		
COI primer/sequence name	**Tm (°C)**	**GC content (%)**	**Sequence (5'-3')**
†Universal COI 5P primer:			
mlCOIintF	-	-	GGWACAGGWTGAACWGTWTAYCCYCC
‡Predator sequences and blocking primers:			
Australian Fur Seal, *Arctocephalus pusillus* (AM181018)	-	-	GGTACCGGATGAACGGTTTACCCTCCCCTAGCGGGAAAC-CTGGCCCATGCAGGAGCTTCCGTAGACTTGACTATTT...
CO15P_DPOblk-AFS	72.7	62.5	--------------GGTTTACCCTCCCCTAGCgGGAAAC-CTgGCCCAtGCAGGa44444CGTAGACTTGA3
Australian Sea Lion, *Neophoca cinerea* (AM181020)	-	-	GGTACCGGATGAACGGTTTACCCTCCCCTAGCAGGGAAC-CTAGCCCACGCAGGGGCTTCCGTAGACTTGACTATTT...
CO15P_DPOblk-ASL	72.4	65.0	--------------GGTTTACCCTCCCCTAGCaGGgAAC-CTaGCCCAcGCAGGg44444CGTAGACTTGA3
Long-nosed Fur Seal, *Arctocephalus forsteri* (NC_004023)	-	-	GGTACCGGATGAACAGTTTACCCTCCTCTAGCAGGAAAT-CTAGCCCATGCAGGAGCTTCCGTAGACTTAACTATTT...
CO15P_DPOblk-LNFS	67.4	50.0	--------------aGTTTACCCTCCtCTAGCaGGaAAt-CTaGCCCAtGCAGGa44444CGTAGACTTaA3
Non-specific seal blocking primer:			
CO15P_DPOblk-Universal-Seals	71.2	60.0	--------------RGTTTACCCTCCYCTAGCRGGRAAY-CTRGCCCAYGCAGGR44444CGTAGACTTRA3
§Prey consensus sequences:			
Fish	-	-	GGNACNGGNTGAACNGTNTAYCCNCCNYTNKCNGGNAAY-YTNGCNCAYGCNGGNGCNTCHGTNGAYYTNACNATYT...
Elasmobranchs	-	-	GGDACHGGNTGAACHGTHTAYCCHCCNYTNGCNRGHAAY-HTHGCHCAYGCHGGVSCNTCHGTNGAYYTDRCHATYT...
Cephalopods	-	-	GGDACHGGDTGAACHGTWTAYCCNCCYYTWTCWAGWAAY-YTNKCHCAYRYDGGHCCHTCWGTWGAYYTWGCHATYT...
Crustacea	-	-	GGDACWGGWTGRACHGTVTAYCCYCCYYTWKCNGCNRSN-RTHGCBCAYRCNGGDGCHTCDGTHGAYHTNGSDATYT...
Birds	-	-	GGYACAGGRTGRACWGTRTAYCCBCCWCTAGCWGGHAAY-CTDGCYCAYGCHGGDGCHTCAGTHGAYYTRGCHATCT...
Other taxa	-	-	GGDRCWGGWTGRACHRTHTAYCCBCCNYTDKCYRKNDRHTHYDKMHCABDSNGRBNBNDSNRYNGAYNWNSYNATYK...

[*] As calculated for the 5' region using tools available from Integrated DNA Technologies (https://sg.idtdna.com/analyzer/Applications/OligoAnalyzer/)

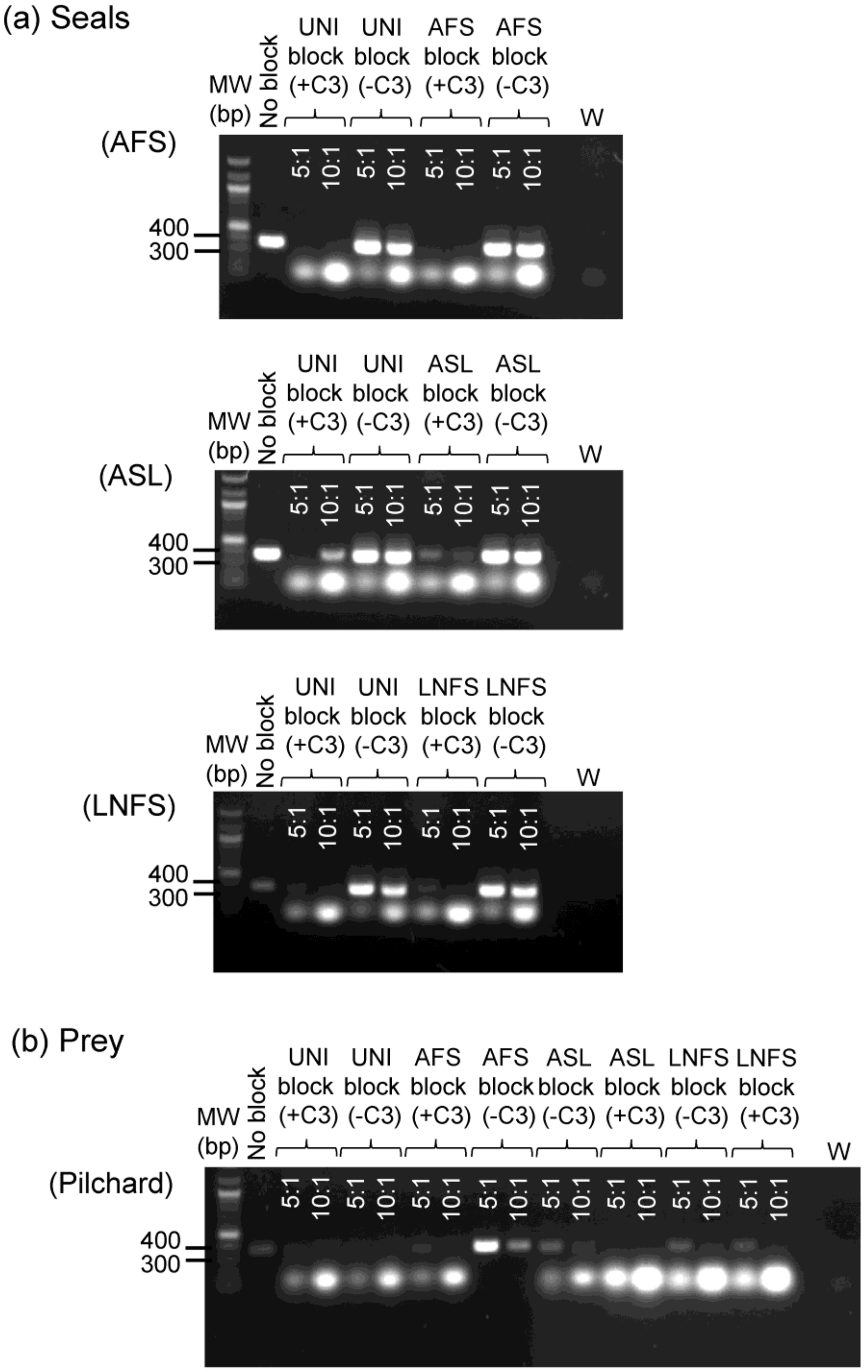
[†] Reference source: Leray *et al*. 2013a

[‡] Genbank accession numbers are given in parentheses for the seal COI gene sequences.

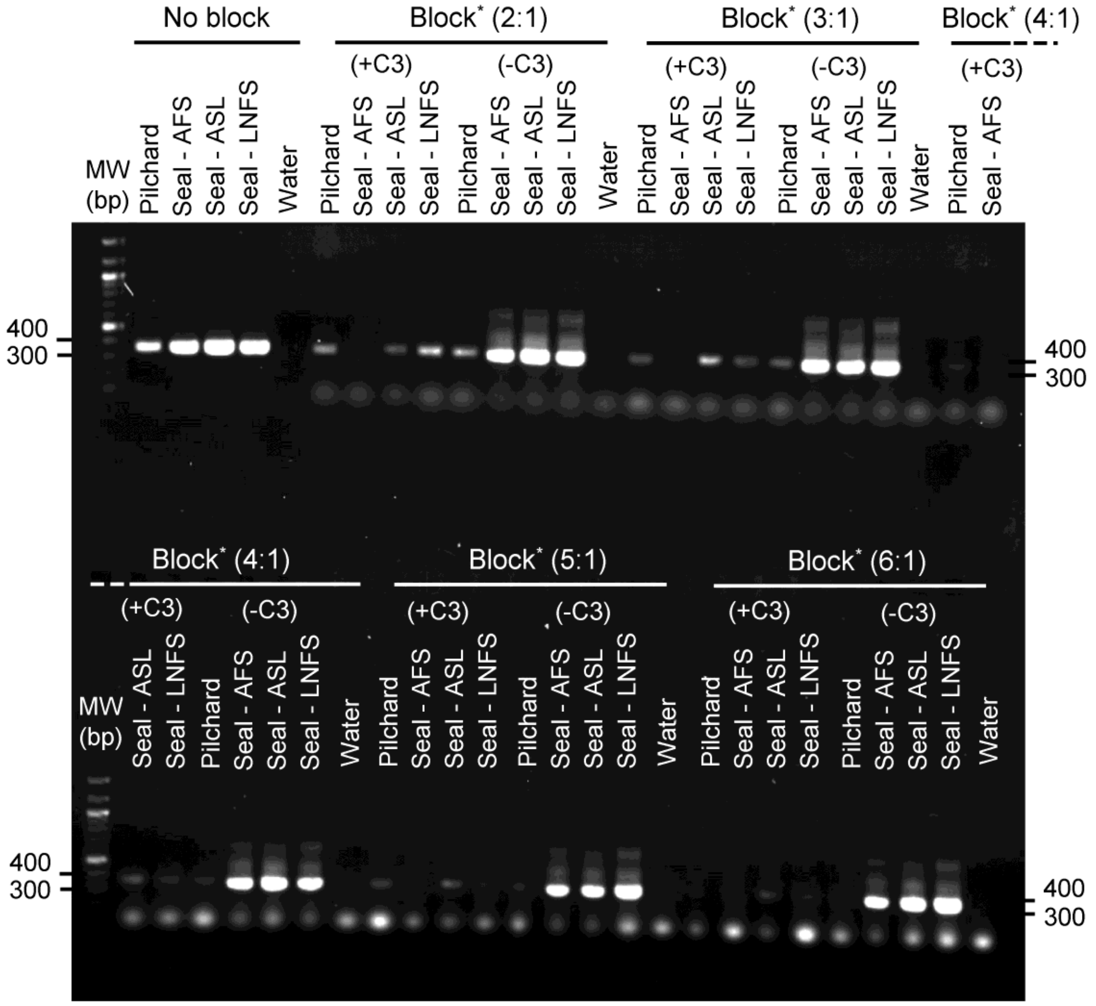
[§] As derived from COI 5P gene sequences of taxa listed in Table 3.3.

4= deoxyinosine; 3=C3 spacer

Appendix 3.2. Data supporting the methodology used in the development and assessment of the dietary NGS assays

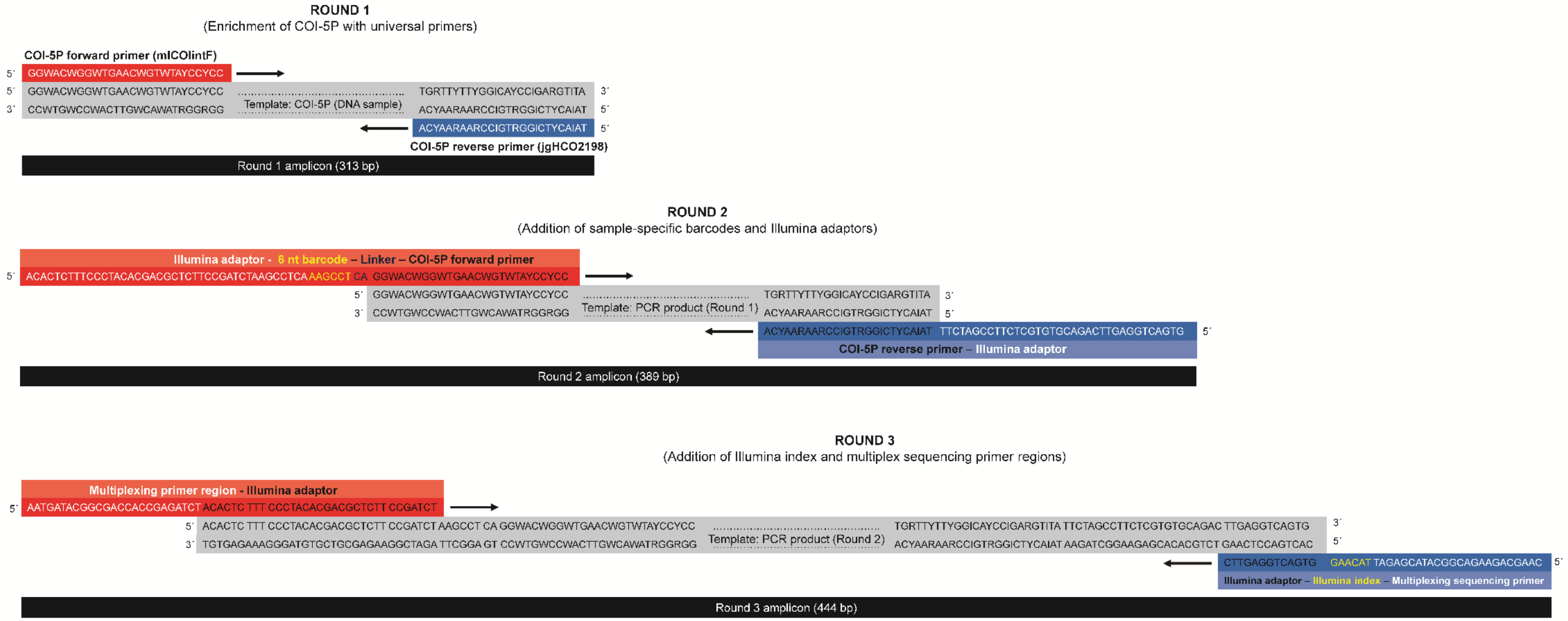


Appendix 3.2, Figure 1. Efficiency of Universal seals (UNI) and seal species-specific Dual Priming Oligonucleotide (DPO) primers for blocking PCR amplification of DNA from (a) Seals (Australian Fur Seal, Australian Sea Lion and Long-nosed Fur Seal); and their influence on (b) Prey (Pilchard [Australian Sardine]) DNA amplification. Primers were evaluated with and without the addition of a C3 spacer (+C3/–C3) and at a concentration of 5:1 and 10:1 blocker: COI gene forward (mlCOIintF) primer. As a control, samples were also subjected to PCR using the COI gene primers (mlCOIintF/jgHCO2198) without a blocker (No block). Positive amplification is denoted by the presence of a band from 300-400 bp; signal intensity reflects the amount of amplification. MW – molecular marker (100bp ladder, NEB); W – no template negative control (water).

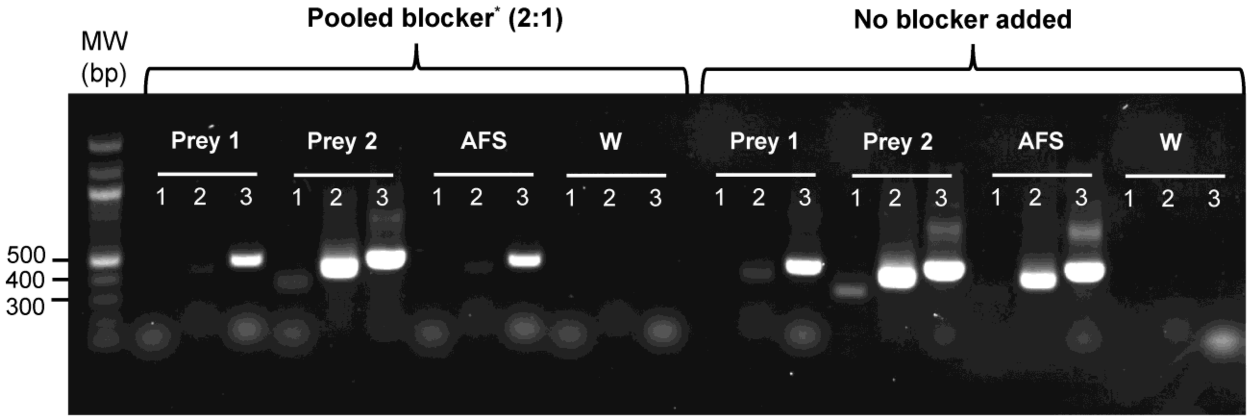


Appendix 3.2, Figure 2. Efficiency of the pooled seal species-specific Dual Priming Oligonucleotide (DPO) primer for blocking PCR amplification of seal (Australian Fur Seal AFS, Australian Sea Lion ASL, Long-nosed Fur Seal LNFS) DNA and its influence on Prey (Pilchard [Australian Sardine]) DNA amplification. Primers were evaluated with and without the addition of a C3 spacer (+C3/–C3) and at concentrations of 2:1, 3:1, 5:1 and 6:1 blocker: COI gene forward (mlCOIintF) primer. As a control, samples were also subjected to PCR using the COI gene primers (mlCOIintF/jgHCO2198) without a blocker (No block). Positive amplification is denoted by the presence of a band from 300-400 bp; signal intensity reflects the amount of amplification.

*Blocking primers were prepared using equimolar concentrations of the 3 species-specific blocking primers designed for AFS, ASL and LNFS. MW – molecular marker (100bp ladder, NEB); W – no template negative control (water).

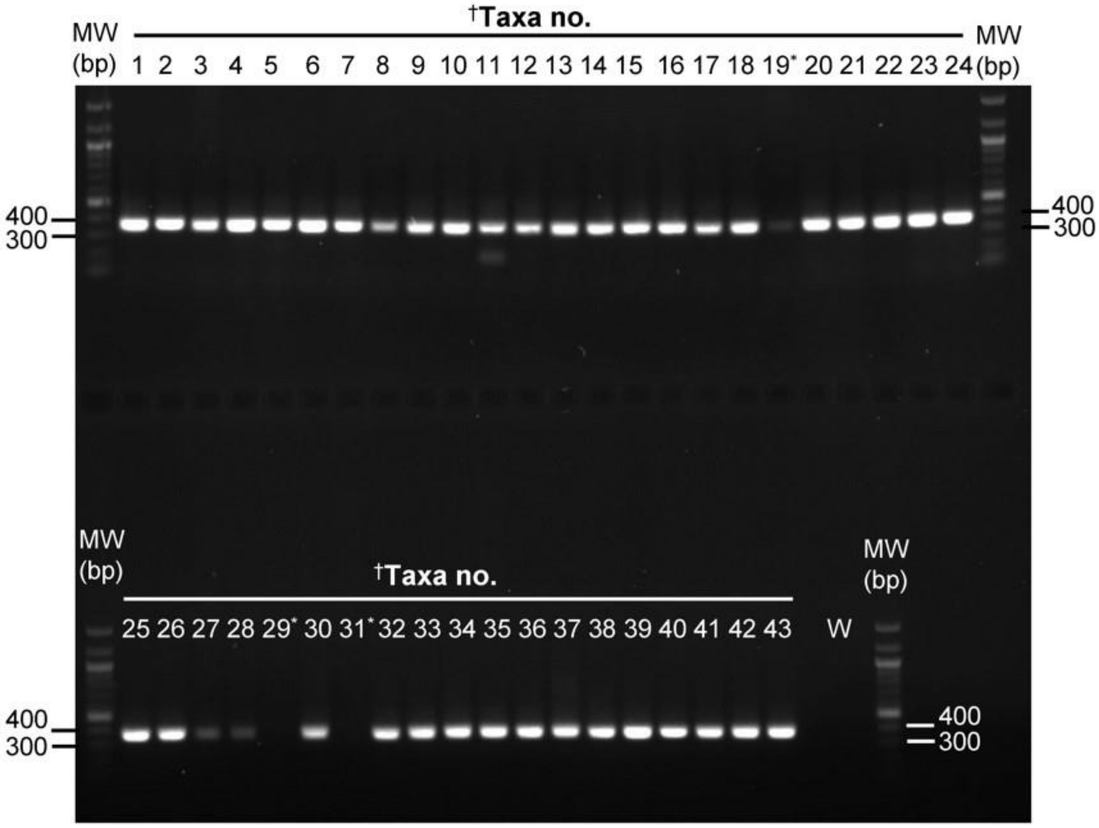


Appendix 3.2, Figure 3. Illumina metabarcoding (COI-5P) library construction scheme. As adapted from Camarinha-Silva *et al*. (2014), the procedure implements a multi-step PCR based strategy whereby sample-specific barcodes and Illumina specific indices, adaptors and multiplex sequencing primer regions are integrated over three consecutive rounds of PCR, with each consecutive round using the product of the previous round as template.



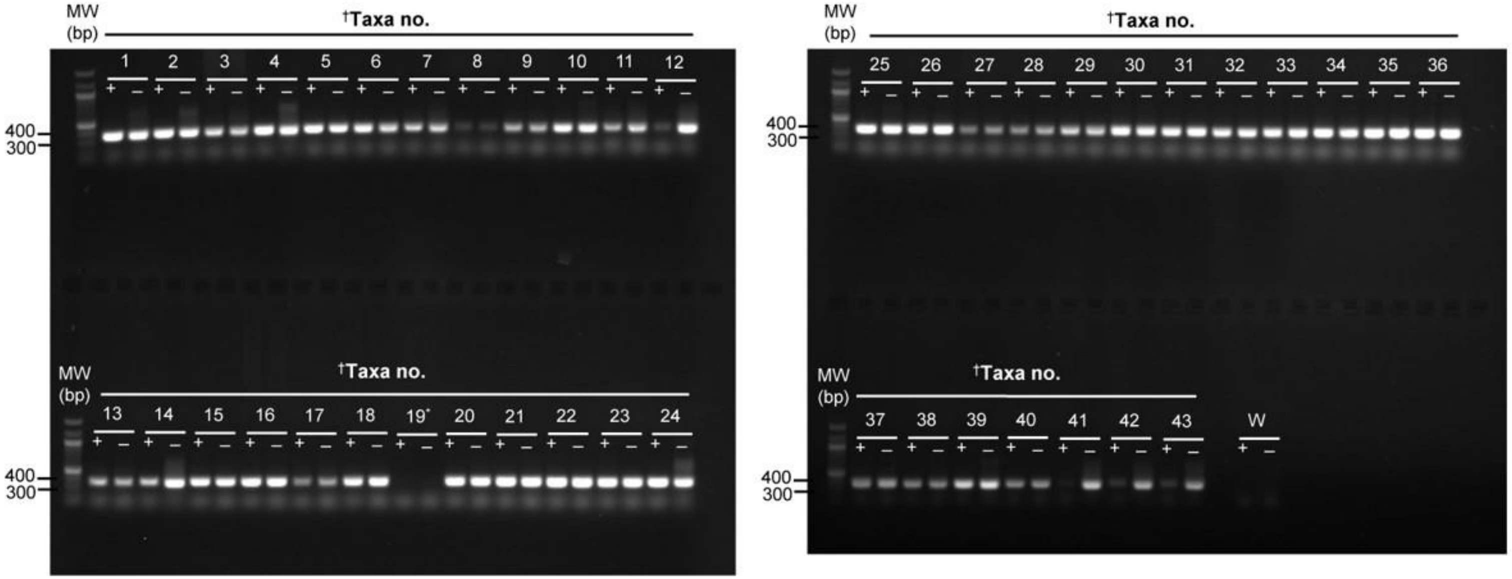
Appendix 3.2, Figure 4. Effect of the pooled seal species-specific Dual Priming Oligonucleotide (DPO) primer on the Illumina NGS metabarcoding (COI gene) assay. The assay was conducted with and without the presence of the pooled blocking primer at a concentration of 2:1 blocker: COI gene forward (mlCOIintF) primer using DNA extracts obtained from two representative prey taxa (Australian Sardine – Prey 1 and Australian Salmon – Prey 2) and Australian Fur Seal (AFS). Reactions were performed over 3 consecutive rounds (1, 2 and 3) according to methods established elsewhere for generating Illumina MiSeq ready libraries (Camarinha-Silva *et al*. 2014). Positive amplification (and library construction) is denoted by the presence of consecutively larger bands over the 3 rounds of PCR from 300-500 bp; signal intensity reflects the amount of amplification.

*Blocking primers were prepared using equimolar concentrations of the 3 species-specific blocking primers designed for AFS, Australian Sea Lion and Long-nosed Fur Seal. MW – molecular marker (100bp ladder, NEB); W – no template negative control (water).

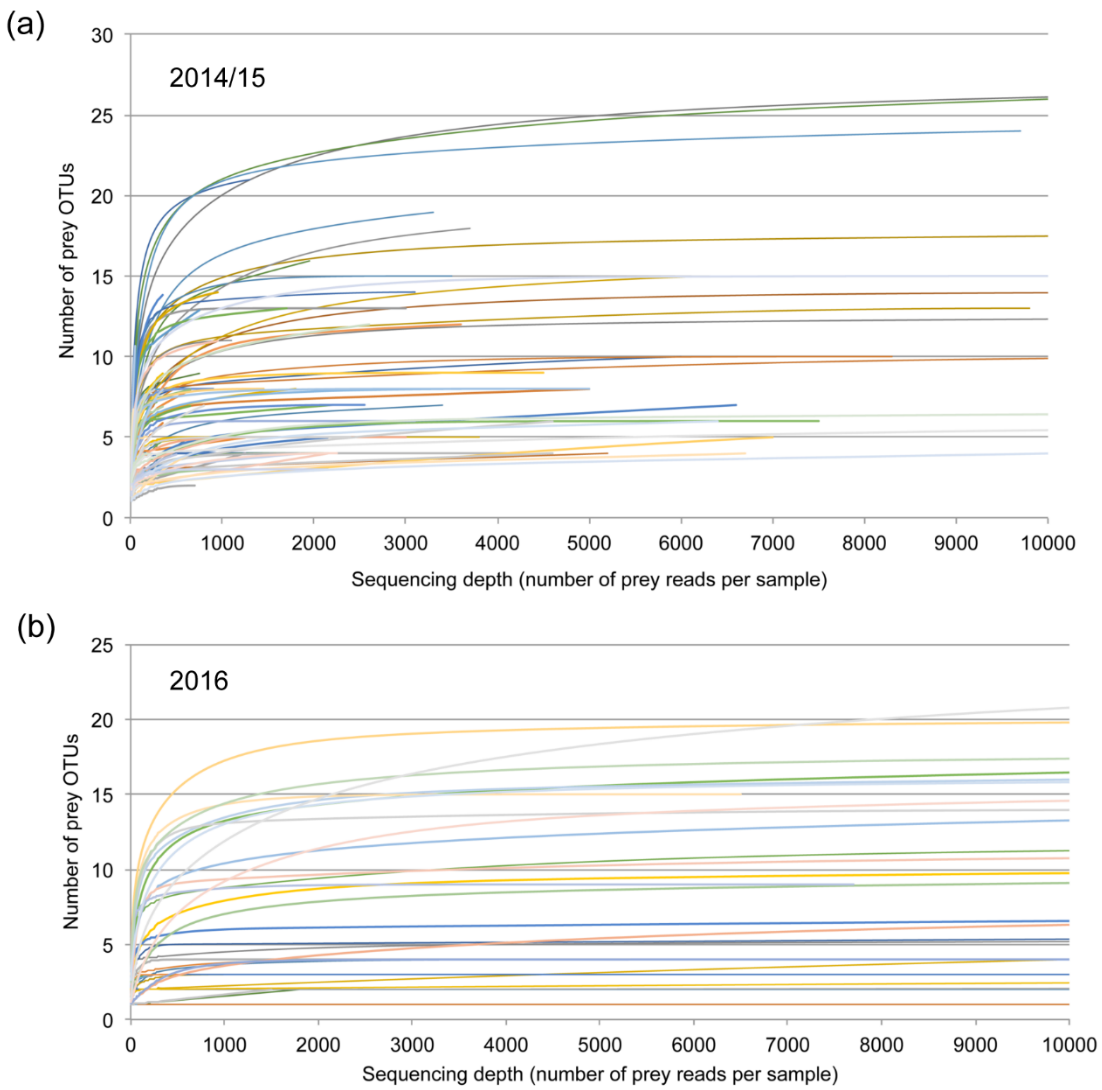


Appendix 3.2, Figure 5. Evaluation of universal COI gene primers (mlCOIintF/jgHCO2198) in the PCR amplification of DNA obtained from seals and 40 representative prey taxa. Positive amplification is denoted by the presence of a band from 300-400 bp; signal intensity reflects the amount of amplification.

†Taxa include: (i) FISH: 1 – Silver Trevally (*Pseudocaranx dentex*; Carangidae), 2 – Bluethroat Wrasse (*Notolabrus tetricus*; Labridae), 3 – Jack Mackerel (*Trachurus declivis*; Carangidae), 4 – Australian Salmon (*Arripis trutta*; Arripidae), 5 – Sweep (*Scorpis lineolate*; Scorpaenidae), 6 – Southern Bluefin Tuna (*Thunnus maccoyii*; Scombridae), 7 – Bight Redfish (*Centroberyx gerrardi*; Berycidae), 8 – Australian Sardine (*Sardinops sagax*; Clupeidae), 9 – Rock Ling (*Genypterus tigerinus*; Ophidiidae), 10 – Sixspine Leatherjacket (*Meuschenia freycineti*; Monocanthidae), 11 – King George Whiting (*Sillaginodes punctatus*; Sillaginidae), 12 – Tiger Flathead (*Platycephalus richardsoni*; Platycephalidae), 13 – Snook (*Sphyraena novaehollandiae*; Sphyraenidae), 14, Yellowtail Kingfish (*Seriola lalandi*; Carangidae); (ii) SHARKS/RAYS: 15 – Gummy Shark (*Mustelus antarcticus*; Triakidae), 16 – School Shark (*Galeorhinus galeus*; Triakidae), 17 – Port Jackson Shark (*Heterodontus portusjacksoni*; Heterodontidae), 18 – Gulf Wobbegong Shark (*Orectolobus halei*; Orectolobidae), 19 – Southern Saw Shark (*Pristiophorus nudipinnis*; Pristiophoridae), 20 – Australian Angelshark (*Squatina australis*; Squatinidae), 21 – Southern Eagle Ray (*Myliobatis tenicaudatus*; Myliobatidae), 22 – Southern Fiddler Ray (*Trygonorrhina dumerilii*; Rhinobatidae), 23 – Smooth Stingray (*Dasyatis brevicaudata*; Dasyatidae), 24 – Banded Stingaree (*Urolophus cruciatus*; Urolophidae), 25 – Melbourne Skate (*Dipturus whitleyi*; Rajidae), 26 – Whitespotted Dogfish (*Squalus acanthias*; Squalidae); (iii) CEPHALOPODS: 27 – Southern Calamari Squid (*Sepioteuthis australis*; Loliginidae), 28 – Red Arrow Squid (*Nototodarus gouldi*; Ommastrephidae), 29 – Nova Cuttlefish (*Sepia novaehollandae*; Sepiidae), 30 – Maori Octopus (*Octopus maorum*; Octopodidae), 31 – Giant Australian Cuttlefish (*Sepia apama*; Sepiidae); (iv) OTHER MOLLUSCS: 32 – Pacific Oyster (*Crassostrea gigas*; Ostreidae), 33 – Southern Cockle (*Acrosterigma cygnorum*; Cardiidae); (v) CRUSTACEA: 34 – Blue Swimmer Crab (*Portunus pelagicus*; Portunidae), 35 – Western King Prawn (*Melicertus latisulcatus*; Penaeidae), 36 – Southern Rock Lobster (*Jasus edwardsii*; Palinuridae), 37 – Balmain Bug (*Ibacus peronei*; Scyllaridae); (vi) BIRDS: 38 – Little Penguin (*Eudyptula minor*; Spheniscidae), 39 – Silver Gull (*Larus novaehollandiae*; Laridae), 40 – Short-tailed Shearwater (*Puffinus tenuirostris*; Procellariidae); (vii) SEALS: 41 – Australian Fur Seal (*Arctocephalus pusillus*), 42 – Australian Sea Lion (*Neophoca cinerea*), 43 – Long-nosed Fur Seal (*Arctocephalus forsteri*). *DNA template used in the PCRs was of low yield and/or quality due to the availability of only poorly preserved/degraded tissues from these specimens resulting in the loss or absence of amplification in these samples. MW – molecular marker (100bp ladder, NEB); W – no template negative control (water).



Appendix 3.2 Figure 6. Effect of the pooled seal species-specific Dual Priming Oligonucleotide (DPO) primer on the PCR amplification of seal and representative prey taxa DNA. Primers were evaluated with and without the addition of a C3 spacer (+/–) at a concentration of 2:1 blocker: COI gene forward (mlCOIintF) primer. Positive amplification is denoted by the presence of a band from 300-400 bp; signal intensity reflects the amount of amplification. [†]Taxa include: (i) FISH: 1 – Silver Trevally (*Pseudocaranx dentex*; Carangidae), 2 – Bluethroat Wrasse (*Notolabrus tetricus*; Labridae), 3 – Jack Mackerel (*Trachurus declivis*; Carangidae), 4 – Australian Salmon (*Arripis trutta*; Arripidae), 5 – Sweep (*Scorpis lineolate*; Scorpaenidae), 6 – Southern Bluefin Tuna (*Thunnus maccoyii*; Scombridae), 7 – Bight Redfish (*Centroberyx gerrardi*; Berycidae), 8 – Australian Sardine (*Sardinops sagax*; Clupeidae), 9 – Rock Ling (*Genypterus tigerinus*; Ophidiidae), 10 – Sixspine Leatherjacket (*Meuschenia freycineti*; Monocanthidae), 11 – King George Whiting (*Sillaginodes punctatus*; Sillaginidae), 12 – Tiger Flathead (*Platycephalus richardsoni*; Platycephalidae), 13 – Snook (*Sphyraena novaehollandiae*; Sphyraenidae), 14, Yellowtail Kingfish (*Seriola lalandi*; Carangidae); (ii) SHARKS/RAYS: 15 – Gummy Shark (*Mustelus antarcticus*), 16 – School Shark (*Galeorhinus galeus*), 17 – Port Jackson Shark (*Heterodontus portusjacksoni*; Heterodontidae), 18 – Gulf Wobbegong Shark (*Orectolobus halei*; Orectolobidae), 19 – Southern Saw Shark (*Pristiophorus nudipinnis*; Pristiophoridae), 20 – Australian Angelshark (*Squatina australis Squatina australis*; Squatinidae), 21 – Southern Eagle Ray (*Myliobatis tenicaudatus*; Myliobatidae), 22 – Southern Fiddler Ray (*Trygonorrhina dumerilii*; Rhinobatidae), 23 – Smooth Stingray (*Dasyatis brevicaudata*; Dasyatidae), 24 – Banded Stingaree (*Urolophus cruciatus*; Urolophidae), 25 – Melbourne Skate (*Dipturus whitleyi*; Rajidae), 26 – Whitespotted Dogfish (*Squalus acanthias*; Squalidae); (iii) CEPHALOPODS: 27 – Southern Calamari Squid (*Sepioteuthis australis*; Loliginidae), 28 – Red Arrow Squid (*Nototodarus gouldi*; Ommastrephidae), 29 – Nova Cuttlefish (*Sepia novaehollandae*; Sepiidae), 30 – Maori Octopus (*Octopus maorum*; Octopodidae), 31 – Giant Australian Cuttlefish (*Sepia apama*; Sepiidae); (iv) OTHER MOLLUSCS: 32 – Pacific Oyster (*Crassostrea gigas*; Ostreidae), 33 – Southern Cockle (*Acrosterigma cygnorum*; Cardiidae); (v) CRUSTACEA: 34 – Blue Swimmer Crab (*Portunus pelagicus*; Portunidae), 35 – Western King Prawn (*Melicertus latisulcatus*; Penaeidae), 36 – Southern Rock Lobster (*Jasus edwardsii*; Palinuridae), 37 – Balmain Bug (*Ibacus peronei*; Scyllaridae); (vi) BIRDS: 38 – Little Penguin (*Eudyptula minor*; Spheniscidae), 39 – Silver Gull (*Larus novaehollandiae*; Laridae), 40 – Short-tailed Shearwater (*Puffinus tenuirostris*; Procellariidae); (vii) SEALS: 41 – Australian Fur Seal (*Arctocephalus pusillus*), 42 – Australian Sea Lion (*Neophoca cinerea*), 43 – Long-nosed Fur Seal (*Arctocephalus forsteri*). [*]DNA template used in the PCRs was of low yield and/or quality due to the availability of only poorly preserved/degraded tissues from these specimens resulting in the loss or absence of amplification in these samples. MW – molecular marker (100bp ladder, NEB); W – no template negative control (water).



Appendix 3.2, Figure 7. Rarefaction curves depicting the number of resolved prey OTUs against the number of prey reads per sample. Charts plot (a) 126 scat samples (32 Australian Sea Lion ASL, 89 Long-nosed Fur Seal LNFS and 5 Australian Fur Seal) from 2014/15, and (b) 39 scat samples (19 ASL, 20 LNFS) from 2016.

4 Diet of Long-nosed Fur Seals: comparison of faecal DNA and hard-part analysis methods

Sara-Lena Reinhold

4.1 Introduction

Top predators can strongly influence the structure and function of many ecosystems and are essential to the maintenance and stability of food webs (e.g. Berger *et al.* 2001, Goldsworthy *et al.* 2013). This is particularly evident for marine predators because they are major consumers at most trophic levels, from primary production (i.e., sirenians) to predatory fish and marine mammals (e.g. killer whales *Orcinus orca* and some pinniped (seal) species) (Boveng *et al.* 1998, De Iongh *et al.* 1995, Heise *et al.* 2003). For example, otter populations recovering from overhunting in the west Aleutian Islands significantly transformed near-shore reefs by limiting the distribution and abundance of herbivorous sea urchins, thereby promoting kelp forest (Estes and Duggins 1995, Estes and Palmisano 1974, Simenstad *et al.* 1978). In addition, species preyed upon by marine predators can also be targeted by fisheries, which can, in-turn, have serious impacts (i.e., prey depletion) on those predators, and broader marine food webs (Goldsworthy *et al.* 2013, Read 2008, Trites *et al.* 1997, Turvey *et al.* 2007). The extent of impacts brought about by resource competition with fisheries is poorly understood (Cherel and Ridoux 1992, DeMaster *et al.* 2001, Gonzalez and Rodhouse 1998). Hence identifying the key prey species that underpin the abundance and distribution of marine mammals is of central importance for ecologists to advise on protected species management (Noss *et al.* 1996, Wirsing *et al.* 2007).

Between the 17th and 19th centuries, uncontrolled commercial harvesting led to severe declines of many marine top predators, including pinnipeds, whales and sharks (Baker and Clapham 2002, Ling 1999, Romero Jr 2001). Seals, for example, were hunted almost to extinction for their skins in parts of the world from the early 17th century until the late 19th century (Ling 1999, Reijnders 1983). Since the cessation of sealing, several pinniped species have recovered or expanded to their former population range. A prime example is the population of the Cape Fur Seal (*Arctocephalus pusillus pusillus*) within the Benguela system, which has increased to approximately 1.7 million animals since the start of the 20th century (Punt and Butterworth 1995). In southern Australia, population levels of both the Australian Fur Seal (*A. p. doriferus,* AFS*)* and Long-nosed Fur Seal (*A. forsteri,* LNFS) have recovered significantly since an estimated minimum of 350,843 skins were harvested in the early 1800s (Ling 1999). After almost 150 years of low population numbers for both species, pup production of the AFS in 2002 showed a 5% annual growth rate since the 1980s (Kirkwood *et al.* 2005). In South Australia (SA), a statewide estimate of pup production of the LNFS in 2013-14 was three times larger than in the 1980s, with an expansion of breeding distribution, particularly on Kangaroo Island (Shaughnessy *et al.* 2015).

This recent strong recovery of LNFS has led to concerns among commercial fishers and community members regarding their impact on prey species and the potential competition for marine natural resources. Arrow squids (*Nototodarus* spp.), for example, are fished annually for up to 30,000 tonnes in New Zealand and are also important prey for pinnipeds in the southern hemisphere (Baylis and Nichols 2009, Childerhouse *et al.* 2001, Fea *et al.* 1999, Page *et al.* 2005a). Because Australian fisheries were predominantly developed during a time of markedly reduced seal populations, such increases in marine predators are predicted to have changed marine ecosystems in ways that can also impact commercial fisheries production (Goldsworthy *et al.* 2003, Goldsworthy *et al.* 2013). In addition, recent reported declines in numbers of Little Penguins (*Eudyptula minor*) at several colonies within SA (Bool *et al.* 2007, Colombelli-Négrel and Kleindorfer 2014, Wiebkin 2011), have coincided with increases in fur seal numbers. While several other threats may have a contributing influence, such as reduced food availability, habitat destruction and terrestrial predation or diseases (reviewed in, Wiebkin 2011), the potential predation by LNFS has been highly publicised. Consequently, there is growing pressure from some sectors of the community to manage fur seal numbers, including by culling. Investigating fur seal diet and the impacts fur seals have on fisheries and the decline of Little Penguins is now central to advising future management of the species.

Dietary studies are essential for understanding how anthropogenic and ecological processes can influence marine predators (Auttila *et al.* 2015, Bowen 1997, Kirkwood *et al.* 2008, Wiebkin 2011, Wright 2014). Analysis of marine predator diet can offer a wealth of information on the predator’s biology, trophic role and foraging behavior (Ainley *et al.* 1998, Field *et al.* 2005), as well as providing information on the ecology, distribution and seasonal fluctuations of the prey species (Preti *et al.* 2004, Kirkwood *et al.* 2008). For example, dietary studies on marine mammals have shown more opportunistic feeding in response to reduced prey resource availability during El Niño periods (DeLong *et al.* 1991, Piatkowski *et al.* 2002, Preti *et al.* 2004), which has also been linked to reduced reproductive success amongst pinnipeds (Trillmich *et al.* 1991). Most dietary information for pinnipeds to date has been derived from hard-part analysis recovered from regurgitates, faeces or stomach contents (De Pierrepont *et al.* 2005, Joyce *et al.* 2002, Lea *et al.* 2002). While these techniques are practical, cost effective and widely used, they are also limited by the selective digestion of prey containing diagnostic features and differences in the retention of these hard parts (Cottrell *et al.* 1996, De Pierrepont *et al.* 2005). Therefore, alternative methods, such as next generation sequencing (Deagle *et al.* 2009), the use of tissues containing dietary fatty acids (Baylis and Nichols 2009)and stable isotopes (Hobson *et al.* 1996, Hooker *et al.* 2001) have also been used to increase detection of morphologically unidentifiable taxa. For consumers with broad dietary habits, like pinnipeds, the resolution of fatty acids and stable isotopes varies between taxa post digestion (Baylis and Nichols 2009, Dalsgaard *et al.* 2003, Deagle *et al.* 2009, Tollit *et al.* 1997), and hard-part analyses remain the most commonly used method to assess pinniped diet.

In SA, previous dietary studies of LNFS have largely focused on the breeding populations on Kangaroo Island (Cape Gantheaume, Cape du Couedic) and the Neptune Islands. Juveniles feed mostly on myctophid fish (*Symbolophorus* sp.), a species found in oceanic waters, and adult females feed typically on ommastrephid squids (*Nototodarus gouldi* and *Todarodes filippovae*) and fish, principally Redbait (*Emmelichthys nitidus*). In contrast, Little Penguins represented the highest proportion of adult males’ diet, followed by ommastrephid squids and Redbait (Baylis and Nichols 2009, Goldsworthy *et al.* 2011, Page *et al.* 2005a, Page *et al.* 2006). Studies also showed that females focus their foraging efforts on the mid to outer shelf during lactation (from November to April) but then shift to oceanic waters to feed on myctophid species from the subtropical front, 700-1000 km south of the main breeding colonies (Baylis and Nichols 2009, Page *et al.* 2005a, Page *et al.* 2006). This foraging shift occurs during winter and spring months when pups are larger, have higher energy demands and greater fasting capabilities (Goldsworthy and Shaughnessy 1994). In contrast, adult males focus their foraging effort on slope waters (Page *et al.* 2006). Information on the diet of juveniles, and particularly subadult males, is limited. Unlike the breeding part of the population, juveniles appear to spend much of their time foraging in shelf waters during winter months (Page *et al.* 2006). Because it is predicted that non-breeding animals are more relevant for understanding the role of fur seals in coastal and shelf ecosystems, where interactions with fisheries and penguins are more likely to occur (Bool *et al.* 2007, Goldsworthy *et al.* 2011, Wiebkin 2011), further studies into the diet of non-breeding animals are needed.

The present study investigated LNFS diet at 13 sites in four regions of SA using hard-part analysis on items recovered from faecal samples. The four regions were: south coast of Kangaroo Island (SCKI), Gulf St Vincent (GSV), Spencer Gulf (SG) and the Coorong. The aims of the study were to: (1) identify the prey taxa consumed by LNFS in South Australian waters; (2) identify spatial variability in their diet; (3) compare the dietary profiles between breeding colonies and haul-out sites, (4) compare hard-part and genetic analysis methods for investigating LNFS diet and (5) identify the importance of commercially fished species and Little Penguins in their diet.

4.2 Methods

Study sites

LNFS scats were collected at 11 haul-out sites and two breeding sites between July and September 2014. For the purposes of this study, Seal and West islands in Encounter Bay were considered to be part of GSV (Figure 4.1). Marine study sites were in three regions. For SCKI, sites were at Cape du Couedic (36.052°S, 136.706°E, a breeding site), Cape Gantheaume (35.934°S, 137.445°E, a breeding site) and Cape Kersaint (36.031°S, 137.132°E). Cape Kersaint has been recorded as a breeding colony with a small number of pups (Shaughnessy *et al*. 2015); for this study scats were collected well away from the breeding area at a haul-out site. For GSV, sites were at Granite Island (35.550°S, 138.617°E), West Island (35.608°S, 138.592°E), Seal Island (35.577°S, 138.644°E), Penneshaw (35.723°S, 137.986°E), Ballast Head (35.723°S, 137.779°E), Kingscote (35.653° S, 137.634° E) and Port Giles (35.033° S, 137.767°E). For SG, sites were at Hummocky (35.606°S, 137.235°E), Pissy Boy Rock (35.686°S, 136.881°E) and Donington Reef (34.721°S, 135.999°E) (Figure 4.1).

At the Coorong, scats were collected from a newly established haul-out site at Tauwitcherie barrage (35.553° S, 138.947°E) between August and September 2015. The Coorong is a wetland system made up of two linear lagoons and a number of ephemeral lakes which span a distance of 140 km. Historically it functioned as a reverse estuary, but water movement is now principally dictated by tidal movements of marine water through the Murray Mouth, with hypersaline waters in the southern lagoon (Phillips and Muller 2006). In 1940, five barrages were established to manage water flows, particularly during years of drought. The barrages prevent tidal intrusion into the lower Murray River system and form a partial ecological barrier between marine/estuarine and freshwater habitats.

Scat collection and analysis

Scats were collected randomly while searching through the sites, placed in separate airtight re-sealable plastic bags and labelled. Due to the small number of samples collected on Granite Island and its proximity to Seal Island (< 1.5 km), scats collected on both islands were pooled and collectively referred to as Seal Island scats. After collection, scats were stored at -20°C.

Before analysis, samples were soaked in warm soapy water in individual plastic containers for at least 24 hours. For prey identification, only scats that were fresh when collected were used in order to minimise bias from samples that were dried out and broken apart (Tate 1981). Pre-soaked scat samples were washed with tap water through nested 1.0 and 0.5 mm sieves. Prey remains were sorted into broad taxonomic categories. Cephalopod beaks were stored in 70% ethanol in small plastic vials (70 ml), and individually labelled. Other prey remains were air dried and then stored in individually labelled re-sealable plastic bags. Each scat sample was categorized, based on the presence of hard parts identifiable to major prey categories: (1) fish (bones, eye lenses with rounded lens, scales and otoliths); (2) cephalopods (beaks and eye lenses with flat lens); and (3) birds (presence of feathers). The bird category was further divided into Little Penguin and other seabird remains, based on feather shape and coloration.

For all scat samples, the relative importance of the three prey categories was assessed by calculating the per cent frequency of occurrence (FO%) across the four regions. The FO% represents the proportion of scats that contain a particular prey type. Specifically, the FO% was calculated by dividing the number of scats in which a prey species occurred by the total number of scats that contained identifiable prey remains (see Lance and Jeffries 2006). For the penguin prey category, the FO% was calculated for each site.

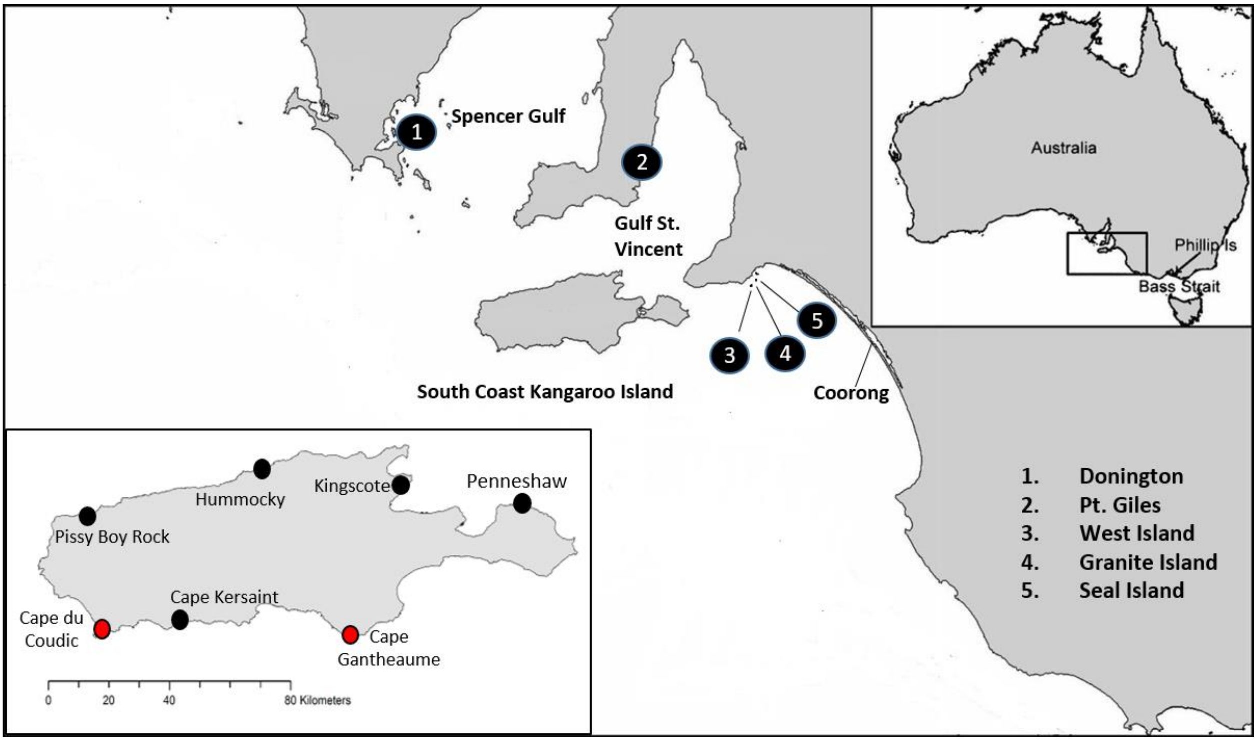


Figure 4.1: Map of part of South Australia showing four regions sampled for LNFS scats between July and September 2014: South coast, Kangaroo Island, Gulf St Vincent, Coorong and Spencer Gulf. The map presents the specific sites sampled within each region (black for haul-out sites, red for breeding colonies).

Sub-sample analysis

Twenty scat samples from each site, with the exception of Donington Reef (32 scats – all used) and Coorong (64 scats – all used), were selected at random as a sub-sample for more detailed prey-hard-part analysis (316 scats in total). A larger number of samples collected from Donnington Reef and Coorong were analysed due to the low sample size available for Spencer Gulf and Coorong respectively. Comparatively, GSV and South Coast Kangaroo Island, were each made up of three to five sample sites. Otoliths and cephalopod beaks were identified to the lowest taxonomic level with the aid of reference collections and atlases (Furlani *et al.* 2007, unpublished data, Lu and Ickeringill 2002, Smale 1995) (see Table 4.1). Otoliths were sorted into taxa and paired (left and right otoliths), photographed and either measured along the horizontal diameter using digital imaging software Optimas 6.5 (Media Cybernetics San Diego, Image-pro Plus 7.0 MediaCybernetics San Diego), which is accurate to 0.01 mm, or weighed (using electronic scales accurate to 0.0001 g), depending on which regression equation was available to reconstruct the estimated fish biomass from otolith length or otolith mass from reference atlases (Furlani *et al.* 2007, Smale 1995). Because equations were not available for all identified species, alternative equations from species in the same genus or family were used for 20 taxa (see Table 4.1). For cephalopod beaks, the hood length of upper or lower beaks was measured using digital calipers (accurate to 0.1 mm) and those measurements were used to reconstruct estimated prey biomass following methods described in Lu and Ickeringill (2002). Cephalopod beaks not identifiable to species level were identified to the level of genus, family or order. Regression equations of the species closest to the genus or family were then applied (Table 4.1); if more than one species was available, the most common species in SA waters was chosen.

The minimum number of fish and cephalopod taxa represented in each scat sample was estimated by taking the maximum number of left or right otoliths, and upper or lower beaks, respectively. In addition to otolith and beak identification, the total number of cephalopod and fish eye lenses divided by two was used to estimate the minimum number of individuals. For example, a sample with eight fish eye lenses and two identified otolith pairs (left and right otolith = 1 fish), was enumerated as one identified and three unidentified fish individuals (eight eye lenses = 4 fish). Unquantifiable hard parts, such as fish bones, teeth, mouth parts and feathers, were recorded as originating from a single individual (e.g., a sample with 100 fish bones was considered as one individual fish).

The relative importance of each prey taxa was examined for the sub-sample (n=316 scats), for each of the four regions, and for sex and age group (breeding sites versus haulouts – excluding the Coorong). The sex and age group classifications was determined by the type of site sampled; breeding sites predominated by adult females nursing pups or haulouts predominantly made up of sub-adult and juvenile males(Goldsworthy and Shaughnessy 1994).Three standardised measures were used to explore LNFS diet: (1) the percentage of numerical abundance (NA%), calculated as the number of a taxon present in samples divided by the total number of prey items within the region (NA% per region) or age group (NA% per adult females and subadult males); (2) the frequency of occurrence (FO%) of a taxon in samples and (3) the per cent biomass contribution. The estimated reconstructed biomass of each taxon was divided by the overall reconstructed mass of all taxa in the sample (combined biomass of taxa present) and calculated as the proportional biomass for each region or sex and age group, respectively. For key commercially targeted species, length estimates were also calculated using regression equations based on otolith or beak measurements. The size of these species was compared to their commercial size limits.

Seabird abundance and biomass reconstruction

A pilot feeding trial investigated the passage rate of Little Penguin feathers in captive LNFS. Two males with body masses of 78.5 kg (10 years old), and 50 kg (6 years old) were housed in individual pool enclosures with access to a haul-out area at Taronga Zoo, Sydney. Portions of about 5x5 cm of penguin skin with feathers attached (weighing approx. 50 g) were cut from thawed penguin carcasses, autoclaved for 15 minutes at 122ºC and fed to both animals across four feeding experiments (total of eight feeding experiments). Penguin skin squares were folded and stuffed tightly into Su07 size (28 ml) dissolvable gelatin capsules. These were hidden inside an Australian Salmon by pushing them into the body cavity through the gills and fed to the seals during their regular mid-morning feed. For each seal, three trials containing one capsule were undertaken and one trial containing two capsules. After the seals had been fed penguin feathers, they continued their normal diet of 5.5 kg and 2.5 kg of mixed fish and squid spread over three feeding sessions each day. The trials were conducted at least 10 days apart and samples were collected over 96 hours. Seals produced one and sometimes two scats per day, and these were collected each morning or whenever scats were seen in their enclosures. Seals were checked at least every two hours between 07:00 and 18:00 hours. Scats were removed and sieved for the presence of feathers. Collection of scats continued until two successive scats did not contain penguin feathers, which was 83 to 142 hours after feeding.

Feathers in scats from the wild were allocated a biomass and individual contribution as per the captive LNFS feeding trial results. White feathers that were not from a Little Penguin were considered to be from shearwaters, a species previously described in LNFS diet (Page *et al.* 2005a) (Table 4.1).

Statistical analysis

Analyses were conducted in PRIMER version 5.1.2 (PRIMER-E Ltd., Plymouth, UK). The difference in the percentage biomass contribution of each prey taxon within each region and site was tested using nonparametric analysis of similarity (ANOSIM), using a Bray-Curtis similarity matrix. ANOSIM is a hypothesis-testing procedure that generates a probability value and test statistic (R) which lies between 1 and -1. High positive R values indicate greater variation between groups than within groups, and negative values indicate high levels of within group variation compared to between group variation.

Values of R of zero represent the null hypothesis of no significant difference between groups. Similarity percentage analysis (SIMPER, Plymouth Routines in Multivariate Ecological Research) was used to identify which prey taxa were responsible for inter-regional and site differences (see Catalán *et al.* 2006). Unidentified fish and cephalopods were not included in biomass summaries to ensure that inter-regional or sex and age group prey taxa differences were not driven by allocation of weights to the unidentified prey individuals. ANOSIM and SIMPER analyses using the Bray-Curtis association were also used to explore prey composition variation for comparisons between breeding sites and haul-out sites.

Hard-part analysis versus DNA analysis

Molecular analysis of 37 randomly selected sub-sample scats across 11 sites was undertaken for comparison with hard-part analysis for prey taxa detection. The samples were from Ballast Head (1 scat), Cape du Couedic (1), Cape Gantheaume (6), Cape Kersaint (2), Coorong (1), Donington Reef (2), Hummocky (5), Kingscote (6), Penneshaw (4), Seal Island (4) and West Island (5). The methods used for molecular analysis are described in Chapter 3.

The frequency of occurrence was calculated for species identified by hard-part analysis and DNA analysis. The total number of samples for which a prey species was detected using either method was also calculated

Table 4.1. References for formulae and weights used to estimate the contribution of each prey taxa to the total biomass consumed by Long-nosed Fur Seals (* indicates commercially fished taxa).

Prey type	**Species used for estimate**	**Reference for biomass estimate**
Fish (Marine)		
Anchovy *(Engraulis australis)**	same species[1]	Furlani et al. (2007)
Barracouta (*Thyrsites atun*)	same species[1]	Furlani et al. (2007)
Blue Cubehead (*Cubiceps caeruleus*)	same species	Smale et al. (1995)
Centroberyx sp. (*Centroberyx* sp.)	*C. affinis*	Furlani et al. (2007)
Common Bullseye *(Pempheris multiradiata)*	same species[1]	Furlani et al. (2007)
Common Jack Mackerel *(Trachurus declivis)**	same species	Furlani et al. (2007)
Deepwater Hardyhead (*Atherinason hepsetoides*)	same species	Furlani et al. (2007)
Hardyhead sp. (Atherinidae)	*Atherinason hepsetoides*	Furlani et al. (2007)
King George Whiting (*Sillago punctata*)*	*S. flindersi* [1]	Furlani et al. (2007)
Leatherjackets (Monocanthidae)*	*M. freycineti* [3]	Furlani et al. (2007)
Mulloway (*Argyrosomus japonicas*)*	same species	G.Ferguson, unpubl. data
Myctophid sp. 1 (*Diaphus* sp.)	*D. danae* [3]	Furlani et al. (2007)
Myctophid sp. 2 (*Gymnoscopelus sp.*)	*G. piabilis*	Smale et al. (1995)
Myctophid sp. 3 (*Myctophidae*)	*E.rissoi*	Furlani et al. (2007)
Myctophid sp. 4 (*Symbolophorus sp.*)	*S.barnardi*	Smale et al. (1995)
Red Mullet (*Upeneichththys vlamingii*)	same species	Furlani et al. (2007)
Red rock cod (*Pseudophycis bachus)*	same species	Furlani et al. (2007)
Redbait (*Emmelichthys nitidus)**	same species[2]	Furlani et al. (2007)
Redbait or Jack Mackerel*	*E. nitidus*	Furlani et al. (2007)
Sardine (*Sardinops sagax*)*	*S. neoplichardus* [2]	Furlani et al. (2007)
Short Boarfish (*Parazanclistius hutchinsi*)	*P. hutchinsi* average weight	M. Steer, unpubl. data
Skipjack Trevally (*Pseudocaranx georgianus*)*	*P. dentex*	Furlani et al. (2007)
Slender Bullseye (*Parapriacanthus elongates*)	*Epigonus robustus*	Smale et al. (2007)
Southern sea Garfish *(Hyporhamphus melanochir)**	same species	Furlani et al. (2007)
Tommy Ruff (*Arripis georgianus*)	*A.trutta*	Furlani et al. (2007)
Western Australian Salmon (*Arripis truttaceus*)	same species	Furlani et al. (2007)
Western Gemfish (*Rexea solandri*)	same species	Furlani et al. (2007)
Western school Whiting (*Sillago bassensis*)*	same species	Furlani et al. (2007)
Yellow-eye Mullet (*Aldrichetta forsteri*)*	same species	Furlani et al. (2007)
Fish (Freshwater)	same species	S. Reinhold, unpubl data
Bony Herring (*Nematolosa erebi*)	same species	P. Brown, unpubl data
Common Carp (*Cyprinus carpio*)	*Afurcagobius tamarensis*	Furlani et al. 2007
Goby sp. (Gobiidae)	same species	Furlani et al. 2007
Tamar goby (*Afurcagobius tamarensis*)		
Cephalopods		
Calamari squid (*Sepioteuthis australis*)* upper beal	same species [3]	Lu & Ickeringill (2002)
Calamari squid (*S. australis*)* lower beaks	same species [3]	Lu & Ickeringill (2002)
Clubhook squid (*Onychoteuthis* sp.) upper beaks	*O.banksii*	Lu & Ickeringill (2002)
Clubhook squid (*Onychoteuthis* sp.) lower beaks	*O. banksii*	Lu & Ickeringill (2002)
Giant cuttlefish (*Sepia apama*) upper beaks	same species[1]	Lu & Ickeringill (2002)
Giant cuttlefish (*S. apama*) lower beaks	same species[1]	Lu & Ickeringill (2002)
Gould's squid (*Nototodarus gouldi*)* upper beaks	same species[2]	Lu & Ickeringill (2002)
Gould’s squid (*N.gouldi*)* lower beaks	same species	Lu & Ickeringill (2002)
Luminous Bay Squid (*Uroteuthis noctiluca*) upper be	same species	Lu & Ickeringill (2002)
Luminous Bay Squid (*U. noctiluca*) lower beaks	same species	Lu & Ickeringill (2002)
Ommasterphidae (Ommastrephidae)* upper beaks	*N. gouldi* [3]	Lu & Ickeringill (2002)
Ommasterphidae (Ommastrephidae)* lower beaks	*N. gouldi* [2]	Lu & Ickeringill (2002)
Octopus sp. 1 (*Octopus* sp.) upper beaks	*O. berrima* [1]	Lu & Ickeringill (2002)
Octopus sp. 1 (*Octopus* sp.) lower beaks	*O. berrima* [1]	Lu & Ickeringill (2002)
Octopus sp. 2 (*Octopus* sp.) upper beaks	*O. pallidius*	Lu & Ickeringill (2002
Octopus sp. 2 (*Octopus* sp.) lower beaks	*O. pallidius*	Lu & Ickeringill (2002)
Seabirds		
Unidentified seabirds (Puffinus sp.)	*Puffinus tenuirostris* [4]	B. Page, unpubl. Data
Little Penguins (Eudyptula minor)	*same species* [5]	Colombelli-Négrel (2015)

[1]Regressions based on data that include the range of predicted lengths or weights. [2]Regressions based on data that did not include the lower predicted lengths or weights. [3]Regressions based on data that did not include upper or lower lengths. [4]118g (1/5 total average weight). [5]252g (1/5 total average weight 1258g).

4.3 Results

Hard-part analysis

Of the 422 scat samples collected, fish remains were found in 397 (94.1%), cephalopod remains in 161 (38.2%) and bird feathers in 48 (11.4%). There was evidence of Little Penguin remains in 39 (9.2%) scats, being 81.3% of the 48 scats containing bird remains.

Overall proportional presence of prey categories

The overall presence of the prey categories detected in samples varied regionally (Figure 4.2). The presence of fish in scats ranged from 89.2% (GSV) to 100% (Coorong). Cephalopods were present in 58.9% of scats from SCKI and 51.1% from GSV compared to 19.6% in SG scats. No cephalopod hard parts were detected in samples from the Coorong. The proportion of scats with seabirds was highest in GSV (19.3%) and SCKI (10%), followed by SG (4.4%) and Coorong (1.6%) (Figure 4.3). Of the scats containing evidence of seabird predation (i.e., feathers) from GSV, 97% comprised Little Penguins, compared to 55.5% for SCKI. All feathers in samples from SG were attributed to shearwaters.

Penguin feeding trials

The number of scats containing feathers across 96 hours ranged from 3 to 6 (Table 4.2) with an overall average of 5 for both seals. Of samples with feathers, approximately 30% contained >100 penguin feathers, 14% contained between 10 and 50, and 57% of scats contained fewer than 10. Most feathers passed were clumped in one or two scats containing more than 100 feathers and were collected between 20 and 72 hours after feeding. Feathers from the double-capsule feeding trial were passed over three scats (from seal 1) and six scats (from seal 2), which is within the range of the number of scats passed during single-capsule feeding trials. On average, penguin feathers were passed over five scats (single and double capsule feeding trials combined) over an average time of 79 (sd = 25.25 hours), range 43 hours. Based on these results, scats with feathers were allocated the average biomass of a penguin (1258 g, Colombelli-Négrel pers. comm) or shearwater (590 g, Page *et al*. 2005) divided by five (i.e., penguin 252 g per scat, shearwater 118 g per scat).

Sub-sample hard-part analysis

In the sub-sample of scats (n=316) subjected to detailed hard-part analysis, a total of 1326 prey items were identified including 34 fish taxa, eight cephalopods and two seabirds (Table 4.3). Overall, samples represented a reconstructed biomass of 48.71 kg, based on the estimated mass of 1030 individual fishes, 289 cephalopods and seven seabirds. Feathers were identified in 35 scats and were estimated to represent six penguins and one shearwater. For the purposes of summarising the data, sites are discussed below as freshwater (Coorong scats) and marine (other sites).

For marine sites (n=252 scats), Luminous Bay Squid (NA 17%, FO 8.7%), *Symbolophorus barnardi* (i.e., Myctophid sp. 4, NA 13.1%, FO 8.3%), Garfish (NA 12.8%, FO 12.7%), Sardines (NA 10.8%, FO 11.9%) and Leatherjackets (NA 7.5%, FO 21%) were the most numerically abundant species identified (Table 4.3). Whilst *S. barnardi* made up 13.1% of individuals detected across marine sites, this species was found predominantly in SCKI samples and it was absent in SG samples. Based on biomass estimates, Leatherjackets (41.1%), Little Penguins (16.8%) and Southern Calamari (8.0%) contributed most (Table 4.4).

In Coorong samples (n=64 scats), Tamar Goby (NA 76.4%, FO 7.8%), Bony Herring (NA 10.2% FO 26.6%) and goby species (NA 9%, FO 7.8%) were numerically the most abundant prey taxa (Table 4.5). Common Carp contributed most to overall biomass (68.8%), followed by Bony Herring (19.3%) and goby species (7.0%) (Table 4.5). These freshwater species occurred only in Coorong samples.

Key finding: Common Carp were identified as LNFS prey and contributed to 68.8% of diet of LNFS in the Coorong.

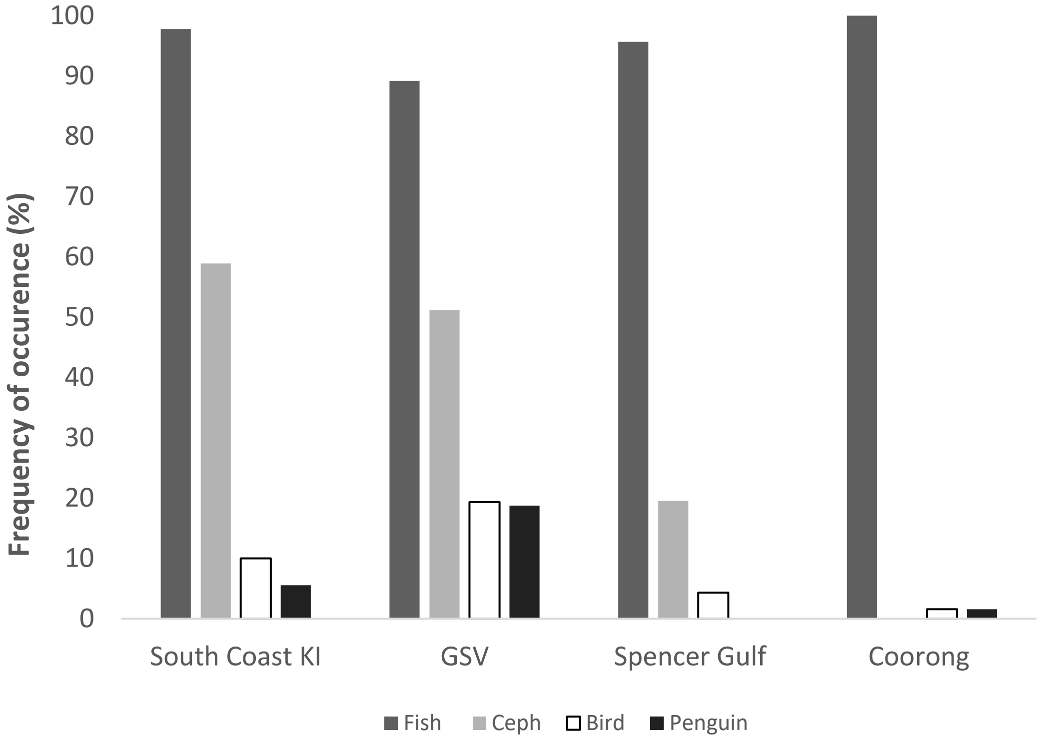


Figure 4.2. Frequency of occurrence (%) of prey categories identified in Long-nosed Fur Seal scats collected between July and October 2014 (n=422). Data are presented for each region (South coast, Kangaroo Island, Gulf St Vincent (GSV), Spencer Gulf and Coorong). Data representing bird remains include Little Penguins.

Table 4.2. Summary of scats examined for the presence of feathers from two captive Long-nosed Fur Seals up to 96 hours after the feeding of single or double penguin skins (collected approximately once or twice per day).

Single or double penguin skin	Seal No.	No. of scats collected	No. of scats with feathers	N>100 feathers	10<N<50 feathers	N<10 feathers
Single	1	10	5	1	0	4
Single	1	12	3	1	0	2
Single	1	7	6	2	2	2
Double	1	8	5	2	0	3
Single	2	10	6	1	1	4
Single	2	6	4	2	1	1
Single	2	8	5	1	0	4
Double	2	6	3	1	10	1
Total			**37 (avg. 5 per trial)**	**11**	**5**	**21**

Key finding: Penguin feathers from a single meal were passed on average over five scats and ~79 hours.

Regional comparison

In the sub-sample of marine sites (n=252 scats), the most important prey taxa (highest numerical abundance, by per cent) varied between the three regions. For SCKI samples, *S. barnardi* (NA 29.4%, FO 33.3%), Sardines (NA 20.9%, FO 28.3%) and myctophid species 3 (NA 16.2%, FO 23.3%) contributed the most numerically (Table 4.3). Combined, myctophid species made up 46.1% of individuals identified in SCKI samples compared to 5% for GSV (n=120). Of the six GSV sites, only samples from Ballast Head contained myctophid otoliths. Garfish were abundant in GSV samples, both numerically and by frequency of occurrence (NA 21.4%, FO 20.8%). Other key prey species included Luminous Bay Squid (NA 33%, FO 18.3%), Little Penguins (NA 0.8%, FO 18.3%) and Leatherjackets (NA 5.2%, FO 19.2%) (Table 4.3). In SG (n=72), Leatherjackets (NA 37.1%, FO 38.9%) were also dominant. In addition, Redbait/Jack Mackerel (NA 15%, FO 4.2%) and Garfish (NA 10.3%, FO 4.2%) were numerically abundant whilst Shearwaters and Sardines were the second most frequently identified prey taxa across samples from SG (FO 5.6%) (Table 4.3).

Diet biomass summary

The most important prey taxa by biomass also varied among regions (Table 4.4). In samples from SCKI, the three species which contributed most to biomass were *S. barnardi* (17.7%), Little Penguins (11%) and Barracouta (10.6%). In terms of numerical abundance, Barracouta comprised <3% of individuals, demonstrating the effect of low abundance coupled with high individual biomass. For GSV, taxa contributing most to biomass were Leatherjackets (27.9%), Little Penguins (27.9%) and Southern Calamari (14.2%). For SG, Leatherjackets (87.6%) and Shearwaters (4.3%) contributed approximately 92% of prey biomass. Freshwater samples collected from the Coorong demonstrated that Common Carp (68.8%) and Bony Herring (19.3%) were the key contributing species in terms of biomass (Table 4.5).

The prey composition of samples from SCKI differed significantly from samples collected in both GSV (ANOSIM *P*=0.001, *R*=0.172) and SG (ANOSIM *P* =0.001, *R*=0.331). For GSV and SCKI, ANOSIM analysis resulted in a low R value (<0.1 to 0.25), indicating similarity in prey biomass contribution between the regions. This could be explained by the presence of overlapping key prey species, at different proportions for both sites. SIMPER results (average dissimilarity 96.47%) demonstrated that observed differences were driven by a higher relative proportion of Leatherjackets (GSV 27.86% vs. SCKI 5.89%) and Little Penguins (GSV 27.87% vs. SCKI 10.93) coupled with a lower proportion of Sardines in samples from GSV (0.5%) compared to SCKI (7.84%). Differences between SCKI and SG were driven by a higher relative proportion of Leatherjackets (SG 87.56% vs. SCKI 5.87%), lower proportion of Sardines (SG 0.78% vs SCKI 7.84%) and of Myctophid sp. 4 (SG 0.00% vs. SCKI 17.67%).

No significant differences in prey biomass contributions were found for GSV and SG (ANOSIM *P*=0.007, *R*=0.061). This could be explained by Leatherjackets making up the highest percentage biomass contribution for both Gulfs (SG 87.56% vs. GSV 27.86%, Table 4.4). SIMPER analysis indicated an average dissimilarity of 84.82% in prey biomass contributions. This difference was driven by a lower proportion of Garfish (SG 1.07% vs. GSV 5.89%) and Little Penguin (SG 0.00% vs. GSV 27.87%, Table 4.4).

Samples from the Coorong, were significantly different from those collected from the three marine regions (Coorong vs. SCKI *P*=0.001 *R*=0.384, Coorong vs. GSV *P*=0.001 *R*=0.252, Coorong vs. SG *P*=0.001 *R*=0.441). These differences were predominantly driven by the high relative proportion of freshwater species, Bony Herring (19.28%) and Common Carp (68.76%), in Coorong samples that were absent from the other regions (Tables 4.4 and 4.5).

Key finding: Prey species detected most frequently in samples varied to the species that contributed most to LNFS diet in biomass. GSV and SG were similar in pery biomass composition but both sites differed significantly to SCKI.

Table 4.3. Per cent numerical abundance (NA) and per cent frequency of occurrence of prey taxa found in Long-nosed Fur Seal scats from South coast, Kangaroo Island (KI), Gulf St Vincent (GSV) and Spencer Gulf (n=252 scats). The number of scats examined, minimum number of identified individuals and the combined minimum number of unidentified fish and cephalopods are in parentheses. The minimum number of unidentified fish and cephalopods are in the second set of parentheses. Totals for each prey group are also presented (* indicates commercially fished taxa).

	South coast, KI		**GSV**		**Spencer Gulf**		**TOTAL**	
Prey Type	(90/377/341)		(120/538/340)		(72/127/137)		(252/1042/791)	
	(296/45)		(249/91)		(121/16)		(666/152)	
	NA	**FO**	**NA**	**FO**	**NA**	**FO**	**NA**	**FO**
Fish	82.2		59.3		92.3		71.6	
Unidentified Fish		26.7		39.1		38.9		36.1
Anchovy *(Engraulis australis)**	1.8	1.7	3	4.2	0.8	1.4	2.3	2.78
Barracouta (Thyrsites atun)	1.3	5					0.5	1.2
Blue Cubehead (Cubiceps caeruleus)	0.3	1.7					0.1	0.4
Centroberyx sp. (*Centroberyx* sp.)	0.3	1.7	0.2	0.8			0.2	0.8
Common Bullseye *(Pempheris multiradiata*)	0.8	3.3	0.2	1.7			0.5	1.6
Common Jack Mackerel *(Trachurus declivis*)*	5.3	6.7			8.7	2.8	3	2.4
Deepwater Hardyhead (*Atherinason hepsetoides*					9.5	1.4	1.1	0.4
Hardyhead sp. (Atherinidae)			6.7	4.2	2.3	1.4	3.7	2.4
King George Whiting (*Sillago punctata*)*			0.2	0.8			0.1	0.4
Leatherjackets (Monocanthidae)*	0.5	3.3	5.2	19.2	37.1	38.9	7.5	21
Mulloway (*Argyrosomus japonicas*)*			0.4	0.8			0.2	0.4
Myctophid sp. 1 (*Diaphus sp.*)	0.5	1.7					0.2	0.4
Myctophid sp. 2 (*Gymnoscopelus* sp)			0.2	0.8			0.1	0.4
Myctophid sp. 3 (*Myctophidae* .)	16.2	23.3					5.8	5.6
Myctophid sp. 4 (*Symbolophorus barnardi*)	29.4	33.3	4.8	0.8			13.1	8.3
Red Mullet (*Upeneichththys vlamingii)*			0.6	2.5			0.3	1.2
Red rock cod (*Pseudophycis bachus*)			0.2	0.8			0.1	0.4
Redbait (*Emmelichthys nitidus)**	0.3	1.7	0.4	1.7			0.3	1.2
Redbait or Jack Mackerel*	0.3	1.7	1.1	2.5	15	4.2	2.5	2.8
Sardine (*Sardinops sagax*)*	20.9	28.3	5.4	7.5	4.7	5.6	10.8	11.9
Short Boarfish (*Parazanclistius hutchinsi)*			0.4	1.7			0.2	0.8
Skipjack Trevally (*Pseudocaranx georgianus)**			1.5	1.7	3.1	1.4	1.2	1.2
Slender Bullseye (*Parapriacanthus elongates*)	0.8	3.3	4.1	7.5			2.4	4.4
Southern sea Garfish *(Hyporhamphus melanochir*)*	1.6	6.7	21.4	20.8	10.3	4.2	12.8	12.7
Tommy Ruff (*Arripis georgianus*)*			0.9	2.5	0.8	1.4	0.6	1.6
Western Australian Salmon (*Arripis truttaceus*)	0.3	1.7	0.2	0.8			0.2	0.8
Western Gemfish (*Rexea solandri*)	1.6	3.3					0.6	0.4
Western school Whiting (*Sillago bassensis*)*			1.5	0.8			0.8	0.4
Yellow-eye Mullet (*Aldrichetta forsteri*)*			0.7	2.5			0.4	1.2
Cephalopods	17.4		39.8		7.1		27.7	
Unidentified Cephalopods		15		12.5		6.9		11.5
Calamari squid (*Sepioteuthis australis*)*	1.6	5	5	14.2	0.8	1.4	3.3	8.3
Clubhook squid (*Onychoteuthis* sp.)	11.3	26.7					4.1	6.3
Giant cuttlefish (*Sepia. apama.*)	0.3	1.7	0.4	1.7	0.8	1.4	0.4	1.6
Gould's squid (*Nototodarus gouldi*)*	3.4	10	0.4	1.7			1.4	3.2
Luminous Bay Squid (*Uroteuthis noctiluca)*			33	18.3			17	8.7
Octopus sp. 1 (*Octopus* pallidius)*			0.6	2.5	3.9	1.4	0.8	1.6
Octopus sp. 2 (*Octopodidae sp.*)			0.2	0.8	0.8	2.8	0.2	1.2
Ommastrephidae (Ommastrephidae)*	0.8	3.3	0.2	0.8	0.8	1.4	0.5	1.6
Seabirds	0.4		0.9		0.6		0.7	
Unidentified seabirds (*Puffinus sp.*)	0.2	5	0.1	1.7	0.6	5.6	0.2	3.6
Little Penguins (*Eudyptula minor*)	0.2	5	0.8	18.3			0.5	9.9

Table 4.4. Per cent biomass of prey taxa found in Long-nosed Fur Seal scats from South coast, Kangaroo Island (KI), Gulf St Vincent and Spencer Gulf (n=252 scats). Totals of each prey type are also presented, prey taxa that average <0.05% of biomass are indicated by #; commercially fished taxa are indicated by *.

Prey Type	**South coast, KI**	**Gulf St. Vincent**	**Spencer Gulf**	**Total**
	(90)	**(120)**	**(72)**	**(525)**
Fish	69.5	45.4	93.8	63.8
Anchovy *(Engraulis australis)* *	0.5	0.4	0.1	0.3
Barracouta (*Thyrsites atun*)	10.6			2
Blue Cubehead (Cubiceps caeruleus)	1			0.2
Centroberyx sp. (*Centroberyx* sp.)	5	0.2		1
Common Bullseye *(Pempheris multiradiata*)	1.9	0.4		0.6
Common Jack Mackerel *(Trachurus declivis*) *	5.4		0.8	1.3
Deepwater Hardyhead (*Atherinason hepsetoides)*			0.3	0.1
Hardyhead sp. (Atherinidae)		0.2	#	0.1
King George Whiting (*Sillago punctata*)*		0.5		0.3
Leatherjackets (Monocanthidae)*	5.9	27.9	87.6	41.1
Mulloway (*Argyrosomus japonicas*)*		2.9		1.5
Myctophid sp. 1 (*Diaphus sp.*)	0.3			0.1
Myctophid sp. 2 (*Gymnoscopelus* sp)		#		#
Myctophid sp. 3 (*Myctophidae* .)	4.4			0.8
Myctophid sp. 4 (*Symbolophorus barnardi*)	17.7	0.2		3.3
Red Mullet (*Upeneichththys vlamingii)*		0.5		0.3
Red rock cod (*Pseudophycis bachus*)		0.1		#
Redbait (*Emmelichthys nitidus)**	1	0.2	#	0.3
Redbait or Jack Mackerel*	0.7	0.5	1.8	0.9
Sardine (*Sardinops sagax*)*	7.8	0.5	0.8	2
Short Boarfish (*Parazanclistius hutchinsi)*		1.4		0.8
Skipjack Trevally (*Pseudocaranx georgianus)**		0.6	1.1	0.6
Slender Bullseye (*Parapriacanthus elongates*)	0.2	0.6	0.1	0.4
Southern sea Garfish *(Hyporhamphus melanochir*)*	0.7	5.9	1.1	3.5
Tommy Ruff (*Arripis georgianus*)*		0.6	0.1	0.4
Western Australian Salmon (*Arripis truttaceus*)	2.6	0.9		1
Western Gemfish (*Rexea solandri*)	3.8			0.7
Western school Whiting (*Sillago bassensis*)*		0.8		0.4
Yellow-eye Mullet (*Aldrichetta forsteri*)*		0.2		0.1
Cephalopods	14.3	25.5	1.9	16.7
Calamari squid (*Sepioteuthis australis*)*	2.4	14.2	0.2	8
Clubhook squid (*Onychoteuthis* sp.)	6.8			1.2
Giant cuttlefish (*Sepia. apama.*)		6.6	#	3.5
Gould's squid (*Nototodarus gouldi*)*	2.1	0.1		0.4
Luminous Bay Squid (*Uroteuthis noctiluca)*		4.6		2.5
Octopus sp. 1 (*Octopus* pallidius)*		0.1	1.2	0.4
Octopus sp. 2 (*Octopodidae sp.*)		#	#	#
Ommastrephidae (Ommastrephidae)*	3		0.5	0.7
Seabirds	16.2	29.1	4.3	19.6
Unidentified seabirds (*Puffinus sp.*)	5.2	1.2	4.3	2.8
Little Penguins (*Eudyptula minor*)	11	27.9		16.8
Total (est. biomass kg)	**100 (6.9)**	**100 (19.8)**	**100 (10.8)**	**100 (37.5)**

Table 4.5. Per cent numerical abundance, frequency of occurrence and biomass of prey taxa found in Long-nosed Fur Seal scats from the Tauwitcherie barrage in the Coorong. Commercially fished taxa are indicated by *.

Prey Type	**NA%**	**FO%**	**Bio%**
	(284)	**(64 scats)**	**(11.2 Kg)**
Fish	69.5	-	97.7
Bony Herring (*Nematolosa erebi*) *	10.2	26.6	19.3
Common Carp (*Cyprinus carpio*) *	3.5	12.5	68.8
Goby sp. (Gobiidae)	9.0	7.8	1.1
Mulloway (*Argyrosomus japonica*) *	0.4	1.6	0.2
Tamar goby (*Afurcagobius tamarensis*)	76.4	7.8	7.0
Yellow-eye Mullet (*Aldrichetta forsteri*) *	0.4	1.6	1.3
Seabirds	0.1		2.3
Little Penguins (*Eudyptula minor*)	0.1	1.6	2.3

Table 4.6. Per cent biomass of prey taxa in Long-nosed Fur Seal scats from marine haul-out sites and breeding colonies (n=252 scats). Prey taxa that average <0.05% of biomass are denoted by #; commercially fished species are denoted by *.

Prey Type	**Haulout sites**	**Breeding Colonies**	**Total**
	(212)	**(40)**	**(252)**
Fish	**63.9**	**61.9**	**63.8**
Anchovy (*Engraulis australis*)*	0.4	#	0.3
Barracouta (Thyrsites atun)	1.1	8.7	2.0
Blue Cubehead (Cubiceps caeruleus)	0.2		0.2
Centroberyx sp. (*Centroberyx* sp.)	1.1		1.0
Common Bullseye (*Pempheris multiradiata*)	0.6		0.6
Common Jack Mackerel (*Trachurus declivis*)*	0.5	7.9	1.3
Deepwater Hardyhead (*Atherinason hepsetoides*	0.1		0.1
Hardyhead sp. (Atherinidae)	0.1		0.1
King George Whiting (*Sillago punctata*)*	0.3		0.3
Leatherjackets (Monocanthidae)	45.9		41.1
Mulloway (*Argyrosomus japonicas*)*	1.7		1.5
Myctophid sp. 1 (*Diaphus sp.*)		0.6	0.1
Myctophid sp. 2 (*Gymnoscopelus* sp)	#		*
Myctophid sp. 3 (*Myctophidae* .)	0.2	5.8	0.8
Myctophid sp. 4 (*Symbolophorus barnardi*)	0.8	24.5	3.3
Red Mullet (*Upeneichththys vlamingii*)	0.3		0.3
Red rock cod (*Pseudophycis bachus*)	*		*
Redbait (*Emmelichthys nitidus*)*	0.3		0.3
Redbait or Jack Mackerel*	0.9	1.2	0.9
Sardine (*Sardinops sagax*)*	1.2	8.3	2.0
Short Boarfish (*Parazanclistius hutchinsi*)	0.8		0.8
Skipjack Trevally (*Pseudocaranx georgianus*)*	0.7		0.6
Slender Bullseye (*Parapriacanthus elongates*)	0.5		0.4
Southern sea Garfish (*Hyporhamphus melanochir*)*	3.9	0.4	3.5
Tommy Ruff (*Arripis georgianus*)*	0.4		0.4
Western Australian Salmon (*Arripis truttaceus*)	0.5	4.5	1.0
Western Gemfish (*Rexea solandri*)	0.8		0.7
Western school Whiting (*Sillago bassensis*)*	0.5		0.4
Yellow-eye Mullet (*Aldrichetta forsteri*)*	0.1		0.1
Cephalopods	**16.1**	**22.3**	**16.7**
Calamari squid (*Sepioteuthis australis*)*	8.5	3.6	8.0
Clubhook squid (*Onychoteuthis* sp.)	0.2	10.3	1.2
Giant cuttlefish (*Sepia. apama.*)	3.9		3.5
Gould's squid (*Nototodarus gouldi*)*	0.1	3.3	0.4
Luminous Bay Squid (*Uroteuthis noctiluca*	2.7		2.5
Octopus sp. 1 (*Octopus* pallidius)*	0.5		0.4
Octopus sp. 2 (*Octopodidae sp.*)	#	#	*
Ommastrephidae (Ommastrephidae)*	0.2	5.1	0.7
Seabirds	**20.0**	**15.8**	**19.6**
Unidentified seabirds (*Puffinus sp.*)	2.8	3.0	2.8
Little Penguins (*Eudyptula minor*)	17.2	12.8	16.8
Total (est. biomass kg)	**100 (33.6)**	**100 (3.9)**	**100 (37.5)**

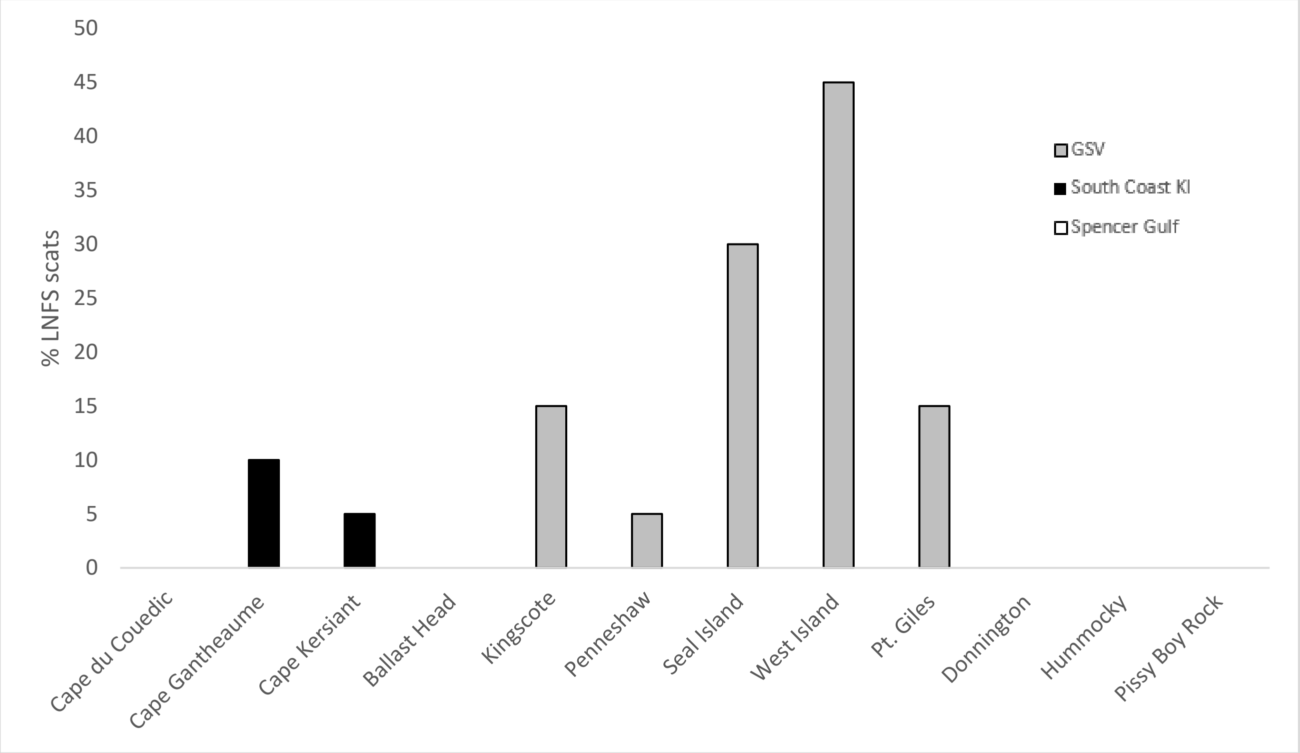


Figure 4.3 Percentage of Long-nosed Fur Seal scats containing Little Penguin remains at the 12 sites sampled in 2014 from 252 scats. Data are for three marine regions: South coast, Kangaroo Island, Gulf St Vincent and Spencer Gulf.

Sex and age demographic comparison

In this study, scats were collected from ten haul-out sites and two breeding colonies (Cape Gantheaume and Cape du Couedic, both on Kangaroo Island) in marine locations (Table 4.6). Overall, there was a significant difference in per cent biomass of prey composition between the scats collected at haul-out sites and those collected at the breeding colonies (ANOSIM P=0.001, R=0.137). SIMPER results (average dissimilarity 96.88%) demonstrated that the observed differences between samples from haul-out sites (HO) and breeding colonies (BC) were driven by the higher relative proportion of Leatherjackets at haul-out sites (HO 31.5% vs. BC 0.00%). This was coupled with a lower proportion of Sardines (HO 4.64% vs. BC 21.58%), Clubhook Squid (*Onychoteuthis* sp.) (HO 0.45% vs. BC 22.12%) and *Symbolophorus barnardi* at haul-out sites compared to breeding colonies (HO 2.1% vs BC 14.6%).

Key finding: Haulouts demonstrated a high diversity of prey species and low presence of oceanic prey species compared to breeding sites with low diversity and oceanic spp. contributing to a high proportion of diet.

Little Penguins

Overall, 9.9% of scats (n=252) from marine sites contained evidence of Little Penguin predation (Table 4.3). Regionally, the highest proportion of scats with Little Penguin remains was from GSV (FO 18.3%) and SCKI (FO 5%) (Table 4.3, Figure 4.3). Evidence of Little Penguin predation was not present in SG samples, but shearwaters were identified in 5.6% of those scats. Based on the allocated weight of 252 g (one fifth of average penguin weight) per scat with feathers, Little Penguins contributed to 16.8% of diet (Table 4.4). Little Penguins contributed to 27.9% of prey biomass in samples collected from GSV, 11% for SCKI and 0% for SG. The importance of Little Penguins varied across sites, 7 of 12 sites (2 for SCKI, 5 for GSV) contained Little Penguin remains and the incidence of scats with Little Penguin remains ranged from 5 to 45% (Figure 4.3). West Island and Seal Island, located approximately 60 km apart in Encounter Bay, had the highest incidence of Little Penguin remains in scats (West Island 45% and Seal Island 30%). On Kangaroo Island, Little Penguin remains were not found in samples collected from Cape du Couedic or Ballast Head.

Hard-part analysis versus DNA analysis

Hard-part analysis

Of the 37 scats investigated for hard parts and by using DNA, 27 (73%) contained recognisable hard parts. A total of 138 individual prey from 25 unique taxa across three prey groups were identified at or below family level by hard part analysis: 18 fish, six cephalopod and one seabird. Of the samples with recognisable prey, 37% (10) had one taxon, 22% had two or more species and the maximum number of prey taxa identified was four.

Based on hard-part analysis, the most dominant species numerically and by frequency of occurrence was Luminous Bay Squid (NA 34%, FO 16.2%) (Table 4.7). However, biomass estimates showed they only contributed to 4.3% of diet, with Leatherjackets (28.8%) and Little Penguins (21.4%) making up approximately 50% of the reconstructed diet (Table 4.7).

Genetic analysis

A minimum of 266 prey individuals represented by 77 prey taxa were identified from genetic analysis of the 37 scats. These taxa were identified at, or below, family level across five prey groups: 53 fish, 15 cephalopod, 7 crustacean, 1 ray and 1 seabird. With the exception of two scats (containing one and two prey taxa), genetic analysis detected between 4 and 15 unique prey taxa in each scat. Southern Calamari was most frequently detected (59.5% of scats), followed by Gould’s Squid and Garfish, which were equally frequent (45.9%). Leatherjackets were also dominant; five identified Monocanthidae species (Degens Leatherjacket, Toothbrush Leatherjacket, Velvet Leatherjacket, Ocean Jacket and Bridled Leatherjacket) were found in 46% of scats. These species were pooled to allow for comparisons with hard-part analysis where otoliths were only identifiable to family level (Monocanthidae).

Comparison of methods

The combination of genetic and hard-part analysis methods enabled detection of 82 unique taxa across six prey groups: 58 fish, 15 cephalopod, seven crustacean, one ray and one seabird (Figure 4.4). Genetic analysis demonstrated a higher overall taxonomic resolution compared to hard-part analysis for all 37 scats. Ten scats (27% of all samples) did not contain diagnostic hard parts, but prey taxa were identified for each scat using genetic analysis, with up to 15 prey taxa per sample.

Of the 82 prey taxa identified, 77 (94%) were detected using genetic analysis and 25 (30%) using hard-part analysis. Of the prey species identified, 57 (70%) were undetected in hard-part analysis compared to 5 (6%) using genetic analysis (only detected using hard-part analysis), however, these 5 species were 20% of the taxa recorded from hard-parts. Identification of prey taxa overlapped between the two methods for 20 species (24% of all detected species) (Figure 4.4).

Key prey taxa described by both methods included Southern Calamari (HP 10.8% vs DNA 59.5% FO%), Garfish (HP 8.1% vs DNA 45.9% FO%) and Leatherjackets (HP 13.5% vs DNA 46% FO%) (Table 4.7, Figure 4.4). For prey taxa detected using both methods, the frequency of occurrence was on average three times higher in samples using genetic analysis compared to hard-part analysis (Table 4.7).

The five species with the highest frequency of occurrence from genetic analysis (Southern Calamari, Leatherjackets, Garfish, Gould’s Squid and Slender Bullseye) were also identified via hard-part analysis. Based on hard-part analysis, these five species made up 18.2% of numerical abundance, 40.5% of frequency of occurrence and contributed 45.8% to the reconstructed biomass (Table 4.7). Although Leatherjackets made up 28.8% of total biomass compared to Gould’s Squid 0.3%, both species were detected in 45.9% of samples using genetic analysis compared to 13.5% and 5.4%, respectively in hard-part analysis. Of the species undetected in hard-part analysis, Australian Herring (FO 18.9%), Barracouta (18.9%) and Dumpling Squid (16.2%) were detected most frequently using DNA. Several species such as Shorthead Worm Eel, Blackring Waryfish and Bigscale Ruby Fish have not been described in the diet of LNFS previously.

Of the 25 species identified from hard-part analysis, five fish species, King George Whiting, Mulloway, Myctophid sp. 3, Redbait/Jack Mackerel and Yellow-eye Mullet were undetected using genetic analysis (Table 4.7). Each was found in one of the 37 samples (five separate samples) with a frequency of occurrence of 2.7%. Numerically, the most abundant prey taxa undetected in genetic analysis were Myctophid sp. 3 (NA 5.07%), Yellow-eye Mullet (NA 2.17%) and Mulloway (NA 1.45%). Combined, the five species contributed 17.8% to the reconstructed biomass of the 37 scats. Of the five species, Mulloway (Bio 9.7%), Yellow-eye Mullet (Bio 5.6%) and King George Whiting (Bio 1.7%) contributed most biomass. Approximately 33% of scats (9 scats) with diagnostic evidence of prey taxa contained hard parts which were not identified within that particular scat via genetic analysis. For example, Myctophid sp. 1 was detected in a scat via hard-part analysis but not by genetic analysis, however this species was found in other scat samples using genetic analysis.

Little Penguins

Five of the 37 samples contained Little Penguin feathers; genetic analysis confirmed the presence of Little Penguins as a prey taxa for these samples. Genetic analysis detected Little Penguins in two other samples that did not contain Little Penguin feathers.

Commercially Fished Species

Commercially fished species - marine

Combined, commercially fished species made up 69.4% of prey individuals across all samples investigated using hard-part analysis (n=252 scats) and contributed 59.8% to reconstructed biomass (of which 41.1% was made up of Leatherjackets) (Tables 4.3 and 4.4). Garfish (12.8 NA%), Sardines (10.8 NA%) and Leatherjackets (7.5 NA%), contributed most to the occurrence of commercially fished species by number (Table 4.3). The three commercially fished species with the highest biomass contributions were Leatherjackets (41.1%), Southern Calamari (8%) and Garfish (3.5%) (Table 4.4).

Based on all 252 scats, Garfish made up approximately 3.5% of diet biomass (Table 4.4). Size reconstruction from otoliths indicated that approximately 86% of Garfish predated across the three marine regions were below the legal catch size (Figure 4.5). Overall, GSV samples accounted for 94% of Garfish detected, of which 61% were in scats from one haul-out site, Ballast Head, located on the north-east coast of Kangaroo Island. Gulf St Vincent samples also contributed to 93.3% of the commercially undersized Garfish individuals compared to 5.7% for SCKI and 1% for SG. Southern Calamari and Garfish were more important (in terms of biomass contribution) for seals using GSV sites (Southern Calamari 14.2%, Garfish 5.9%), compared to those using SCKI (Southern Calamari 2.4%, Garfish 0.7%) or SG (Southern Calamari 0.2%, Garfish 1.1%) sites. Leatherjackets made a higher biomass contribution in samples from SG (87.6%) than GSV (27.9%) or SCKI (5.9%).

Ranges of the estimated length of Garfish, Southern Calamari and Sardines from scat samples were 100-320 mm, 40-200 mm and 40-160 mm, respectively (Figures 4.5, 4.6 and 4.7). Sardines contributed 2% to overall diet by biomass (Table 4.4) and were a key prey species for animals using SCKI, contributing 7.8% by biomass (Figure 4.7). Approximately 95% of Sardines predated by LNFS were below the estimated size of sexual maturity in SA (>140 mm, Ward *et al*. 2012), with an overall mean size of 70.3 mm.

Genetic analysis detected 40 commercially targeted species compared to 16 using hard-part analysis. Key commercial species detected using both methods included Southern Calamari, Garfish and Sardines. In addition, Snapper and Prawns (*Melicertus* spp.) were detected using genetic analysis only (Tables 4.7 and 4.8). Both Snapper (Seal Island sample) and Prawns (*Melicertus* spp.) (Penneshaw sample) were detected in one sample (FO 2.7% each, separate samples) compared to Sardines (FO 8.1%), Garfish (FO 45.94%) and Southern Calamari (FO 67.6%) which were detected across several samples and regions using DNA analysis (Tables 4.7 and 4.8).

For scats compared using DNA with hard-part analysis (n=37), the frequency of occurrence of Southern Calamari, Garfish and Sardines was higher using genetic analysis by factors of 5.5, 5.6 and 3.0, respectively (Table 4.7). Biomass contributions from the sub-sample (n=37) were comparable to the broader findings of Garfish biomass contribution to diet (sub-sample 2% vs all samples 3.5%). However, for this species there was a notable difference in the detection of occurrence by the two methods (HP 8.1% versus DNA 45.9%).

Commercially fished species - Coorong

This is the first study to investigate the diet of LNFS foraging in the Coorong. Hard-part analysis detected six fish species: Common Carp, Bony Herring, Mulloway, Yelloweye Mullet and two Goby species (Table 4.5). In terms of biomass, Common Carp (69%) was most prevalent. With the exception of Yelloweye Mullet, these species have not been described previously in LNFS diets. Because a high proportion of samples collected from the Coorong did not contain identifiable hard parts, possibly due to the poor quality of samples collected, the data is likely to under-represent species predated there.

Two commercially fished species, Yelloweye Mullet and Mulloway, were detected. Each was separately detected in one sample (two samples overall). They contributed 1.5% of the reconstructed prey biomass (1.32% and 0.18%, respectively).

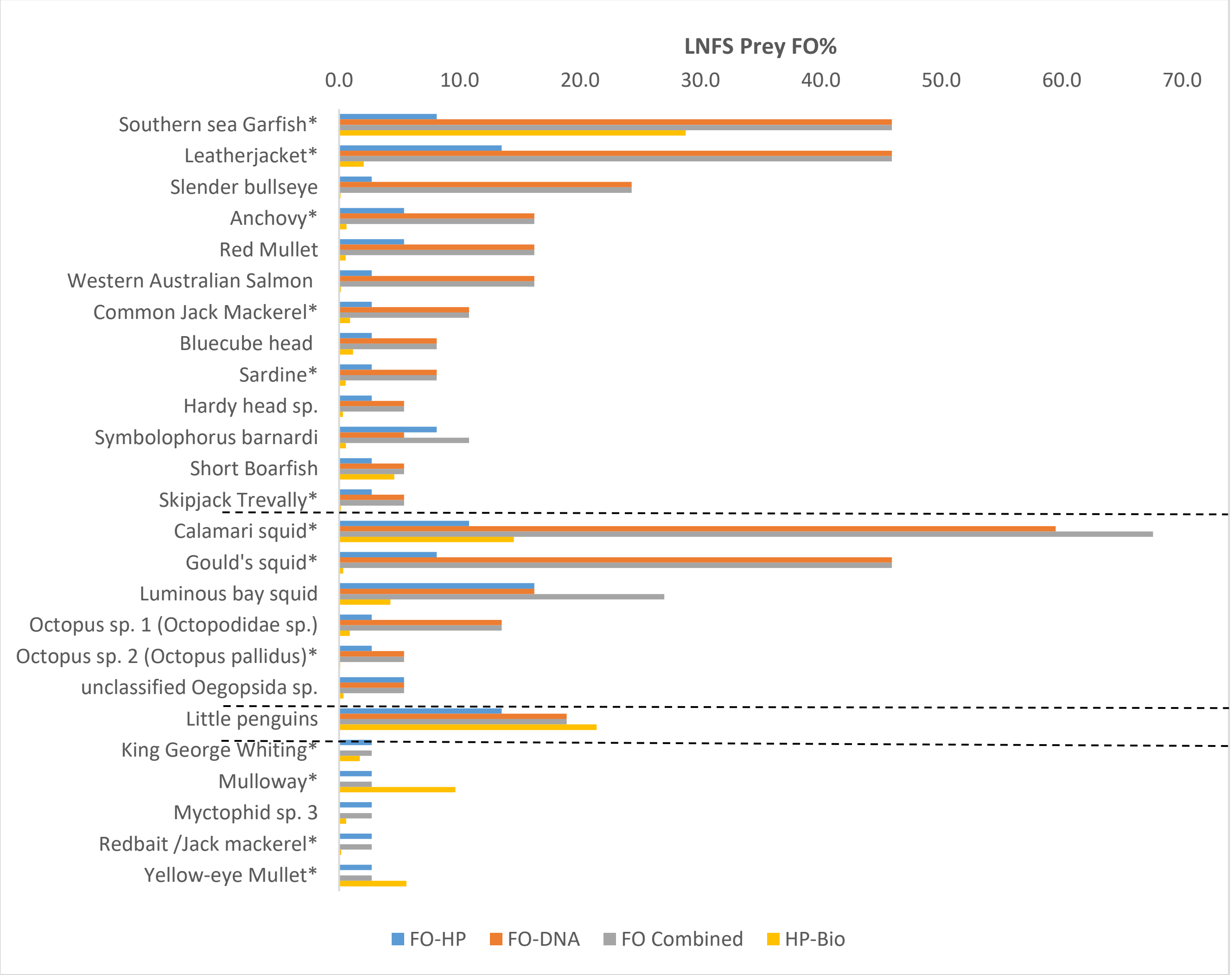


Figure 4.4 Frequency of occurrence (FO) of prey species of Long-nosed Fur Seals detected in scats using hard-part analysis (HP), DNA analysis and both methods combined for the 20 species detected by both methods. The species are grouped as fish (13 species), cephalopods (six), birds (1), with the five species that were detected by hard part analysis only at the bottom of the graphic. Also included are per cent biomass contributions of prey taxa determined from hard parts (HP-Bio). Commercially fished taxa are indicated by *.

Table 4.7. Comparison of the results of hard-part analysis and DNA analysis. Per cent numerical abundance (NA), frequency of occurrence (FO) and biomass contribution (Bio) of prey taxa found in Long-nosed Fur Seal scats from South coast, Kangaroo Island, Gulf St Vincent and Spencer Gulf based on hard part analysis of 37 scats. For comparison, the frequency of occurrence for prey taxa detected using DNA analysis (DNA FO%) is included. The table heading includes the minimum number of individuals (NA), scat samples (FO) and biomass contribution (Bio) in parentheses. Five species identified by hard part analysis and not by using DNA are at the bottom of the table (HP identified spp.).

Prey taxa		**HP NA%**	**HP FO %**	**HP Bio%**	**DNA FO%**
		(138)	**(37)**	**(5.89 kg)**	**(37)**
Fish					
Anchovy	*Engraulis australis*	5.8	5.4	0.6	16.2
Bluecube head	*Cubiceps caeruleus*	0.7	2.7	1.2	8.1
Common Jack Mackerel	*Trachurus declivis*	0.7	2.7	0.9	10.8
Hardy head sp.	*unclassified Atherinason sp.*	9.4	2.7	0.5	8.1
Leatherjacket	Monocanthidae	6.5	13.5	28.8	46.0
Myctophid sp. 4	*Symbolophorus barnardi*	6.5	10.8	0.6	5.4
Red Mullet	*Upeneichthys vlamingii*	1.4	5.4	0.5	16.2
Sardine	*Sardinops sagax*	3.6	2.7	0.3	8.1
Short Boarfish	*Parazanclistius hutchinsi*	1.4	2.7	4.6	5.4
Skipjack Trevally	*Pseudocaranx sp.*	0.7	2.7	0.1	5.4
Slender bullseye	*Parapriacanthus elongates*	0.7	2.7	0.1	24.3
Southern sea Garfish	*Hyporhamphus melanochir*	2.2	8.1	2.0	45.9
Western Australian Salmon	*Arripis truttacea*	0.7	2.7	0.1	16.2
Cephalopods					
Calamari squid	*Sepioteuthis australis*	6.5	10.8	14.5	59.5
Gould's squid	*Nototodarus gouldi*	2.2	5.4	0.3	45.9
Luminous bay squid	*Uroteuthis noctiluca*	34.1	16.2	4.3	16.2
Octopus sp. 1	*Unclassified Octopodidae sp.*	0.7	2.7	0.9	13.5
Octopus sp. 2	*Octopus pallidius* *	0.7	2.7	0.1	8.1
Onychoteuthis sp.	*Unclassified Oegopsida sp.* *	1.4	5.4	0.4	2.7
Seabirds					
Little penguin	*Eudyptula minor*	3.6	13.5	21.4	18.9
HP identified spp.					
King George Whiting	*Sillaginodes puncata*	0.7	2.7	1.7	
Mulloway	*Argyrosomus japonicas*	1.4	2.7	9.7	
Myctophid sp. 3	*Myctophidae*	5.1	2.7	0.6	
Redbait /Jack mackerel	*Perciformes*	0.7	2.7	0.2	
Yellow-eye Mullet	*Aldrichetta forsteri*	2.2	2.7	5.6	

Table 4.8. Minimum number of individuals and frequency of occurrence of prey taxa detected using DNA analysis. This table lists all prey taxa detected using DNA analysis that were undetected using hard-part analysis.

Prey taxa only identified from DNA analysis		**No. DNA**	**FO%**
Fish			
Degens leatherjacket	*Thamnaconus degeni*	10	27.0
Toothbrush leatherjacket	*Acanthaluteres vittiger*	3	8.1
Velvet leatherjacket	*Meuschenia scaber*	1	2.7
Ocean Jacket	*Nelusetta ayraud*	2	5.4
Bridled leatherjacket	*Acanthaluteres spilomelanurus*	1	2.7
Australian herring	*Arripis georgianus*	7	18.9
Barracouta	*Thyrsites atun*	7	18.9
Bearded cod	*Pseudophycis barbata*	1	2.7
Bigscale Bullseye	*Pempheris multiradiata*	2	5.4
Bigscale rubyfish	*Plagiogeneion macrolepis*	1	2.7
Blackring waryfish	*Scopelosaurus meadi*	1	2.7
Blue mackerel	*Scomber australasicus*	2	5.4
Blue sprat	*Spratelloides robustus*	1	2.7
Blue warehou	*Seriolella brama*	4	10.8
Bony bream	*Nematalosa erebi*	1	2.7
Bright lanternfish	*Myctophum phengodes*	2	5.4
Common stinkfish	*Synchiropus calauropomus*	1	2.7
Congolli/Freshwater flathead	*Pseudaphritis urvillii*	2	5.4
Coorong mullet	*Aldrichetta forsteri*	1	2.7
Common Carp	*Cyprinus carpio*	2	5.4
Hector's lanternfish	*Lampanyctodes hectoris*	1	2.7
King gar/Saury	*Scomberesox saurus*	1	2.7
Maray/herring	*Etrumeus teres*	1	2.7
Murray-Darling Golden Perch	*Macquaria ambigua*	1	2.7
Red gurnard	*Chelidonichthys kumu*	1	2.7
Sandy sprat	*Hyperlophus vittatus*	3	8.1
Silverbelly	*Parequula melbournensis*	4	10.8
Smalleye squaretail	*Tetragonurus cuvieri*	1	2.7
Snapper	*Chrysophrys auratus*	1	2.7
Snook	*Sphyraena novaehollandiae*	1	2.7
Southern rock cod	*Pseudophycis bachus*	1	2.7
Swallowtail	*Centroberyx lineatus*	2	5.4
Tasselled Angler	*Rhycherus filamentosus*	1	2.7
Unclassified cod species	*Pseudophycis breviuscula*	1	2.7
Unclassified Dragonfish sp.	*Flagellostomias boureei*	3	8.1
Unclassified Squirrelfish species	*Myripristis leiognathus*	4	10.8
Unclassified wayfish species	*Scopelosaurus ahlstromi*	1	2.7
Western roughy	*Optivus agrammus*	1	2.7
Yellowtail scad	*Trachurus novaezelandiae*	3	8.1
Conger Eel	*Gnathophis bathytopos*	1	2.7
Shorthead Worm Eel	*Scolecenchelys breviceps*	5	13.5

Table 4.8. continued

Prey taxa only identified from DNA analysis		**No. DNA**	**FO%**
Elasmobranches			
Thornback skate	*Dipturus lemprieri*	1	2.7
Cephlapods			
Unclassified Octopus	*Callitoctopus bunurong* *	1	2.7
Giant Australian Cuttlefish	*Sepia apama*	5	13.5
Oceanic squid	*Lycoteuthis lorigera*	1	2.7
Southern dumpling squid	*Euprymna tasmanica*	6	16.2
Southern sand octopus	*Octopus kaurna*	2	5.4
Unclassified Octopus sp.	*Pareledone* cf. *aequipapillae* *	2	5.4
Unclassified Octopus sp.	unclassified Octopodidae sp.	5	13.5
Unclassified Octopus sp.	*Enteroctopus dofleini* *	1	2.7
Unclassified octopus species4	*Ommastrephes bartramii*	3	2.7
Crustaceans			
Prawns	*Melicertus* spp.	1	2.7
Rough rock crab	*Nectocarcinus integrifrons*	2	5.4
Unclassified rock crab species	*Nectocarcinus antarcticus*	1	2.7
Unclassified sand crab species	*Ovalipes catharus*	3	8.1
Unclassified swimming crab species	*Liocarcinus corrugatus*	2	5.4
Unclassified Decapod sp.	unclassified Alpheidae sp.*	2	5.4
Unclassified Decapod sp.	unclassified Decapoda sp. *	1	2.7

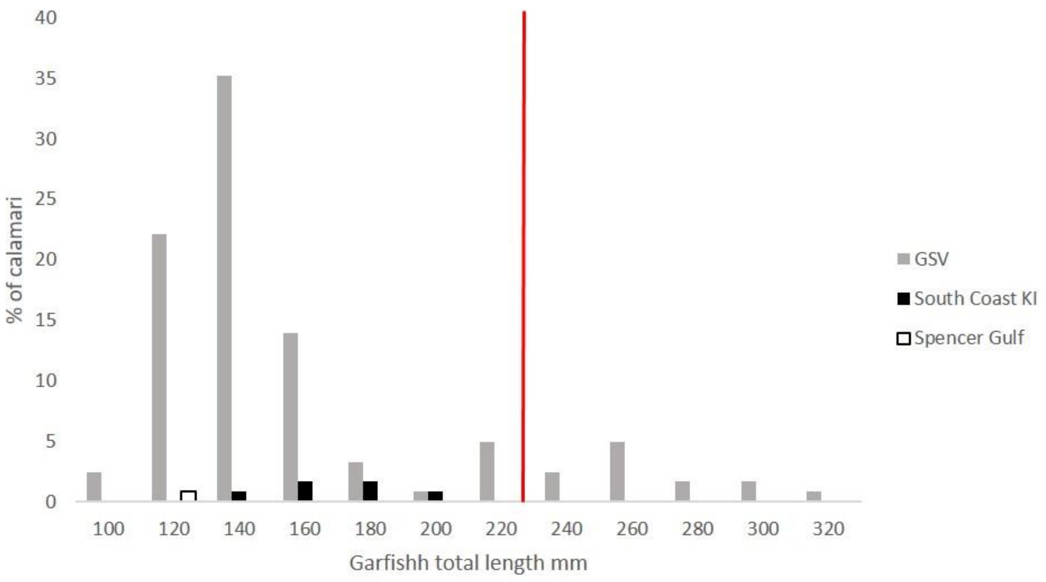


Figure 4.5 Garfish length (mm) estimated from otoliths extracted from Long-nosed Fur Seal scats from three marine regions: Gulf St Vincent, South coast of Kangaroo Island and Spencer Gulf. The red line represents the minimum legal size of Garfish for commercial fisheries (230 mm).

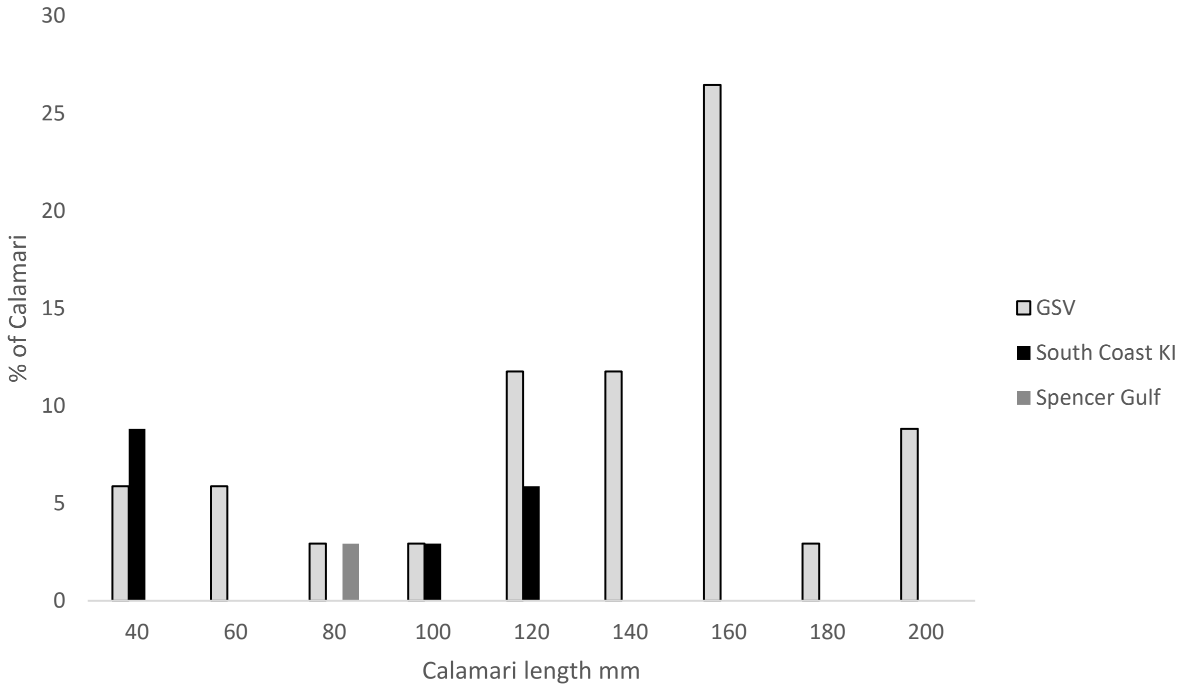


Figure 4.6 Calamari length (mm) estimated from upper and lower beaks extracted from Long-nosed Fur Seal scats from three regions: Gulf St Vincent, South coastof Kangaroo Island and Spencer Gulf.

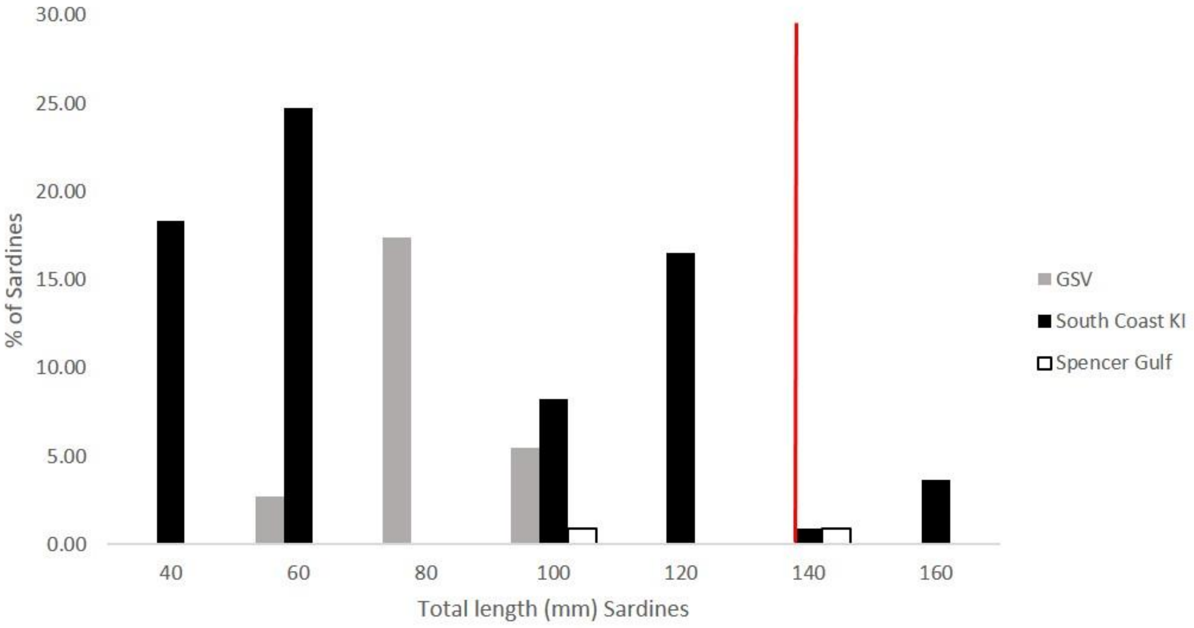


Figure 4.7 Sardine length (mm) estimated from otoliths extracted from Long-nosed Fur Seal scats from three marine regions: Gulf St Vincent, South coast of Kangaroo Island and Spencer Gulf. The red line represents the size of sexually mature Sardines in South Australia (>140 mm).

4.4 Discussion

Of the 40 prey taxa (29 fish, nine cephalopods and two birds) identified from hard-part analysis, Leatherjackets, Little Penguins, Southern Calamari and Garfish made up approximately 70% of the reconstructed biomass. These species were detected in samples from all three marine regions. Although they have been identified previously in LNFS diet studies in SA (Baylis and Nichols 2009, Page *et al.* 2005a), they were not described previously as key prey species. This is one of the first studies to investigate the diet of subadult males located at haul-out sites in GSV and SG. In SA, previous dietary studies of LNFS have largely focused on the breeding populations on Kangaroo Island (Cape Gantheaume, Cape du Couedic) and the Neptune Islands (Baylis and Nichols 2009, Page *et al.* 2005a). In this study, sample sites from SCKI comprised two breeding colonies (Cape Gantheaume, Cape du Couedic) and one haul-out site (Cape Kersaint). As found in previous studies of breeding animals, the key prey species were predominantly oceanic prey taxa, including myctophid fishes and Gould’s Squid (Baylis and Nichols 2009, Page *et al.* 2005a).

The spatial scale of this study enabled identification of significant regional differences in the LNFS diet. Leatherjackets and Southern Calamari were most commonly consumed by LNFS across the range. While the dietary significance of Leatherjackets may have increased in the absence of other key prey species (see below), some of the variation is likely to reflect prey availability (Hume *et al.* 2004, Lake *et al.* 2003) and differences in foraging areas between fur seals using breeding sites compared with haul-out sites (Baylis and Nichols 2009, Page *et al.* 2005a).

Contrary to other studies conducted on Kangaroo Island and the Neptune Islands (Baylis and Nichols 2009, Page *et al.* 2005a), we found little evidence for Redbait, Gould’s Squid and Southern Ocean Arrow Squid in the diet. The two squid species may not have been highly abundant in our study due to the small sample size and the limited temporal scale, as all sampling was conducted during winter and spring. Previous studies have demonstrated that large cephalopods, particularly Arrow Squid, generally predominate through summer and autumn (Fea *et al.* 1999, Page *et al.* 2005a). DNA analysis (see below) also indicated that hard-part analysis underestimated the contribution of cephalopod species for LNFS diet, particularly for Arrow Squid.

The low contribution of Redbait in this study, previously described as a key prey species in the diet of LNFS in SA, may reflect changing dynamics in small pelagic fish populations. Kirkwood *et al.* (2008) monitored the annual variation in the diet of Australian Fur Seals (AFS) at Seal Rocks, Victoria over a nine-year period. The importance of Redbait varied considerably across the monitored period; it was prevalent from 2001 to 2005, but almost absent from the diet in other years when it was replaced mainly by Jack Mackerel, Barracouta, Red Cod and Leatherjackets. Kirkwood *et al.* (2008) suggested that the presence of juvenile Redbait within the fur seal foraging ranges may have been influenced by oceanographic fluctuations which affected inflow of cooler waters from the outer shelf. Scats used in diet studies of LNFS by Page *et al.* (2005a) and Baylis and Nichols (2009) were collected during the period when Redbait were prevalent in the diet of the AFS in Bass Strait. This suggests that factors governing the prevalence of Redbait in diets of LNFS and AFS in both regions may be similar. Accordingly, the dietary significance of Leatherjackets for LNFS in SG and GSV may have increased in the absence of Redbait within foraging areas.

For SG, key prey species were Leatherjackets and Shearwaters, with Leatherjackets contributing over 85% of the LNFS diet. Whilst this contribution may have been higher due to the potential influence of oceanic fluctuations, Leatherjackets are prevalent within SG. Leatherjackets are a key species in SG Ecosystem Models and accounted for 70% of the total trawl catch for the SG prawn fishery (Currie *et al.* 2009, Currie and Sorokin 2010, Gillanders *et al.* 2015). Leatherjackets scavenge at aquaculture sites (Svane and Barnett 2008). Tracking data from Chapter 5 demonstrated that LNFS foraged near aquaculture pens consistently prior to the harvest of aquaculture species, which may result in more predator-prey interactions than otherwise.

For haul-out sites in GSV, Leatherjackets, Little Penguins, Southern Calamari and Garfish were the key prey species. Although Garfish and Southern Calamari were described as key prey species for GSV, stock assessments for both species indicate that abundance is higher in SG (Fowler *et al.* 2015, Steer *et al.* 2016). Samples collected from GSV demonstrated greater species richness and diversity in comparison to SG and SCKI samples, which may be attributed to the greater number of sites and samples collected from the GSV region. Assessing LNFS diet composition at a regional scale is difficult due to the long distances they travel. Tracking data from Chapter 5 and previous tracking studies have demonstrated that during one foraging trip, adult females and juveniles travel up to 642 and 688 km respectively, and adult males travel 1,154 km (this study, Page *et al.* 2005a). This suggests that prey taxa recovered from LNFS scats can reflect localised, inter-regional and/or oceanic foraging.

Samples collected from haul-out sites in both Gulfs had a higher presence of prey taxa found in shelf and coastal waters compared to those from SCKI in which oceanic species were prevalent. The difference in prey recorded between SCKI and the two Gulfs may reflect, in part, the relative distance to oceanic waters. GSV and SG sites are located between 150 to 200 km from the shelf break compared to SCKI, which is ~60km away. For example, the presence of myctophid fish, found in oceanic water (Watanabe *et al.* 2002), was only evident in our study amongst samples collected on Kangaroo Island (predominantly from south coast samples).

Comparison between breeding colonies and haul-out sites

The prey composition of samples collected from SCKI was significantly different from samples collected from SG and GSV. The region SCKI comprises two breeding colonies and one haul-out site whilst the other two regions (9 sites in total) comprise haul-out sites only. Breeding colonies are dominated by lactating females nursing pups (in addition to some breeding and non-breeding males (Page *et al.* 2005a), while at haul-out sites non-breeding animals, such as juveniles and subadult males, are most prevalent (Goldsworthy and Shaughnessy 1994). A higher prey diversity was found amongst samples collected from Cape Kersaint (19 prey taxa) than the two breeding colonies on SCKI (14 prey taxa for both sites combined). Cape Kersaint had a lower presence of oceanic prey species such as myctophid fishes and ommastrephid cephalopods and a higher presence of shelf-water fishes such as Garfish, Gemfish and Common Bullseyes. These results are consistent with the broader findings of this study, namely, that scats from haul-out sites, which are favoured by subadult males and juveniles, have more diverse shelf-water prey composition compared to adult females from breeding colonies that forage in oceanic waters.

Several satellite tracking studies have shown that most lactating females forage in oceanic waters of the subtropical front during winter (Baylis and Nichols 2009, Page *et al.* 2005a). Females with pups are constrained to breeding sites to feed their pups, which in turn restricts their foraging range because young pups cannot be left alone for extended periods (Goldsworthy and Shaughnessy 1994). During winter and spring (when sampling was undertaken), pups are older and larger and can sustain longer fasting periods (Goldsworthy and Shaughnessy 1994), which allows females to undergo long foraging trips, beyond the shelf break, to nutrient rich waters of the subtropical front where they consume high abundances of prey (Page *et al.* 2006). It has been suggested that fatty acids found in myctophid species may be important to lactating females because continental shelf species are relatively low in fatty acids (Baylis and Nichols 2009).

In contrast to lactating females, adult males and juveniles do not experience the constraints linked with dependant young (Goldsworthy and Shaughnessy 1994), and therefore are expected to undergo shorter foraging trips closer to their haul-out sites. However, foraging beyond shelf waters is not exclusive to adult females as scats collected from haul-out sites on the south and north coasts of Kangaroo Island included myctophids (Page *et al.* 2005a). In addition, a higher incidence of penguin remains in the diet from haul-out sites could be explained by a more variable diet including foraging in nearshore waters. Non-breeding animals, potentially represented by a more variable age spread, are more likely to demonstrate higher variability in foraging compared to breeding females, which are constrained by the energy needs of lactation and have been shown to undertake foraging trips mostly to offshore areas (Harcourt *et al.* 2002, Page *et al.* 2006). The higher number of haul-out sites sampled (9) compared to breeding colonies (2) may have led to a greater diversity of prey taxa identified from haul-out sites.

Comparison of hard-part analysis and DNA analysis

To our knowledge, this is the first study to investigate the use of hard-part analysis of scats in conjunction with DNA methods for LNFS diet. Consistent with previous pinniped dietary investigations, this study demonstrates that whilst DNA analysis generates a higher taxonomic resolution than hard-part analysis, these methods in combination maximise prey taxa detection (Deagle *et al.* 2009, Jeanniard-du-Dot *et al.* 2017, Peters *et al.* 2014). Both methods combined identified 82 prey taxa across five prey groups: fish, cephalopod, seabird, skate and crustacea. DNA analysis detected 57 species that were not described using hard-part analysis, and increased the number of occurrences and taxonomic resolution of some families. With the exception of myctophid species, the detection of prey species identified using both methods was three times higher for DNA analysis. Substantial increases in the amount of information attained by combining DNA-based and morphological analyses of scat samples have also been described for pinnipeds by Tollit *et al*. (2009) and Jeanniard-du-Dot *et al.* (2017) (2017). In their studies, DNA-based methods increased the number of prey occurrences by ~25% and 20%, respectively. In this study, prey detection using DNA methods was notably higher than hard-part analysis (increased prey occurrence detection 57.5%), which may reflect the advances in DNA methods developed in this project (i.e., use of a highly specific predator blocking primer, development of a new molecular (metabarcoding) assay). The relatively small number of samples investigated (37 this study, compared with ~100-150 by Jeanniard-du-Dot *et al.* 2017, Tollit *et al.* 2009) may also have resulted in greater variances between the two methods.

Skates and crustaceans were described in samples using DNA analysis only. This is the first time a skate species has been reported in LNFS diet and crustaceans have predominantly been reported in regurgitate samples for LNFS (Fea *et al.* 1999, Page *et al.* 2005a). Several cephalopod species previously described in LNFS diets for SA, including Southern Arrow Squid, *Octopus maorum* and *O. berrima* (Page *et al.* 2005a) were not detected in this study. Large cephalopod beaks and crustacean hard parts can sometimes be resistant to digestion and tend to cluster at the bottom of a stomach before being regurgitated (Gales and Cheal 1992). Hard parts of crustaceans may also have been detected due to consumption as secondary prey (Braley *et al.* 2010). Only 44% of cephalopods and 29% of crustaceans identified in DNA analysis were resolved to a species level (Chapter 3). Assessing the contribution of these prey groups is difficult for both methods due to the poorly resolved taxonomy and morphological similarity of hard parts across species (Berry *et al.* 2015).

Consistent with other dietary investigations, key prey taxa were predominantly detected using both methods (Braley *et al.* 2010, Deagle *et al.* 2009) (Figure 4.4). The highest contributing species, Leatherjackets, Luminous Bay Squid, Gould’s Squid, Southern Calamari and Little Penguins were found at a higher rate using DNA analysis than hard-part analysis (Figure 4.4). This suggests that hard-part analysis underestimates both the diversity of prey species and the contribution of key prey taxa. It is likely that reduced detection can be explained by the loss of cephalopod beaks through regurgitation or by deterioration of hard parts. Species with small and fragile otoliths that are less likely to stay intact, such as Anchovy and Sardines, were also more commonly detected using DNA analysis (Table 4.7). Prey species identified using DNA analysis only that occurred in high proportions included Giant Cuttlefish and Barracouta (Table 4.8). The absence of these large species in hard-part analysis may be explained by them being digested, or incorporated in a number of scats and thus not detected. Seals feed on large prey by breaking them into smaller pieces and may also avoid swallowing large, hard or spikey heads (e.g., Barracouta). Deagle *et al*. (2009) found Leatherjackets more commonly using hard-part analysis than DNA-based methods in Australian Fur Seal diets, as Leatherjackets possess both otoliths and resilient teeth suitable for hard-part identification. Contrary to these findings, Leatherjackets were detected in an additional 49% of samples using DNA analysis here, although they were the second most commonly detected prey using hard-part analysis.

DNA analysis is an effective method for capturing prey species that are consistently present at low frequencies. For example, Red Rock Cod and Swallowtail were only identified using DNA based methods; both species were detected in this study using hard-part analysis of samples not included in the sub-sample of 37 scats (n=252). DNA analysis also detected Silverbelly, Southern Cardinal Fish and Longfin Pike in low frequencies; these prey have previously been described in LNFS diets for SA using hard-part analysis (Bool *et al*.2007, Page *et al.* 2005a). DNA analysis assisted in the identification of an additional three fish species (with the aid of otolith reference atlases) for which otoliths were not identified: Blue Cubehead, Short Boarfish and Slender Bullseye. Both Blue Cubehead and Short Boarfish have not been described previously in LNFS diets.

For all prey species detected using both methods, DNA analysis generated a higher overall frequency of occurrence with the exception of *Symbolophorus barnardi* (Figure 4.4). Myctophids are oceanic fish species which link primary consumers like copepods, and euphausiids with top marine predators, such as squids and seals (Catul *et al.* 2011, Page *et al.* 2005a). The higher occurrence of myctophid species (Myctophid sp. 3 and *Symbolophorus barnardi*) in hard-part analysis may be explained by the distance that animals travel between feeding and where they pass myctophid otoliths on land. During the travel from oceanic waters back to land, the flesh of myctophid fishes may be completely digested whilst otoliths are retained for a longer time and then passed on land (Cottrell *et al*. 1996, Gales *et al.* 1993). Whilst overall comparison of the two methods has demonstrated that DNA analysis provides a higher number and frequency of prey taxa detected compared to hard-part analysis, 6% of prey taxa were detected by the latter method only. There are also quantitative limitations to DNA analysis, because it is not possible to estimate occurrence by number, prey size (see discussion on commercially targeted species) and biomass contributions. DNA analysis has provided an insight into the diversity of LNFS prey and demonstrated that these generalist predators use benthic and pelagic waters in coastal and oceanic environments. The comparison of dietary investigation methods has highlighted that previous investigations using only hard-part analysis have under-represented the spectrum of prey species.

Commercially fished species – marine

This study identified 40 commercially caught species through the combination of hard-part and genetic analyses (including hard-part analysis for 252 scats), which represents 48% of all prey taxa described. This is a higher contribution than previously reported; Page *et al*. (2005a) found commercially targeted species made up 10% of prey taxa for LNFS on SCKI using hard-part analysis only. Results from this study demonstrated that Leatherjackets, a predominant bycatch species of prawn trawling and marine scale fisheries (Fowler *et al.* 2015), made up 41.1% of LNFS biomass diet. Excluding Leatherjackets, commercially fished species contributed to 18.7% of prey taxa biomass, suggesting that they are important in LNFS diet.

DNA analysis contributed to the identification of an additional 24 commercially targeted species not found by hard-part analysis. Five key commercial species were identified, three of which, Southern Calamari, Garfish and Sardines were described using both methods. The other two, Snapper and Prawns (*Melicertus* spp.) were detected in one sample each using DNA analysis. Southern Calamari and Garfish have been identified as key prey for LNFS and were detected in a higher proportion of samples using DNA analysis, an additional 72% and 82% of samples, respectively. Of the commercial prey taxa previously described in seal dietary studies (Baylis and Nichols 2009, Gales *et al.* 1993, Page *et al.* 2005a), none have been identified as key prey species. In terms of biomass, commercially targeted species contributed to 11.8% of the diet for SCKI sites, 61.4% for GSV and 93.2% for SG. Leatherjackets dominated the contribution of commercially targeted species, particularly for SG (Table 4.4). Higher species diversity of commercially targeted fish was found at GSV haul-out sites and may be due to the larger sample size and more sites sampled. Overall, commercially targeted species accounted for a higher proportion of diet amongst haul-out sites compared to breeding colonies. Most dietary studies in SA have focused on breeding animals (which forage in oceanic waters during winter); the absence of dietary data from haul-out sites likely explains the lower contribution of commercial species reported previously (Baylis and Nichols 2009, Page *et al.* 2005a).

Garfish made up approximately 3.5% of diet biomass; size reconstruction from otoliths indicated that approximately 88% of Garfish predated across the three marine regions were below the legal minimum catch size. Within SA, Garfish fisheries are economically important, valued at roughly AUD $2 million per annum (Knight and Tsolos 2011). Recent stock assessments within GSV have indicated high levels of fishing exploitation demonstrated by the truncated sizes and ages (majority of catch is aged less than three years) of most Garfish caught (Steer *et al.* 2016, Steer *et al.* 2012). The northern GSV fishery was classified as over-fished in 2016 (Steer *et al.* 2016), and a major stock re-building initiative is underway. All Garfish detected in samples collected from SCKI and SG were below the legal minimum size (230 mm) for recreational anglers, as were 83% for GSV (the legal minimum size for commercial fishers was increased from 230mm to 250mm in 2015). GSV samples accounted for 94% of Garfish detected in this study. Over half of Garfish otoliths detected in samples across the three marine regions were from Ballast Head, a haul-out site on the north-east coast of Kangaroo Island. The role of natural mortality for Garfish, including mortality from predation by fur seals, may need to be factored into managing for stock recovery. Further research is warranted to determine if the catch of commercially fished species may be impacting negatively on LNFS, or to the extent fur seal predation is impacting the available biomass of commercially fished species.

Sardine and Southern Calamari contributed to overall diet by 2% and 8%, respectively. Sardines were a key prey species for animals using SCKI sites, making up 7.8% of diet. Sardine size and age to sexual maturity varies between locations and it ranges between 100 mm to 180 mm fork length, and 1.8 to 2.8 years (Blackburn 1950, Butler *et al.* 1996, Joseph 1981). Despite difficulties in using certain ageing methodologies, Sardines in SA waters have shown higher growth rates than in other parts of Australia (Ward *et al.* 2017). The mean commercial catch size for Sardine in SA ranges between 135 and 145 mm, and catch quotas are allocated according to the catch size within this range (Ward *et al.* 2017). Sardine identified in LNFS scats had a mean size of 70.2 mm with only 4.5% of individuals reaching sexual maturity size (>140 mm). This suggests that LNFS predominantly predate sexually immature Sardine. However there are accuracy limitations in the fish lengths generated from otolith-fish length regressions, particularly because some Sardine otoliths were beyond the regression range. DNA analysis also suggested that the contribution of Sardine in LNFS diet using hard-part analysis only may be under-represented. The presence of meso-predators such as Barracouta, Western Gemfish and cephalopod species in LNFS diet, particularly for SCKI may indicate that Sardine is a secondary prey item (Braley *et al.* 2010). Southern Calamari have been described as a key LNFS prey species for the first time, contributing to 8% of LNFS diet. As the third most prevalent species in LNFS diet for GSV haul-out sites, Southern Calamari are an important prey taxa for juveniles and subadults within the region. Southern Calamari are predominantly targeted by the Marine Scale Fishery and are bycatch in the Prawn Fishery (Dixon *et al.* 2012, Fowler *et al.* 2015). DNA analysis detected Southern Calamari in an additional 72% of samples compared to hard-part analysis, once again highlighting the importance of using DNA-based methods to improve understanding of the contribution of commercially fished species in LNFS diet.

Commercially fished species – Coorong

Since 2015, LNFS have been recorded using the Tauwitcherie barrage as a haul-out site, predominantly by juveniles and subadult males, which enter the Coorong through the open Murray mouth (DEWNR Working Group 2017, Earl 2018). The diet of these animals has become of particular interest due to reported interactions with the commercial Lakes and Coorong Fishery (DEWNR Working Group 2017).

Common Carp was the most important prey item in terms of biomass. It is Australia’s largest alien freshwater species and contributes more than 90% of fish biomass in many areas of south-eastern Australia (Gehrke and Harris 2000). The abundance of Common Carp in Lake Albert was estimated to be 179,900 individuals with a biomass of 750,183 kg (Thwaites *et al.* 2010). Carp reduce visibility for visually feeding fish and reduce photosynthetic production by increasing water turbidity whilst feeding (Robertson *et al.* 1997). They destroy aquatic plants (Roberts *et al.* 1995) and attain high densities and biomasses (Harris and Gehrke 1997). Murray Cod and Golden Perch are native predators of juvenile Common Carp, but prefer native prey species (Ebner 2006). LNFS predation of Common Carp in the Coorong presents a unique predator-prey relationship as the historical occurrence of seals in the Coorong is debated.

DNA analysis was successful for a single sample collected from the Coorong. Thornbake Skate and Common Carp were detected, but no hard parts were evident in this sample. Tracking data from Chapter 5 demonstrated that animals hauling out on Seal and West islands forage in Coorong waters. That is corroborated by the detection of freshwater and estuarine fish (Bony Bream, Golden Perch and Congolli) using DNA analysis of samples collected from these islands.

Over the past two years, LNFS interactions with the Coorong and lower lakes fisheries has been extensive with seal deterrent trials undertaken in 2016 (Earl *et al.* in press). LNFS scats contained commercially significant species such as Yellow-eye Mullet, Mulloway and Bony Herring, but in only a small proportion of samples. Anecdotal feedback from commercial Coorong fishermen describe LNFS targeting the stomach of netted fish, the most nutritious part of the animal, rather than the whole fish. This foraging behaviour avoids prey otolith consumption and may limit the detection of commercially fished species in diets using hard-part analysis.

The presence of LNFS in the Coorong and data on their diet demonstrate the adaptability of this species as a generalist predator, allowing it to ‘switch’ among selected prey species to meet energetic requirements (Harcourt 2001, Harcourt *et al.* 2002). Our findings may under-represent interactions with commercial fisheries within the system due to LNFS foraging behaviour, sample quality and inherent biases associated with hard-part analysis. For example, Golden Perch otoliths were detected in regurgitate samples collected during *ad hoc* collections at Tauwitcherie barrage but were not included in analysis for this report. These large, thick otoliths are more likely to be regurgitated than those of smaller fish species.

Occurrence of Little Penguins in the diet of Long-nosed Fur Seals

Although penguins have been described as part of the diet of other pinnipeds, including Antarctic fur seals *Arctocephalus gazella* (Lea *et al.* 2002), Cape fur seals (Du Toit *et al.* 2004), Leopard Seals *Hydrurga leptonyx* (Ainley *et al.* 2005) and New Zealand fur seals (Fea *et al.* 1999), their relative importance as prey items is still debated. Some scientists even hypothesize that seabird predation by seals may largely be an extension of play behaviour (Bonner and Hunter 1982, Hofmeyr and Bester 1993). For example, Hofmeyr and Bester (1993) observed King Penguins (*Aptenodytes patagonicus*) being attacked by Antarctic fur seals, but not all attacks ended with ingestion of the bird. In support of this idea, we found one Little Penguin carcass floating in the water during sampling near West Island, with the majority of its body and stomach intact, and only the head and neck missing.

Predation on penguin species by several seal species has been identified as a behaviour exhibited almost exclusively by males, for example, Cape fur seals (David *et al.* 2003, Du Toit *et al.* 2004) and South American sea lions (*Otaria byronia*) (Rey *et al.* 2012). In SA, Page *et al.* (2005a) found that male LNFS consumed higher proportions of Little Penguins than did adult females and juveniles, with a peak during winter. Our results confirmed these trends, as we found the majority of Little Penguin predation in scats collected at haul-out sites, which are predominantly composed of non-breeding animals (subadult males and juveniles). Amongst Elephant Seals (*Mirounga* spp.*)*, it has been hypothesized that male and female resource partitioning has resulted from sexual selection for larger males. Stewa(David *et al.* 2003, Du

Toit *et al.* 2004)rt (1997) suggested that males target more energy-rich prey to increase their fat reserves and size in order to improve their chances of claiming a territory for reproductive success. LNFS males may target larger prey, such as penguins, for similar reasons.

Within SA, previous studies have shown that the importance of Little Penguins in LNFS diets varies considerably, from 2 to 5% on Kangaroo Island (Baylis and Nichols 2009) (Baylis and Nichols 2009) to 40% on Granite Island (Bool *et al.* 2007). In this study, regional variation was also identified. Penguin remains were evident in 22% of scats collected from GSV, 5% from SCKI and none from SG. Encounter Bay, particularly Granite Island, is a site of concern for seal predation of Little Penguins. This study indicates that the importance of Little Penguins for seals using Seal, West and Granite islands has remained consistent: penguin remains were found in 40% of scats in 2007 compared with 37.5% in 2014 (this study). The number of penguins predated may have increased as the LNFS population has grown (Goldsworthy *et al.* 2017a). Interestingly, West and Seal islands (which showed the highest occurrence of penguin predation) are close to some of the smallest penguin populations (22 on Granite Island, Colombelli-Négrel 2015). In contrast, at Port Giles (in GSV), 15% of scats contained Little Penguin remains and it is located only 12 km from one of the largest penguin colonies in SA (~3000 penguins, Troubridge Island, Wiebkin 2011). These results suggest that regional variation in Little Penguin availability is not the only factor driving predation rates. As such, higher levels of Little Penguin predation in the Encounter Bay area may reflect the absence or reduced availability of other key prey species. Daneri *et al.* (2008) suggested that Antarctic fur seals switched to preying on Chinstrap Penguins (*Pygoscelis antarctica*) in periods of low krill abundance, when the energetic cost of foraging for krill became too high.

Off west Eyre Peninsula, Pearson Island is host to the largest known Little Penguin colony in SA. Recent population estimates suggest burrow density there decreased by 31% between 2004 and 2013 (Goldsworthy *et al.* 2017c). Full burrow counts on Olive Island from 2006, 2013 and 2014 also indicated a decline of 80% in the number of breeding individuals. It is difficult to draw absolute conclusions on Little Penguin trends at Pearson and Olive islands from surveys undertaken in 2013 and 2014, due to differences in survey methodology and the timing of surveys relative to breeding seasons. Predation pressure by seals is considered a less plausible reason for the possible declines at these islands than elsewhere, because the LNFS populations off west Eyre peninsula are very small, with ten colonies producing approximately 400 pups annually (Shaughnessy *et al.* 2015). Understanding whether Little Penguins are declining on key breeding islands off west Eyre Peninsula, with limited exposure to anthropogenic influences and small, stable seal populations, would help assess the role of the threat from LNFS and inform long-term conservation strategies. Another important tool that would help assess the number of individuals being predated includes genotyping feathers from scats collected.

Increasing fur seal populations and consequent predation may partly explain recent declines of Little Penguin colonies near seal colonies and haul-out sites, but its significance relative to other factors remains uncertain. LNFS diet summaries based on previous studies assumed that each feather in a scat represented a whole penguin. Results from feeding trials in this study suggest that may have overestimated the contribution of Little Penguins to LNFS diet. On the other hand, DNA analysis detected Little Penguins in two samples without evidence of Little Penguin remains. This may be due to the larger size of Little Penguins compared to fish and cephalopods.

Several threats other than seal predation that potentially influence Little Penguin declines within SA have been identified: prey availability, terrestrial predation and/or habitat degradation (reviewed in Wiebkin 2011). Fur seals are not the only marine predators suspected to prey on penguins, as demonstrated in a South African study showing that the highest cause of injury amongst Jackass Penguins (*Spheniscus demersus*) was bites by White Sharks *Carcharodon carcharias* (Randall *et al.* 1988). Recent trophodynamic modelling of the eastern Great Australian Bight suggests that many shark species have undergone recent recoveries because of reduced fishing effort and bycatch (Goldsworthy *et al.* 2013).

Inherent biases of dietary analysis

Scat analysis is widely used for describing pinniped diet (Daneri *et al.* 2008, Fea *et al.* 1999, Lake *et al.* 2003). It and other methods of investigating seal diet have inherent biases due to the selective retention and differential digestion of prey taxa (Fea *et al.* 1999, Lake *et al.* 2003). For example, small prey remains, such as otoliths, pass quickly and may be completely digested, potentially underestimating fish taxa (Gales and Cheal 1992). Large cephalopod beaks, on the contrary, can sometimes be resistant to digestion and tend to cluster at the bottom of the stomach before being regurgitated (Gales and Cheal 1992).

More robust prey species, such as penguins, which survive digestion, may be present in several scats and thus could be over-represented (Fea and Harcourt 1997, Gales *et al.* 1993), as indicated in this study. The extent and importance of birds in the diet of fur seals is likely to have been significantly over-estimated, and a correction factor is needed. The trophodynamic model developed for the eastern Great Australian Bight by Goldsworthy *et al*. (2013) could not be balanced using the level of Little Penguin predation estimated by Page *et al*. (2005a). The balancing procedures required adjustment to the diets of some groups where ecotrophic efficiencies (EE) were initially >1. EE is the proportion of production that is either harvested or predated upon by higher trophic levels and therefore it cannot exceed 1. For Little Penguins in the model, EE exceeded 1, and their contribution had to be reduced to <1% of the diet. The study indicated that the available biomass of Little Penguins as prey is inadequate for them to constitute a major component of the diet of fur seals.

In addition, LNFS have a rapid digestion rate and therefore it is suggested that only recently consumed (near-shore) prey are likely to be represented in scat analysis (Fea and Harcourt 1997). However, satellite tracking and diving behaviour studies suggest that fur seals stop feeding during their commute back to land and return directly to the colony from their foraging sites (Page *et al.* 2006). A study on captive adult LNFS demonstrated a passage half time of 51 hours, which represents the amount of time taken for half the total recovered prey remains to appear in scats (Fea and Harcourt 1997). Accordingly, seals arriving from distant foraging grounds would still be digesting some prey items upon their return to land. In our study, evidence of distant foraging trips was represented by the presence of myctophids in the samples collected on the south coast sites of Kangaroo Island; these are pelagic fish mainly found south of the shelf break. However, Baylis and Nichols (2009) identified significant biases associated with scat analysis in comparison to milk-fatty acids for lactating females foraging in distant oceanic waters. Where milk-fatty acid analysis identified 74% of seals were likely to have foraged in oceanic waters, only 7% of scats contained prey items associated with foraging past the shelf break (Baylis and Nichols 2009). Accordingly, it is likely that this study has under-estimated the presence of deep-water species, such as myctophids, particularly for nursing females at breeding sites.

Limitations of converting numerical abundances into biomass estimates were also apparent. Several regressions were based on data from other species and measurements from otolith or beak morphometrics were sometimes outside the size range of the regressions (Furlani *et al.* 2007, Lu and Ickeringill 2002, Smale 1995). This was particularly evident for the beaks of Gould’s Squid, where regression equations calculated an average biomass of 1g per individual for most beaks. Accordingly, biomass reconstructions should be considered as estimates. Our sample size was relatively small (326 scats) compared to other studies with 500 to 1500 scats (Fea and Harcourt 1997, Lake *et al.* 2003, Page *et al.* 2005a). The taxonomic hard-part analysis was undertaken for only 20 scats from each of the 11 sites, increasing the likelihood of prey species being over or under-represented. This study has attempted to address these biases by considering prey composition using several measurements, such as numerical abundance, biomass reconstruction and frequency of occurrence (all represented as percentages), for both hard-part analyse and DNA analyses. These measurements may not represent LNFS diet in its entirety, but do indicate the importance of species relative to one another, which is particularly evident in the biomass reconstructions.

To counteract these biases, several seal dietary studies have presented regurgitate and scat analyses separately due to the difference in retention rates (Fea and Harcourt 1997, Hume *et al.* 2004, Kirkwood *et al.* 2008). In addition, next generation sequencing of scats and stomach contents is being used more frequently in conjunction with hard-part analysis to determine diet among several marine predators (Braley *et al.* 2010, Deagle *et al.* 2009, Peters *et al.* 2014). This study highlights the importance of using both hard-part analyse and DNA analyses, and it has demonstrated that our understanding of LNFS prey taxa based on hard-part analysis alone has substantially under-represented prey diversity. DNA-based analysis of ASL scats provided fine-scale dietary information that was undetectable using traditional hard-part methodology and increased the prey spectrum by ~30 species (Peters *et al.* 2014). Similarly, Deagle *et al*. (2009) found that sequencing prey DNA from AFS scats recorded greater species diversity than other techniques. In this study, an additional 57 species were detected using DNA analysis compared to hard-part analysis. However the contribution of numerical and biomass diet information obtained using hard-part methods are important for improving our understanding of proportional dietary contributions and prey taxa size. The two methods combined demonstrate the broad diversity of LNFS diet from benthic through to pelagic species. This study highlights LNFS are adaptable generalist predators which allows them to ‘switch’ among selected prey species to meet energetic requirements, as noted in earlier studies of this species in New Zealand (Harcourt 2001, Harcourt *et al.* 2002). While species such as Leatherjackets, Southern Calamari and Little Penguins have been identified as key prey species, it is anticipated that over time the identity of key prey species will fluctuate in their contribution to diet based on oceanographic shifts and resource availability.

5 Movement of Long-nosed Fur Seals in proximity to key seafood production areas in South Australia

Alice Mackay, Fred Bailleul, Sarah-Lena Reinhold, Simon Goldsworthy

5.1 Introduction

The distribution of prey in the marine environment is generally patchy, and optimal foraging theory suggests that predators should balance the costs and benefits of foraging in order to maximise survival and reproductive success. Seals are central placed foragers that must return to colonies on land in order to breed or nurse pups, and the spatial and temporal distribution of prey will strongly affect the energetic costs of foraging. Non-breeding seals do not have this constraint, and a number of studies have shown that this portion of the population generally undertakes longer foraging trips than lactating females (e.g. Page *et al.* 2005a, Page *et al.* 2005b). Individual specialisation in foraging strategy including foraging site fidelity has been shown for a number of seal species (Baylis *et al.* 2008a, Bradshaw *et al.* 2004, Chilvers 2008, Kernaléguen *et al.* 2016, Lowther *et al.* 2011). Fidelity to a particular foraging site is likely to be advantageous if the availability of prey is predictable, but fidelity is difficult to predict in the pelagic environment where prey often occurs in patches.

Human activities can provide wildlife with access to concentrated and predictable sources of food that thereby change “natural” foraging behaviour (e.g. Cozzi *et al.* 2016, Lewis *et al.* 2015, Yoda *et al.* 2012). Many seal species show behavioural plasticity in foraging strategies, and interactions between many seal species and fishing and aquaculture activities are widely reported (Kemper *et al.* 2003, Northridge and Hofman 1999, Robinson *et al.* 2008a, Tilzey *et al.* 2006), including evidence of individual specialisation in foraging behaviour. Long-nosed Fur Seals (LNFS, *Arctocephalus forsteri*) and Australian Fur Seals (AFS, *A. pusillus doriferus*) that were relocated over 300 km from capture sites at salmon farms in Tasmania were found to return to salmon farms within days of release (Robinson *et al.* 2008a). Satellite tracked AFS continually targeted trawl vessels off the coast of Tasmania during the fishing season, then switched foraging area once fishing had finished (Tilzey *et al.* 2006). Individually identifiable grey seals (*Halichoerus grypus*) were observed to repeatedly remove fish from trap-nets in the Baltic Sea over a two year study (Königson *et al.* 2013), while South American sea lions (*Otaria byronia*) equipped with telemetry devices showed individual variability in spatial association with salmon farms in Chile (Sepúlveda *et al.* 2015). The potential for seal-fisheries interactions and the nature of these interactions, is related to the extent of the spatial and temporal overlap between areas used by commercial fisheries and the distribution of seal foraging effort (Cronin *et al.* 2016, Hui *et al.* 2015, Tilzey *et al.* 2006).

In South Australia, there are concerns over how commercial fisheries and the broader ecosystem may be impacted by recovering seal populations in the region. This is particularly the case for LNFS whose populations increased more than threefold between 1990 and 2014 (Shaughnessy *et al.* 2015). Direct interactions with LNFS have been reported with the SA finfish aquaculture industry (Goldsworthy *et al.* 2009b) and the Lakes and Coorong Fishery (Mackay 2017), which resulted in damage to catch and gear, and subsequent economic losses. The value of production of South Australian Finfish aquaculture was $126.9 million 2015/16 (Econsearch 2017). The largest sector is the farming of Southern Bluefin Tuna (*Thunnus maccoyii*), which accounted for 50% of South Australia’s gross value of aquaculture production in 2015/16, with farming of other marine finfish, predominantly Yellowtail Kingfish (*Seriola lalandi*) accounting for 12% of gross value and valued at $30 million (Econsearch 2017). Southern Bluefin Tuna are wild-caught between December and March and transferred to sea cages where they are fed baitfish, predominantly Australian Sardine (*Sardinops neopilchardus*), and grown out until harvest which is completed by September. Hatchery reared Yellowtail Kingfish are transferred to sea pens once they around 75 days old, and then farmed for 16 -24 months and fed formulated fish feed. The majority of finfish aquaculture farms in SA are located off Port Lincoln in SG, an area which is in relatively close proximity to a number of LNFS seal and Australian Sea Lion (ASL, *Neophoca cinerea*) breeding colonies and/or haul-out sites (Goldsworthy *et al.* 2015, Shaughnessy *et al.* 2015). Interactions between seals and Southern Bluefin Tuna farms in SG are reported to result in economic loss to industry, either from direct mortalities of fish attributed to seals or the perception that the presence of seals near cages results in cessation of feeding tuna, with a subsequent reduction in the quality of the fish (Goldsworthy *et al.* 2009b). Interactions between the Lakes and Coorong Fishery and LNFS have been reported since the late 2000's and mitigation strategies including the use of seal crackers have been tested (Earl *et al.* in press). However, there is no quantitative information on the level of economic impact of interactions in this fishery.

Understanding the level of interaction between seal populations and commercial fisheries requires data on the spatial overlap of seal foraging effort and commercial fishing effort (Cronin *et al.* 2016, Hui *et al.* 2015). LNFS are generalist predators that show seasonal changes in foraging behaviour that likely reflect changes in availability of different prey types (Harcourt *et al.* 2002). The development of high-resolution telemetry devices has greatly improved our understanding of at-sea movements and foraging behaviours for a number of seal species. This has included the identification of individual foraging strategies such as repeated foraging site fidelity (Arthur *et al.* 2015, Augé *et al.* 2014, Bradshaw *et al.* 2004, Chilvers 2008, Kernaléguen *et al.* 2016, Lowther *et al.* 2011), and foraging in association with fishing and aquaculture activities and anthropogenic structures (Arnould *et al.* 2015, Robinson *et al.* 2008a, Russell *et al.* 2014, Sepúlveda *et al.* 2015, Tilzey *et al.* 2006).

In SA, most of telemetry studies have focused on adult females. As they care soley for their young, prey available in their foraging locations is critical to the recovery and health of populations (Baylis *et al.* 2008a, 2008b, Baylis *et al.* 2012, Page *et al.* 2005b, Page *et al.* 2006). The limited tracking data available for adult male LNFS indicates that they tend to feed offshore in outer shelf or oceanic waters and their diet generally consists of non-commercial species (Page *et al.* 2005a, Page *et al.* 2005b, Page *et al.* 2006). However, it is recognised that most of the LNFS that interact with fisheries, aquaculture and ecotourism in SA are juveniles and subadult males. Their numbers appear to increase over winter months based on observations of their numbers at haul-out sites, suggesting that they may focus their foraging effort in shelf and coastal regions for part of the year. As knowledge on the foraging behaviour and movement patterns of these age-classes is poor, the aim of this study was use satellite telemetry to determine the extent to which individual foraging effort of tracked subadult males was associated with important finfish aquaculture locations and commercial and recreational fishing areas in SA.

5.2 Methods

Study sites

Four haul-out sites in South Australia were chosen to deploy satellite tags on adult male, subadult male and juvenile male LNFSs: Donington Reef, West Island, Kingscote Jetty on Kangaroo Island and Tauwitcherie Barrage in the Coorong (Figure 5.1). Donington Reef (-34.72, 135.99) is a haul-out site approximately 11 km east of Port Lincoln and in close proximity (min. 2.5 km) from finfish aquaculture sites. The three other tagging locations were chosen to collect movement data from LNFSs in an area where concerns have been raised about operational interactions with the Lakes and Coorong Fishery, and about potential impacts of LNFSs on colonies of Little Penguins, *Eudyptula minor* (e.g., at Granite Island).

Tag deployment

Adult and subadult LNFS at Donington Reef, West Island and Kingscote were darted intramuscularly with Zoletil administered using darts fired from a dart gun (Paxarms Ltd, New Zealand). Individuals were maintained under gas anaesthesia using Isofluorane® administered via a purpose-built gas anaesthetic machine with a Cyprane Tec III vaporiser. The juvenile LNFS at Tauwitcherie barrage and West Island were captured using a net and then administered an anaesthetic.

LNFS were instrumented with either a platform transmitter terminal (PTT) or an Argos-linked Sirtrack Fastloc^{TM} GPS device (Table 5.1). Each instrument was glued onto the fur along the dorsal mid-line using a fast setting two-part epoxy glue. Fastloc^{TM} GPS tags were programmed using one of two settings aimed at maximising fine-scale location data or extending tag battery life. The first program was set to attempt a GPS fix every 15 minutes while at sea for the first month of deployment after which a GPS fix would be attempted every 30 minutes. The second program was set to attempt a GPS fix every 30 minutes. The ability for tags to collect at-sea GPS locations is dependent on the animal being at the surface when a fix is attempted. For both settings, once the individual hauled out, the tags would continue to transmit stored data for up to two days before switching to true haul-out mode (no location fixes). The weight, axillary girth and straight-line length of all LNFS were recorded.

Data analysis

GPS data were downloaded using Sirtrack Fastloc^{TM} software and filtered to include only those locations received from five or more satellites. Raw Argos location data were filtered using the function “sdafilter” from the package “argosfilter” in R, Version 3.1.3 (R Development Core Team, 2015). A trip was defined as the time between the end of one haul out and the next haul out. The distance of each trip was calculated. GPS locations were assigned as day or night based daily sunrise and sunset times for the duration of each individual track.

To investigate the overlap between individual movement patterns and finfish aquaculture leases, the proportion of locations transmitted within aquaculture lease areas and the proportion of these transmitted in close proximity (<50m) to aquaculture pens were calculated. For each individual seal, location data within the core area of aquaculture leases were interpolated and kernel density estimates were produced in ArcMap (10.3.1). Pen locations were provided by ASBTIA

Tracks outside the core aquaculture area were filtered using correlated random walk modelling within a state-space framework, and locations were re-estimated every 2 hours. The individual’s use of space is described by the utilisation distribution (UD), which gives the probability density to relocate the animal at any place according to the coordinates (x, y) of that place. The kernel method was used to estimate the UD of each seal using the location data (function *kernelUD* of the package *adehabitatHR* in R, Version 3.1.3 (R Development Core Team, 2015)). We deduced the home-range of each individual in raster mode from the UD (function *getvolumeUD* of the package *adehabitatHR* in R). For example, the 95% home range corresponds to the smallest area in which the probability to relocate the animal is equal to 0.95.

5.3 Results

A total of 15 fur seals were equipped with satellite transmitters between May and October 2015. Thirteen of the satellite transmitters were Argos-linked Sirtrack Fastloc^{TM}, one was a location only PTT (Kiwisat 202 K2G271B (Sirtrack)) and the other was a beta model location only PTT (Kiwisat K2G 273A-beta (Sirtrack)) (Table 5.1). The mean transmission duration of tags was 62 days (16-125 days). The beta model PTT deployed on the male at West Island on 28 September 2015 (individual W2) did not function properly and did not provide any usable location data.

Spencer Gulf deployments - overlap with finfish aquaculture

Fastloc^{TM} GPS satellite linked tags were deployed on seven subadult males and two adult male long-nosed fur seal at Donington Reef during two field trips in May (n=5) and July (n=4) 2015. Deployments were spread over these two months to ensure that movement data were obtained from individual LNFS while Southern Bluefin Tuna aquaculture pens were stocked, and for the period during and after the tuna harvest. On average, tags transmitted for 49.9 days (range 7 to 122 days). Periods when individual tags were transmitting are summarised inTable 5.2.

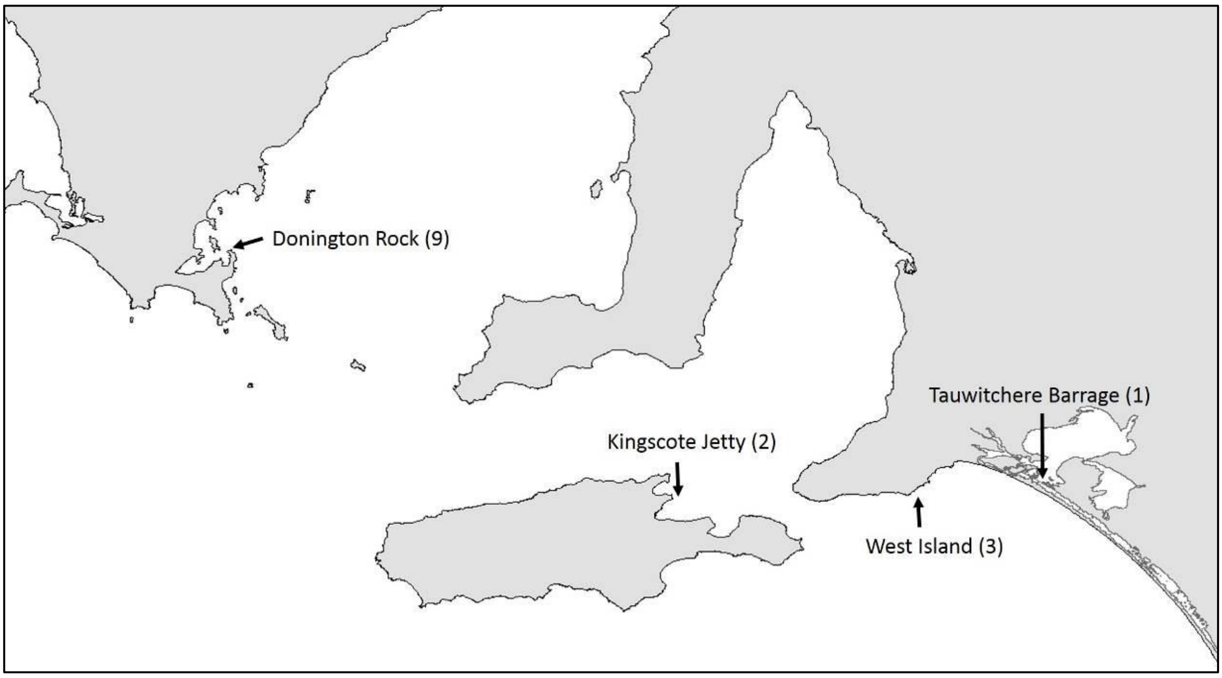
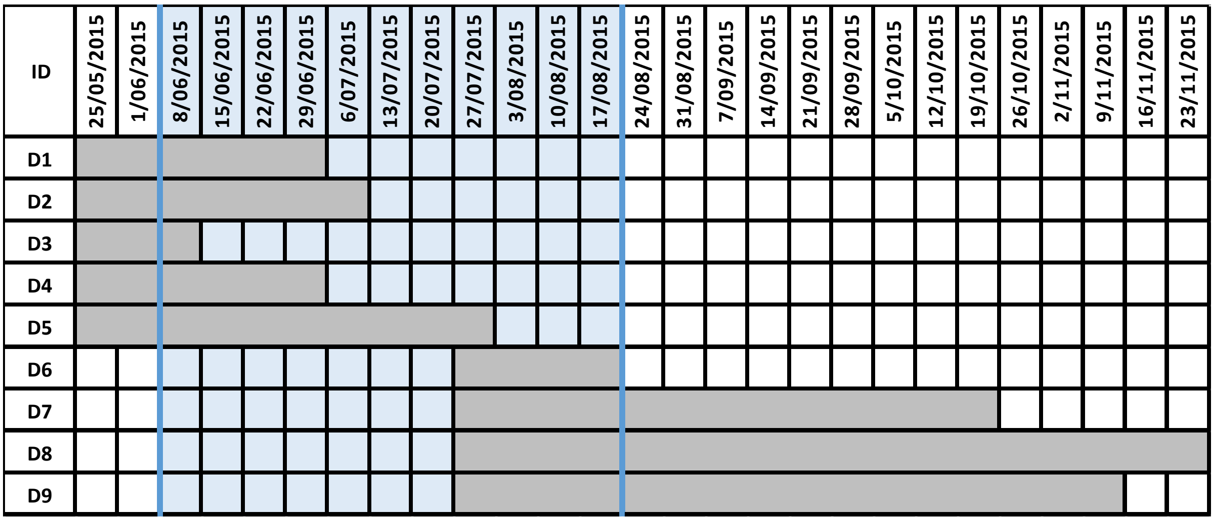


Figure 5.1. Locations of deployment of satellite tags on Long-nosed Fur Seals between May and October 2015. Numbers in parentheses indicate the number of individuals tagged at each location.

Table 5.1. Summary of instrumentation deployments on Long-nosed Fur Seals between 25 May and 20 October 2015. Individual W3 was not weighed because it was too large. The age/sex classes are: JUV M, juvenile male, SAM, subadult male, AM, adult male.

ID	Tag ID	Tag type	Location	Age/sex	Date deployed	Length (cm)	Girth (cm)	Mass (kg)
D1	148446	Fastloc	Donington Reef, Spencer Gulf	SAM	25/05/2015	163	92	66.5
D2	148447	Fastloc	Donington Reef, Spencer Gulf	SAM	25/05/2015	163	89	63.0
D3	148454	Fastloc	Donington Reef, Spencer Gulf	SAM	25/05/2015	176	97	78.0
D4	148452	Fastloc	Donington Reef, Spencer Gulf	SAM	25/05/2015	159	94	77.5
D5	148449	Fastloc	Donington Reef, Spencer Gulf	SAM	25/05/2015	153	86	61.0
D6	148448	Fastloc	Donington Reef, Spencer Gulf	SAM	27/07/2015	151	90	66.5
D7	148450	Fastloc	Donington Reef, Spencer Gulf	AM	27/07/2015	172	108	101.5
D8	148451	Fastloc	Donington Reef, Spencer Gulf	SAM	27/07/2015	159	92	68.0
D9	148453	Fastloc	Donington Reef, Spencer Gulf	AM	27/07/2015	169	112	105.5
C1	55951	PTT	Tauwitchere Barrage, Coorong	JUV M	1/09/2015	95	61	16.0
W1	148441	Fastloc	West Island, Fluerieu Peninsula	SAM	28/09/2015	160	97	74.5
W2	150380	PTT	West Island, Fluerieu Peninsula	JUV M	28/09/2015	108	64	20.0
W3	148443	Fastloc	West Island, Fluerieu Peninsula	AM	28/09/2015	180	128	****
K1	148438	Fastloc	Kingscote, Kangaroo Island	SAM	9/10/2015	164	98	83.5
K2	148455	Fastloc	Kingscote, Kangaroo Island	AM	30/10/2015	166	106	101.5

Table 5.2. Summary of transmission histories for GPS Fasloc^{TM} tags deployed on nine Long-nosed Fur Seals at Donington Reef in May and July 2015. Grey shading indicates periods when tags were transmitting. Blue shaded area indicates the period when Southern Bluefin Tuna were harvested from aquaculture pens.



ID	25/05/2015	1/06/2015	8/06/2015	15/06/2015	22/06/2015	29/06/2015	6/07/2015	13/07/2015	20/07/2015	27/07/2015	3/08/2015	10/08/2015	17/08/2015	24/08/2015	31/08/2015	7/09/2015	14/09/2015	21/09/2015	28/09/2015	5/10/2015	12/10/2015	19/10/2015	26/10/2015	2/11/2015	9/11/2015	16/11/2015	23/11/2015
D1	▨	▨	▨	▨	▨	▨	🟦	🟦	🟦	🟦	🟦	🟦	🟦														
D2	▨	▨	▨	▨	▨	▨	▨	🟦	🟦	🟦	🟦	🟦	🟦														
D3	▨	▨	▨	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦														
D4	▨	▨	▨	▨	▨	▨	🟦	🟦	🟦	🟦	🟦	🟦	🟦														
D5	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	🟦	🟦	🟦														
D6			🟦	🟦	🟦	🟦	🟦	🟦	🟦	▨	▨	▨	▨														
D7			🟦	🟦	🟦	🟦	🟦	🟦	🟦	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
D8			🟦	🟦	🟦	🟦	🟦	🟦	🟦	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
D9			🟦	🟦	🟦	🟦	🟦	🟦	🟦	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		

Subadult male D1

Between 25 May and 21 June 2015, subadult male D1 undertook 31 foraging trips with an average duration of 10.2 hours (range 1.7 - 37.3 hours) and average distance travelled of 12.1 km (range 4.6-36.2 km). The average haul-out duration between foraging trips was 19.7 hours (range 12.25 – 106.9 hours) with all haul outs occurring at Donington Reef. The individual showed a strong association with tuna cage operations, with 90% of non-haul-out locations being transmitted within tuna lease areas (Figure 5.2) and 83% within a 50 m radius of tuna pen locations. The individual repeatedly visited the tuna lease located approximately 5 km north of Donington Reef during 24 of 31 trips, and 74% of locations were transmitted within this lease area. Significantly more locations were recorded within lease areas compared to non-lease areas during the night than the day (chi squared test, $p<0.01$, $\chi^2 = 40.58$).

Subadult male D2

Between 25 May and 31 May 2015, subadult male D2 undertook two foraging trips. The first trip was 41.8 km long and lasted 14.7 hours during which it undertook a circuit of Boston Bay (including aquaculture leases) before hauling out for 20.4 hours on Donington Reef. On 28 May 2015, the individual left the core aquaculture lease area and moved 288 km over 67.2 hours to a location near Baird Bay on the western Eyre Peninsula (Figure 5.3). The tag stopped transmitting on 31 May 2015.

Subadult male D3

Between 25 May and 10 June 2015, subadult male D3 undertook 11 trips with an average duration of 10.8 hours (range 6.3 – 17.3 hours) and average distance travelled of 18.8 km (range 9-27.6 km). The individual hauled out six times at Donington Reef, four times at Sibsey Island and once at Rabbit Island, with an average haul-out duration of 23.5 hours (range 5.2– 64.3 hours). There was a strong association with tuna cage operations, with 83% of non-haul-out locations being transmitted within tuna lease areas and 62% of these within a 50 m radius of tuna pen locations (Figure 5.4). The individual visited four lease areas over the period the tag was transmitting, with the lease site 5 km north of Donington Reef visited during ten of eleven trips. Significantly more locations were recorded within lease areas compared to non-lease areas during the night than the day (chi-squared test, $p<0.01$, $\chi^2 = 10.57$).

Subadult male D4

Between 25 May and 28 June 2015, subadult male D4 undertook 21 trips with an average duration of 19.3 hours (range 1.9 – 55.1 hours) and average distance travelled of 25.1 km (range 6.8-66.8 km). The individual hauled out 17 times at Sibsey Island, three times at Donington Reef, and twice at Rabbit Island, with an average haul-out duration of 18.8 hours (range 0.6 – 66.6 hours). The individual showed a strong association with tuna cage operations, with 75% of non-haul-out locations being transmitted within tuna lease areas and 85% of these within a 50 m radius of tuna pen locations (Figure 5.5). Three lease areas were visited repeatedly over the period the tag was transmitting, with two leases northeast of Donington Reef visited during more than half of the trips (57% and 52%, respectively). Of these, one lease site was visited in 12 of 21 trips and the other was visited in 11 of 21 trips. In contrast to individuals D1 and D3, significantly more locations were recorded within lease areas than non-lease areas during the day than during the night (chi squared test $p<0.01$, $\chi^2 = 6.7456$).

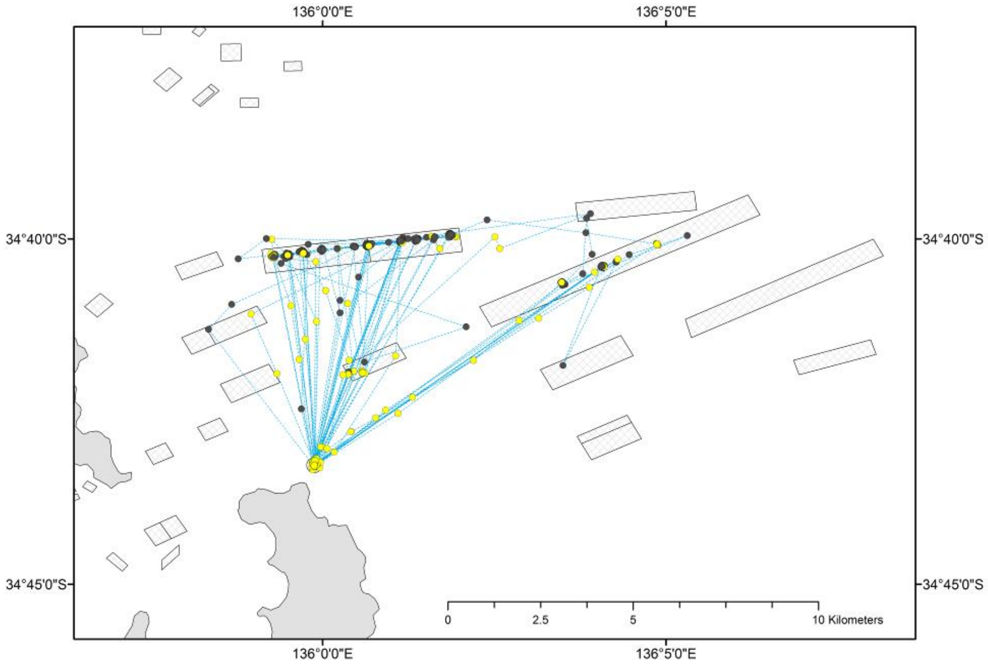


Figure 5.2. GPS locations for subadult male Long-nosed Fur Seal D1 between 25 May and 02 July 2015. Yellow circles indicate daytime locations; black circles indicate night-time locations. The dashed blue line indicates tracks taken by the individual and boxes indicate active finfish aquaculture leases.

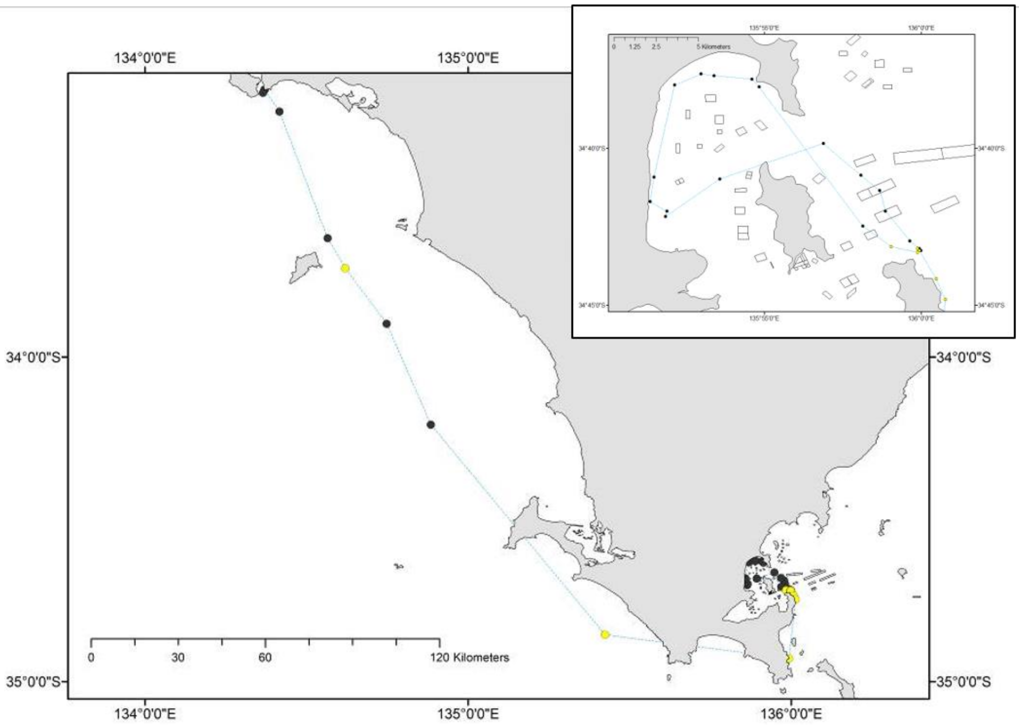


Figure 5.3. GPS locations for subadult male Long-nosed Fur Seal D2 between 25 May and 31 May 2015. The dashed blue line indicates the track taken by the individual and boxes indicate active finfish aquaculture leases. This individual departed the region of aquaculture activity on 28 May 2015.

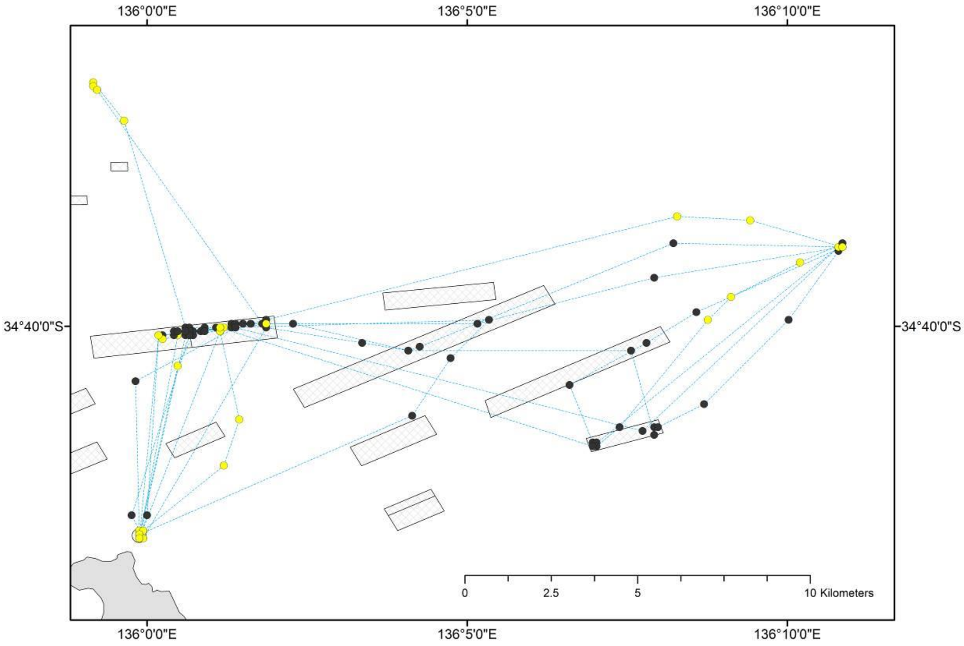


Figure 5.4. GPS locations for subadult male Long-nosed Fur Seal D3 between 25 May and 12 June 2015. Yellow circles indicated daytime locations; black circles indicate night-time locations. The dashed blue line indicates tracks taken by the individual and boxes indicate active finfish aquaculture leases.

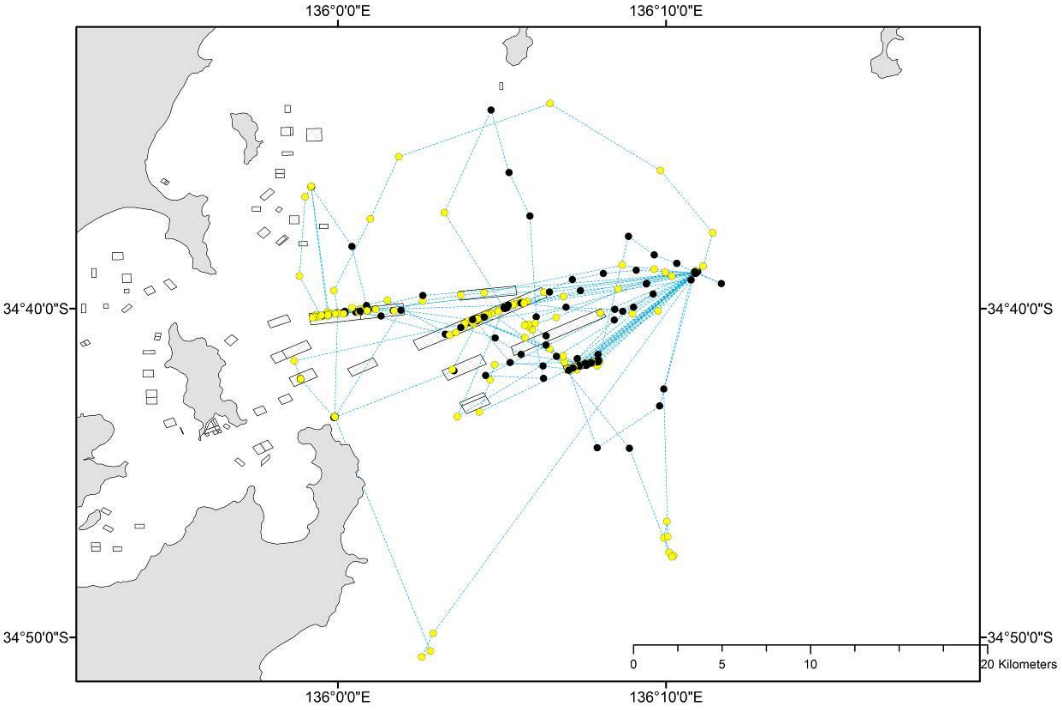


Figure 5.5. GPS locations for subadult male Long-nosed Fur Seal D4 between 25 May and 30 June 2015. Yellow circles indicated daytime locations, black circles indicate night-time locations. The dashed blue line indicates tracks taken by the individual and boxes indicate active finfish aquaculture leases.

Subadult male D5

Between 25 May and 27 July 2015, subadult male D5 undertook 37 trips with an average duration of 13.8 hours (range 0.5 – 110.3 hours) and average distance travelled of 17.1 km (range 0.5 – 246 km). The individual predominantly hauled out at Donington Reef (n=31) although it also hauled out at Sibsey Island five times, and had an average haul-out duration of 27.9 hours (range 11 – 132 hours). The individual showed a strong association with tuna cage operations, with 69% of non-haul-out locations being transmitted within tuna lease areas and 85% of these within a 50 m radius of tuna pen locations (Figure 5.6). One lease site was visited on 49% of foraging trips. However, visitations to lease sites during foraging trips was not consistent, with no lease site visited during 24% of foraging trips. On 17 June, the individual moved north to an area between Arno Bay and Port Gibbon, where it spent three days offshore. On 26 June, it returned to Sibsey Island and undertook 21 further trips that were associated with tuna lease areas before the tag stopped transmitting. While the individual was in the core area of aquaculture leases, significantly more locations were recorded within lease areas compared to non-lease areas during the night than the day (chi-squared test, $p<0.01$, $\chi^2 = 18.19$).

Subadult male D6

Between 27 July and 18 August 2015, subadult male D6 undertook 19 trips with an average duration of 7.6 hours (range 1.4 – 12.3 hours) and average distance travelled of 18.1 km (range 1.66 – 48.2 km). The individual predominantly hauled out at Donington Reef (n=8) and Sibsey Island (n=8) with an average haul-out duration of 19.9 hours (range 12.4 – 37 hours). The individual left Sibsey Island on 18 August and travelled south to Williams Island where it hauled out, after which the tag stopped transmitting. While in the core aquaculture area, the individual showed a strong association with tuna cage operations, with 53% of non-haul-out locations being transmitted within tuna lease areas and 74% of these within a 50 m radius of tuna pen locations (Figure 5.7). Two lease sites north of Donington Reef were visited on a total of 14 foraging trips, six to one lease and seven to the other. All visits to lease sites occurred at night.

Adult male D7

Between 29 July and 25 October 2015, adult male D7 undertook 20 trips with an average duration of 54.8 hours (range 2.3 – 422.8 hours) and average distance travelled of 110.7 km (range 4.1 – 951.8 km). Within this period there were two distinct types of movement patterns, the first was associated with aquaculture leases and occurred between 29 July and 19 August 2015 (while pens were still stocked with fish), and the second predominantly involved foraging trips on the shelf south of SG (Figure 5.8) (following tuna harvest). Data are presented separately for these two periods.

Between 29 July and 19 August, individual D7 undertook 11 trips with an average duration of 11.3 hours (range 2.3 – 45.8 hours) and average distance travelled of 14.8 km (range 4.2 - 23.2 km). The individual predominantly hauled out at Donington Reef (n=10) but also hauled out at Sibsey Island (n=2), with an average haul-out duration of 36.2 hours (range 0.9 – 85.3 hours). During this period 69% of non-haul-out locations were transmitted within tuna lease areas and 66% of these within a 50 m radius of tuna pen locations, with all visits occurring during the night.

On 19 August (Trip 12), D7 moved south from Donington Reef and undertook five trips with an average duration of 45.5 hours (range 2.6 -87.3 hours) and an average distance of 97 km (range 22.2 – 210.4 km), hauling out at Williams Island twice and the Neptune Islands three times. The individual then returned to SG and hauled out on Sibsey Island for 37.7 hours before heading south once more and undertaking two foraging trips out to the 500 m depth contour. The individual then travelled more than 900 km before the tag stopped transmitting on 25 October 2015 approximately 170 km south of Port MacDonnell, South Australia.

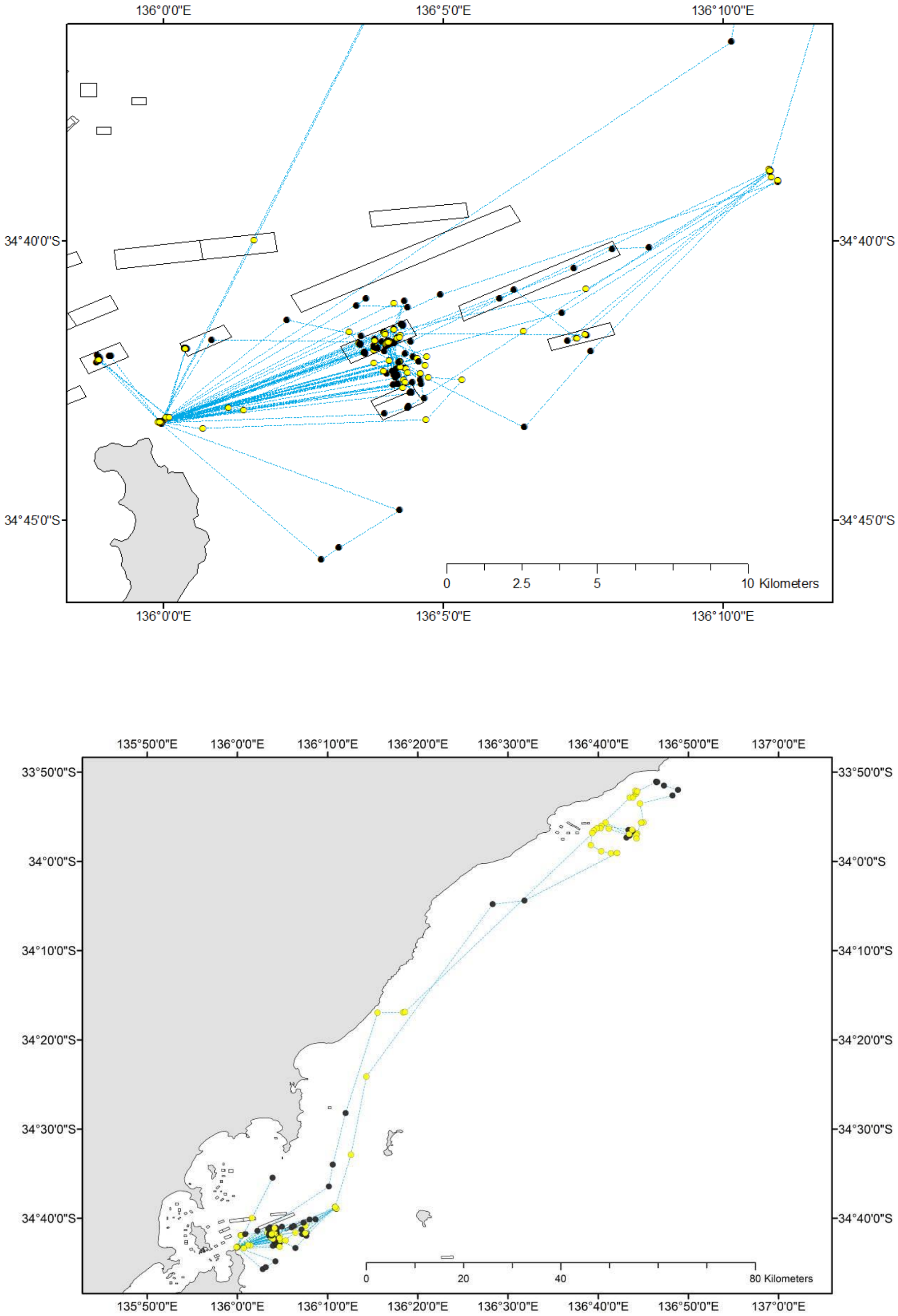


Figure 5.6. GPS locations for subadult male Long-nosed Fur Seal D5 between 25 May and 27 July 2015. Top panel shows GPS locations associated with the core aquaculture area, and the lower panel shows the full track undertaken by the individual. Yellow circles indicate daytime locations; black circles indicate night-time locations. Dashed blue lines indicate tracks. Rectangles represent active finfish aquaculture leases.

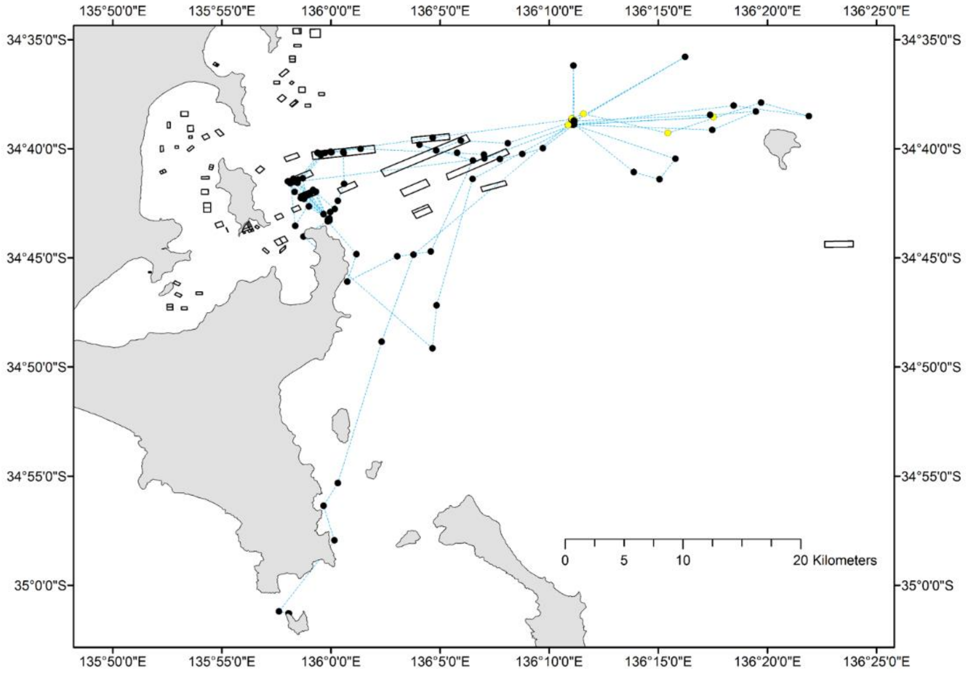


Figure 5.7. GPS locations for subadult male Long-nosed Fur Seal D6 between 27 July and 23 August 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations. Dashed blue lines indicate tracks. Boxes areas represent active finfish aquaculture leases.

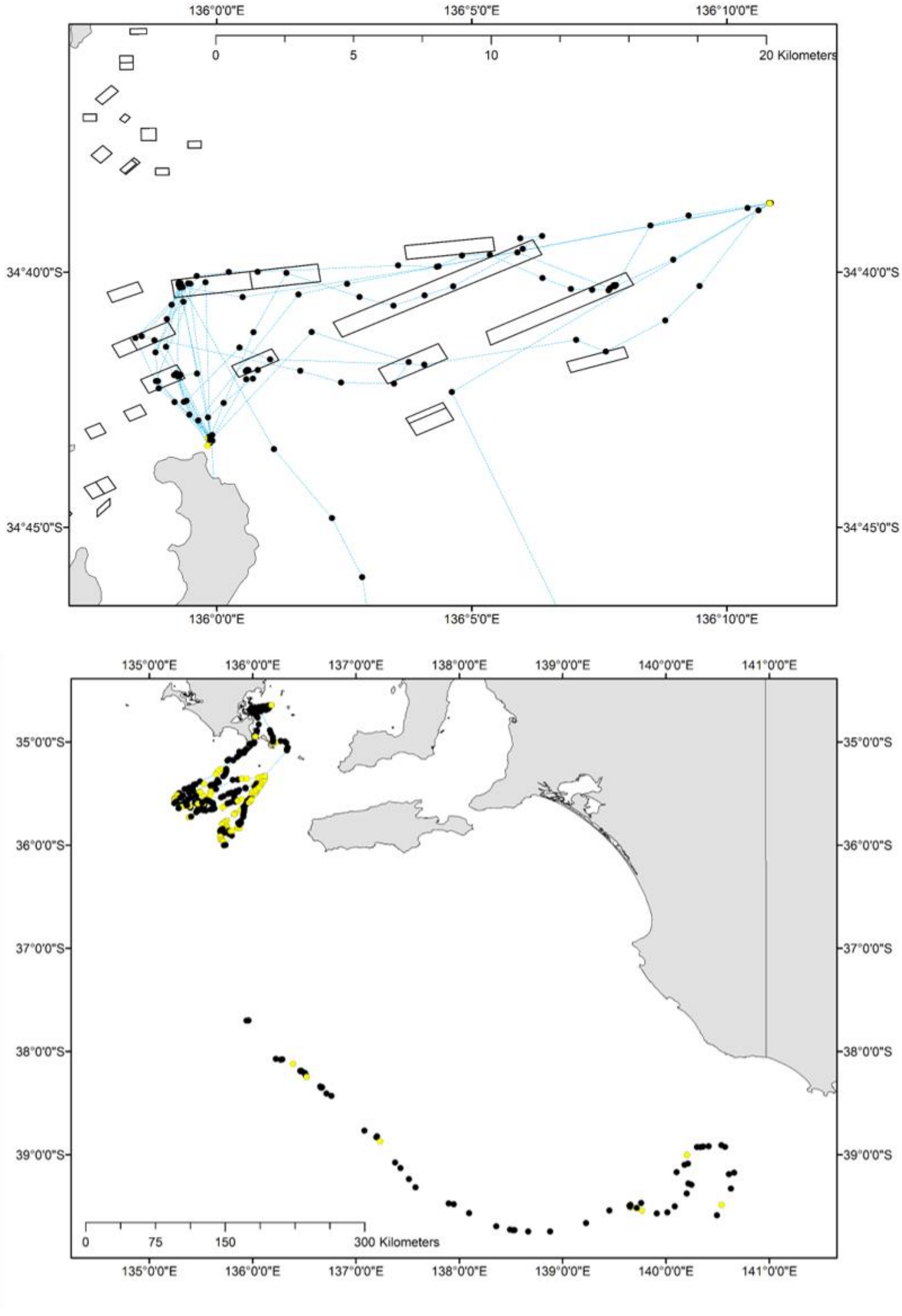


Figure 5.8. GPS locations for adult male Long-nosed Fur Seal D7 between 27 July and 17 September 2015 (top) and its whole track (bottom) until the tag stopped transmitting on 26 October 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations. Dashed blue lines indicate tracks.

Subadult male D8

Between 29 July and 28 November 2015, subadult male D8 undertook 16 trips with an average duration of 149 hours (range 0.3 – 1362.7 hours) and average distance travelled of 332.9 km (range 2.5 - 2,521.7 km). Within this period there were two distinct types of movement patterns, the first was associated with aquaculture leases and occurred between 29 July and 14 August 2015 and the second predominantly involved foraging trips on off-shelf waters southwest of SG (Figure 5.9).

Between 29 July and 14 August, D8 undertook 11 trips with an average duration of 5.93 hours (range 0.25 – 11.48 hours) and average distance travelled of 9.04 km (range 2.5 - 22.1 km). The individual predominantly hauled out at Donington Reef (n=10) and once at Sibsey Island, with an average haul-out duration of 32.3 hours (range 8.5 – 52.1 hours). During this period, 83% of non-haul-out locations were transmitted within tuna lease areas, of which 92% were transmitted at night, and 88% of these within a 50 m radius of tuna pen locations.

On 15 August (Trip 12), the individual moved south from Donington Reef and undertook five trips with an average duration of 463.7 hours (range 0.25 -1362.7 hours) and an average distance of 1045.5 km (range 38.5 – 2,521.7 km) hauling out three times at the Neptune Islands and once at Greenly Island before the tag stopped transmitting on 28 November 2015.

Adult male D9

Between 29 July and 11 November 2015, adult male D9 undertook 28 trips with an average duration of 60.2 hours (range 0.7 – 1041 hours) and average distance travelled of 110.7 km (range 4.1 – 951.8 km). Within this period there were two distinct types of movement patterns, the first was associated with aquaculture leases and occurred between 29 July and 23 August 2015 and the second predominantly involved foraging trips to off-shelf waters southwest of SG.

Between 29 July and 23 August, D9 undertook 21 trips with an average duration of 7.38 hours (range 1.1-12.8 hours) and average distance travelled of 11.5 km (range 2.6 – 20.7 km). The individual predominantly hauled out at Donington Reef (n=18) with two haul outs at Sibsey Island, with an average haul-out duration of 22.3 hours (range 11.5 - 68.7 hours). During this period 83% of non-haul-out locations were transmitted within tuna lease areas of which 92% were at night and 88% of these within a 50 m radius of tuna pen locations (Figure 5.10).

On 24 August, the individual moved south from Donington Reef and undertook seven foraging trips with an average duration of 218.7 hours (range 0.7 -1,040 hours), and an average distance of 601.4 km (range 0.23 – 2,695.2 km). During this period, it hauled out three times at Four Hummocks Islands, once at Greenly Island and twice at Pearson Island before the tag stopped transmitting on 11 November 2015.

Overview for individuals D1 to D9

The movement data collected from the nine LNFS tagged at Donington Reef showed varying degrees of association with active finfish lease areas (Table 5.3, Figure 5.11). Eight individuals visited 14 aquaculture lease areas, with two of these areas visited by seven individuals. One individual (subadult male D2) showed very low spatial overlap with lease sites. Between five and nine different lease areas were visited by individual LNFS. All but one fur seal that associated strongly with aquaculture leases had a higher proportion of locations within lease areas transmitted during the night compared to the day. Individual patterns of movement between haul-out sites within SG and the lease areas also varied. Donington Reef was used by all nine individuals, with seven of them also hauling out at Sibsey Island and two at Rabbit Island.

The movement patterns of individuals D7, D8 and D9 all changed markedly around mid-August when the tuna harvest was completed. The average trip duration was 13 to 78 times longer in duration and 14 to 115 times greater in length after the harvest compared to trips undertaken in the core aquaculture area (Figure 5.12). After the harvest period, all three individuals concentrated their foraging effort in areas associated with the continental shelf break (Figure 5.13).

Key finding: Tracking studies provided new data on the movement of male LNFS in coastal waters. GPS tags fitted to male LNFS hauled-out at Donington Reef adjacent to tuna aquaculture cages in SG, demonstrated a remarkably tight association between the seals and tuna cages. Results demonstrated that while tuna cages are stocked, they provide a reliable and readily accessible source of food to many fur seals that commute from nearby haul-out sites.

Table 5.3. Summary of metrics used to determine the level of association of Long-nosed Fur Seals with finfish aquaculture lease sites. Data for individuals D7, D8 and D9 (*) were calculated using movement data transmitted in the core aquaculture area.

ID	Deployment date	Total days	No. of foraging trips	Average foraging trip duration (hrs)	Average trip distance (km)	Locations within leases (%)	Locations in leases within 50m of pens
D1	25-May-15	38	131	10.2	12.1	90%	83%
D2	25-May-15	7	2	41.5	163.9	0%	0%
D3	25-May-15	16	11	10.9	18.8	83%	62%
D4	25-May-15	34	21	19.3	25.1	75%	85%
D5	25-May-15	63	34	13.8	17.1	69%	85%
D6	27-Jul-15	19	17	7.6	18.1	53%	74%
D7	27-Jul-15	46	20	54.8	110.7	69%*	66%*
D8	27-Jul-15	122	15	149.0	332.9	83%*	88%*
D9	27-Jul-15	104	28	60.2	159.0	30%*	55%*

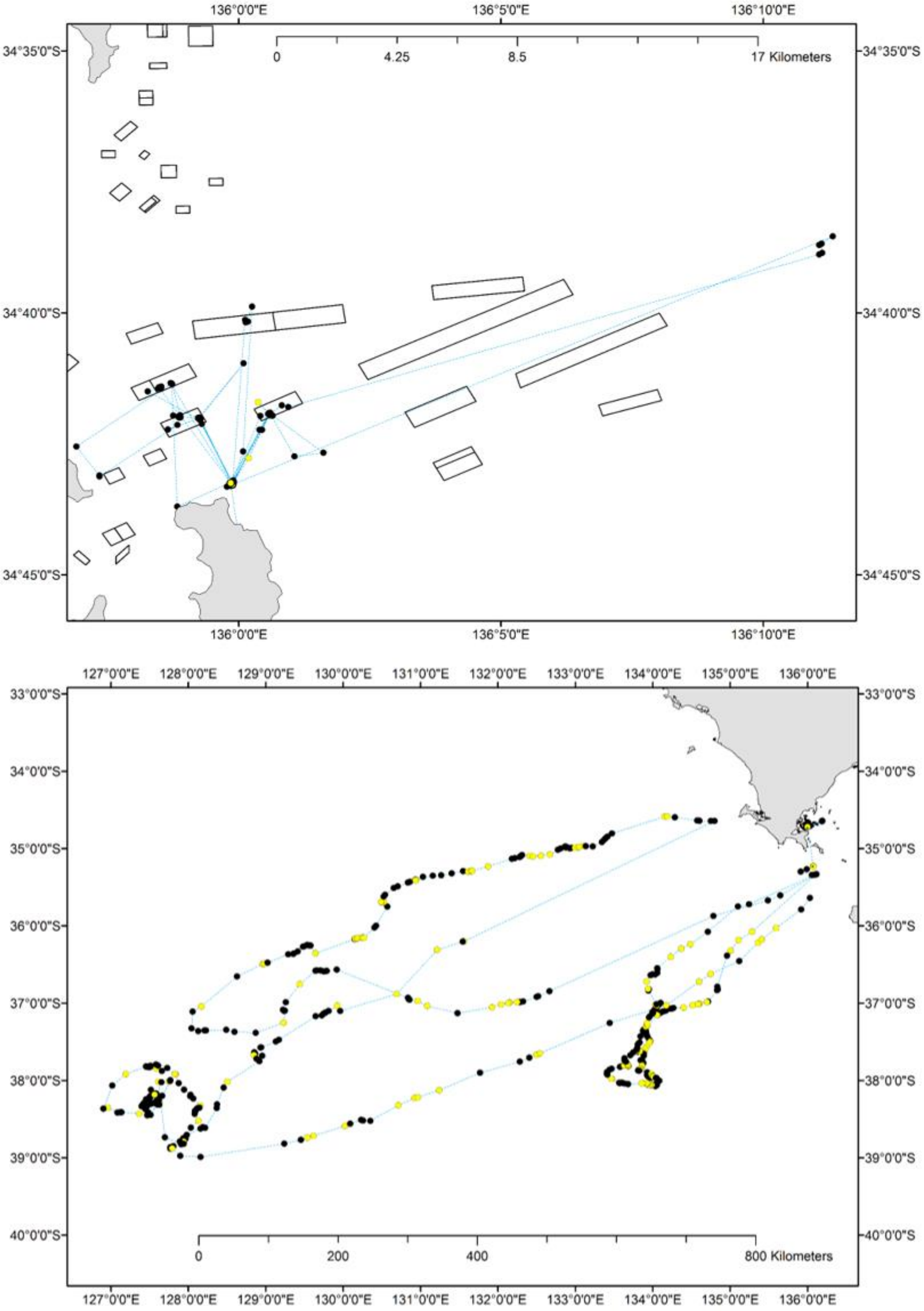


Figure 5.9. GPS locations for subadult male Long-nosed Fur Seal D8 between 27 July and 14 August 2015 (top) and whole track (bottom) until tag stopped transmitting on 28 November 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations. Dashed blue lines indicate tracks. Boxed areas represent active finfish aquaculture leases.

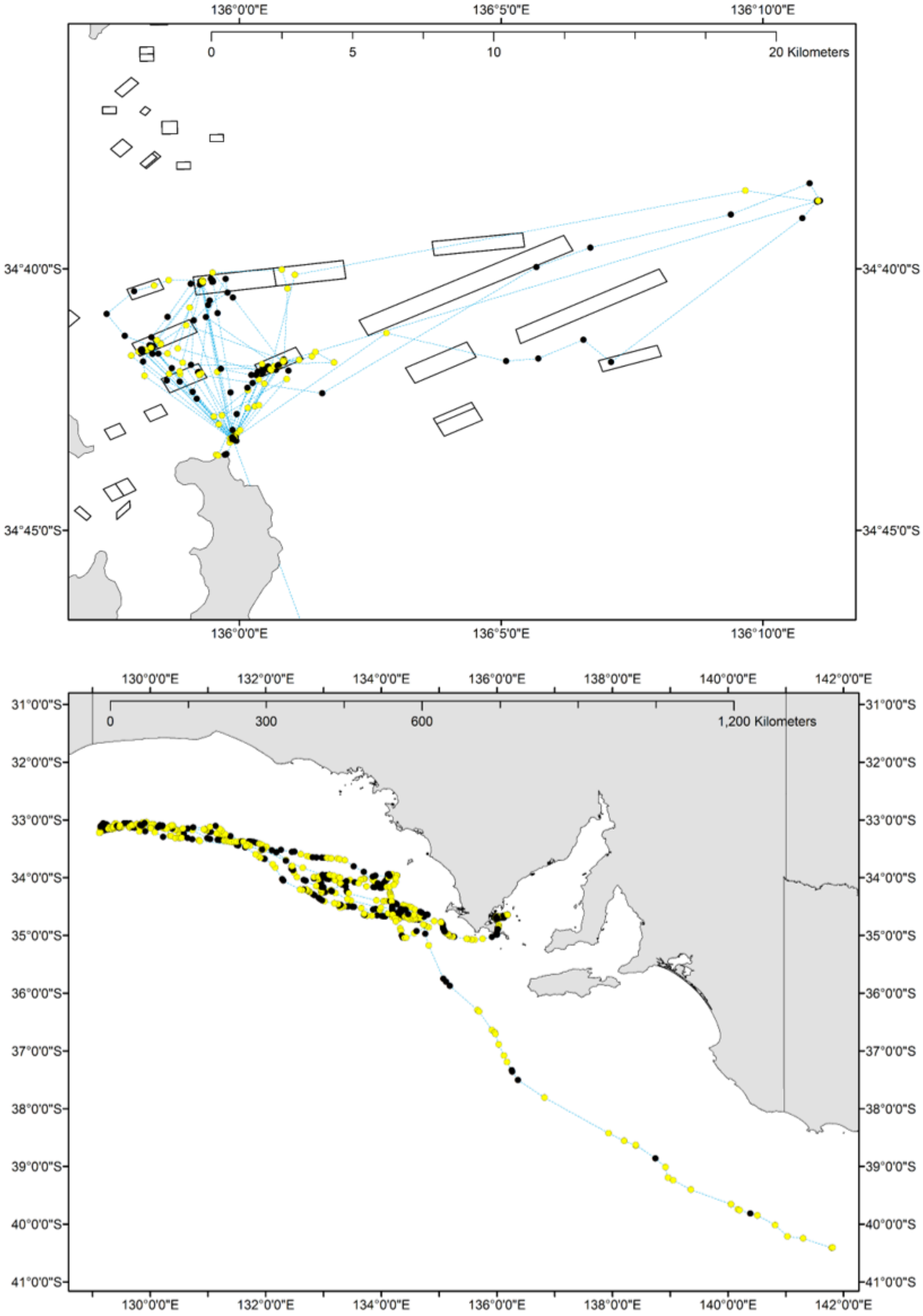


Figure 5.10. GPS locations for adult male Long-nosed Fur Seal D9 between 27 July and 23 August 2015 (top) and whole track (bottom) until its tag stopped transmitting on 11 November 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations. Dashed blue lines indicate tracks. Boxed areas represent active finfish aquaculture leases.

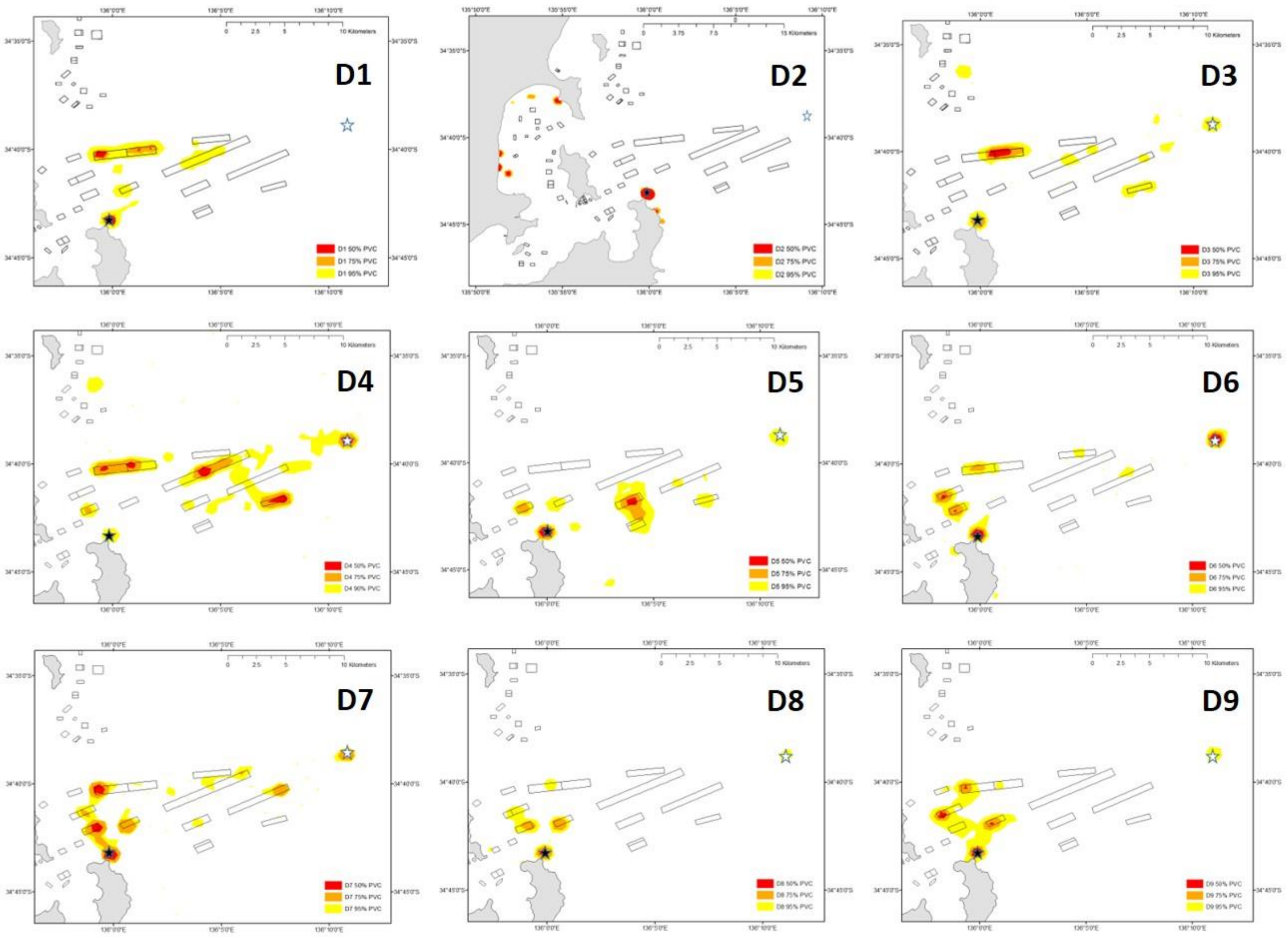


Figure 5.11. Plots of 50%, 75% and 95% percentage volume contours (PVC) of densities of locations of individual Long-nosed Fur Seals in the core area of Southern Bluefin Tuna aquaculture leases. All individuals were tagged at Donington Reef (black star), Spencer Gulf, in May 2015. Colorations are: red, 50% PVC, orange, 75% PVC, yellow 90% PVC. Sibsy Island is indicated by an open star.

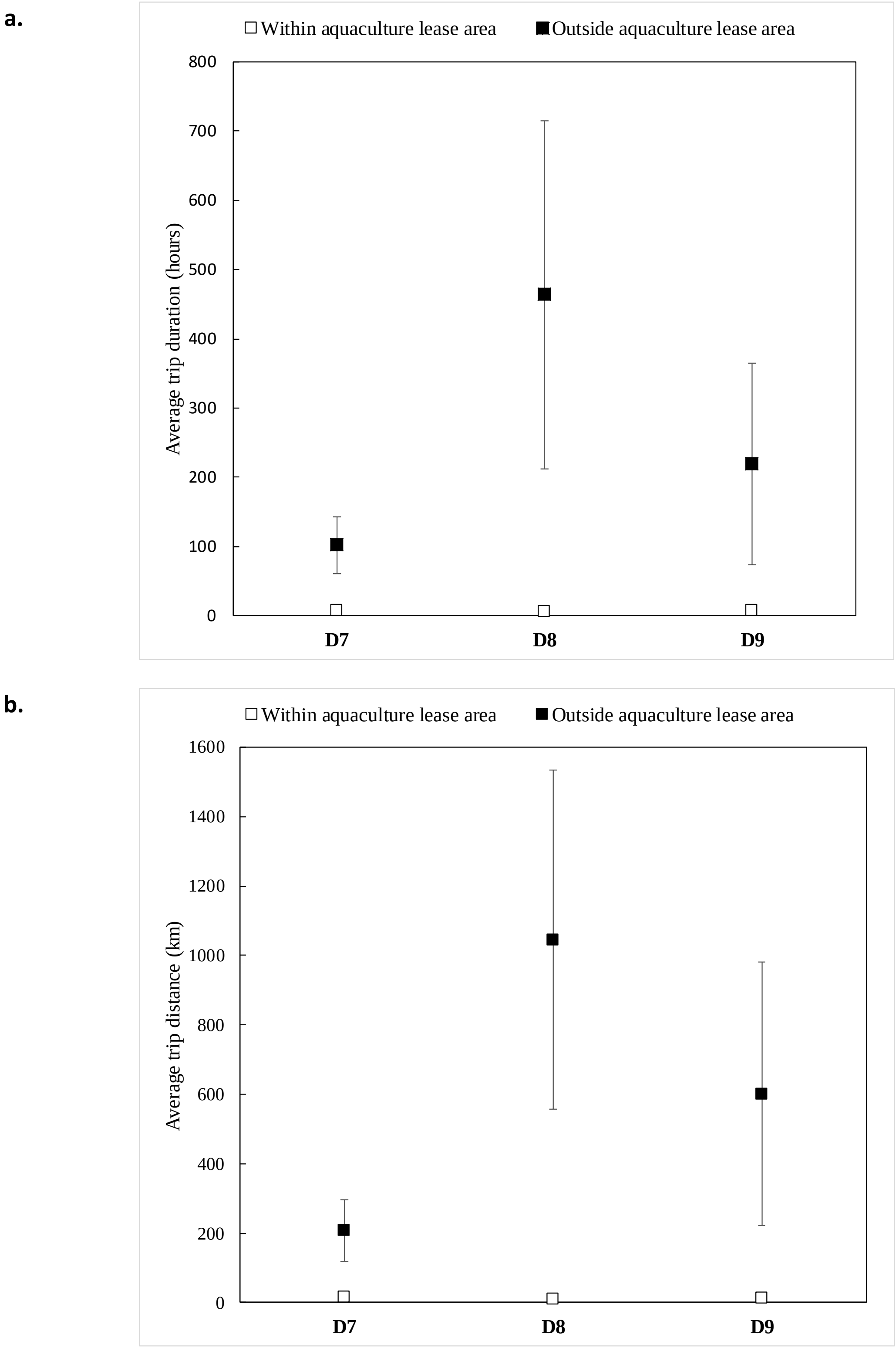


Figure 5.12. Average trip duration (a, top) and trip distance (b, bottom) for individual Long-nosed Fur Seals D7, D8 and D9 for trips undertaken within (white squares) and outside the core aquaculture lease area (black squares). Error bars are standard errors. Duration and distance within the the core aquaculture lease areas are slightly greater than zero.

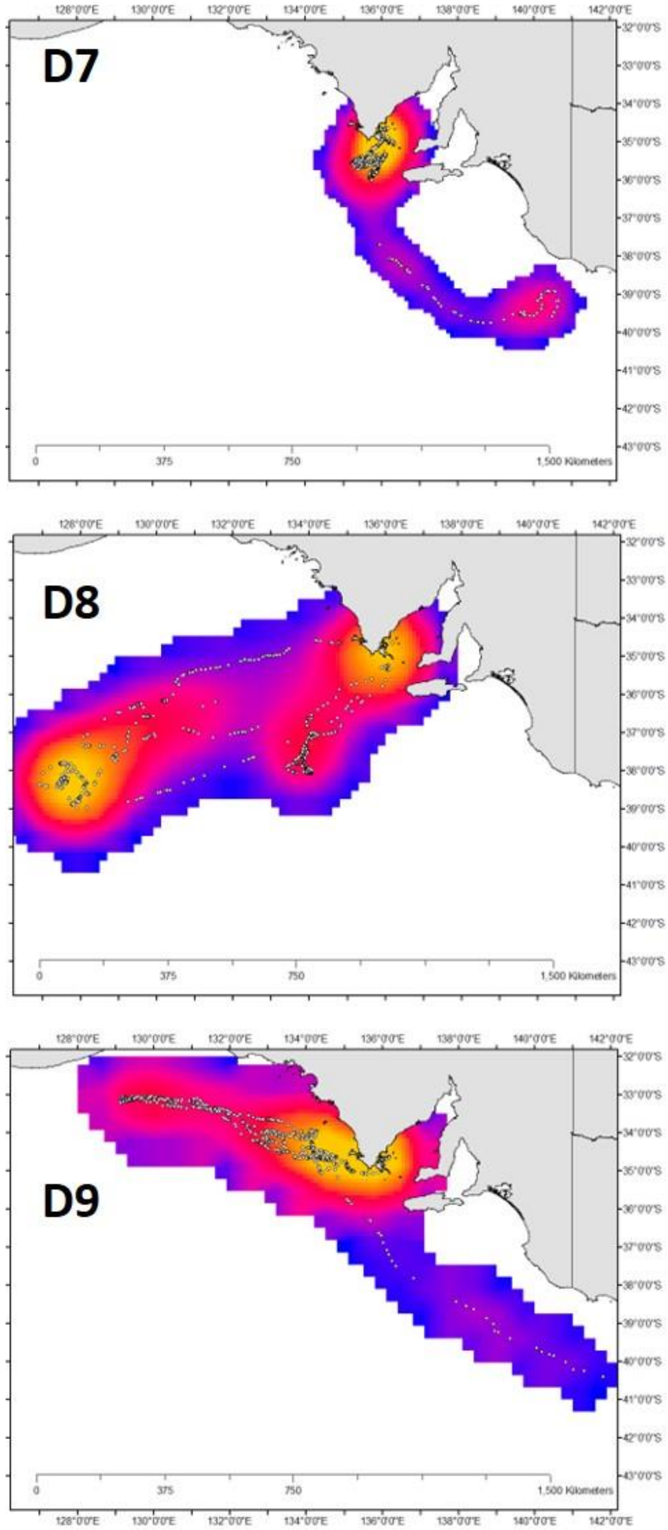


Figure 5.13. Home-range plots of tracks outside the core aquaculture area for individual Long-nosed Fur Seals D7, D8 and D9. White dots indicate location data; warmer colours indicate longer time spent foraging.

Deployments in the Coorong and at West Island.

The juvenile male long-nosed fur seal tagged at Tauwitcherie barrage with a satellite only tag on 1 September 2015 (C1) moved back and forth between the Coorong and West Island on ten occasions between 01 September and 28 October (Figure 5.14). Although ARGOS data were filtered to retain locations with an accuracy within 500 m, it was not possible to accurately determine when the individual hauled out. Therefore, trip lengths represent the time spent within the Coorong, near West Island or on the island. Time spent in the Coorong during each trip ranged from 5.9 hours to 10.2 days (mean = 59.18 hours); at West Island it ranged from 13.9 hours to 4.3 days (mean = 53.58 hours). On 28 October, the individual undertook a 1,792 km trip south and was approximately 800 km south of the Coorong when the tag stopped transmitting 38 days later on 5 December 2015 (Figure 5.14).

One of the three LNFS (a juvenile male, W2) tagged with a satellite linked GPS tag at West Island, Fleurieu Peninsula on 28 September 2015 had an instrument that did not function properly and and did not provide any usable location data. The other two fur seals that were tagged then made trips into the Coorong. The first one (W1, a subadult male) undertook three short trips along southern Fleurieu Penninsula, before a twelve-day 325 km long foraging trip that went over 350 km south of the tagging location. Then it returned to West Island and hauled out for approximately 3.5 days, before moving into the Coorong where it remained for five days when the tag ceased transmitting on 30 October 2015 (Figure 5.15).

The adult male tagged at West Island (W3) made five trips in and out of the Coorong and Lake Alexandrina over a three-week period, then hauled out at West Island for almost a month. It then returned to the Coorong and Lake Alexandrina where it remained for five days after which location transmissions ceased (Figure 5.16). In total, the individual spent 11.3 days in Lake Alexandrina and 4.2 days in the Coorong estuary. During the 64 days that the tag was transmitting, it did not forage outside these two locations. Most locations in the Coorong (91%) and Lake Alexandrina (66%) were transmitted at night.

Deployments at Kangaroo Island

A GPS satellite tag was deployed on a subadult male (K1) at Kingscote, Kangaroo Island on 9 October 2015. Between 9 October 2015 and 26 January 2016, it undertook 14 trips with an average duration of 110 hours (range 2 – 1,128 hours) and the average distance travelled was 170 km (range 2.3-1,856 km). Between 9 October and 22 October, it moved east from Kingscote around the northeast of Kangaroo Island and undertook a 115 km trip before hauling out at or near the breeding colony at Berris Point in the Cape Gantheaume Wilderness Protection Area for almost a month. On 19 November it departed Kangaroo Island and undertook a 276 km foraging trip, then hauled out south of Robe for 34.5 hours. It then remained in coastal waters until 7 December when it embarked on a foraging trip of approximately 1,129 km that lasted 47 days before it hauled out on a small island south of King Island (Bass Strait) on 23 January 2016. The tags stopped transmitting three days later after the individual had hauled out at the Black Pyramid Rock Nature Reserve in Bass Strait (Figure 5.17).

A GPS satellite tag was deployed on an adult male (K2) at Kingscote, Kangaroo Island on 30 October 2015. It moved along the eastern side of the island, and arrived at the Cape Gantheaume LNFS breeding colony on 7 November 2015. It remained hauled-out there for more than one month before the tag was shed or the battery failed (Figure 5.18). The long haul-outs of these two sub-prime males (K1 and K2) just prior to the commencement of the breeding season may represent ‘practice’ fasting haul-outs. Adult males holding breeding territories would normally remain ashore fasting for 5-6 weeks between December and January.

Key finding: Movement data from male LNFS fitted with GPS/satellite tags on the north coast of Kangaroo Island and in or on islands adjacent to the Coorong provided further examples of the highly flexible foraging strategies of male fur seals. Several individuals spent time foraging within the estuary and lakes systems of The Coorong and Lower Lakes, before switching to offshore oceanic foraging.

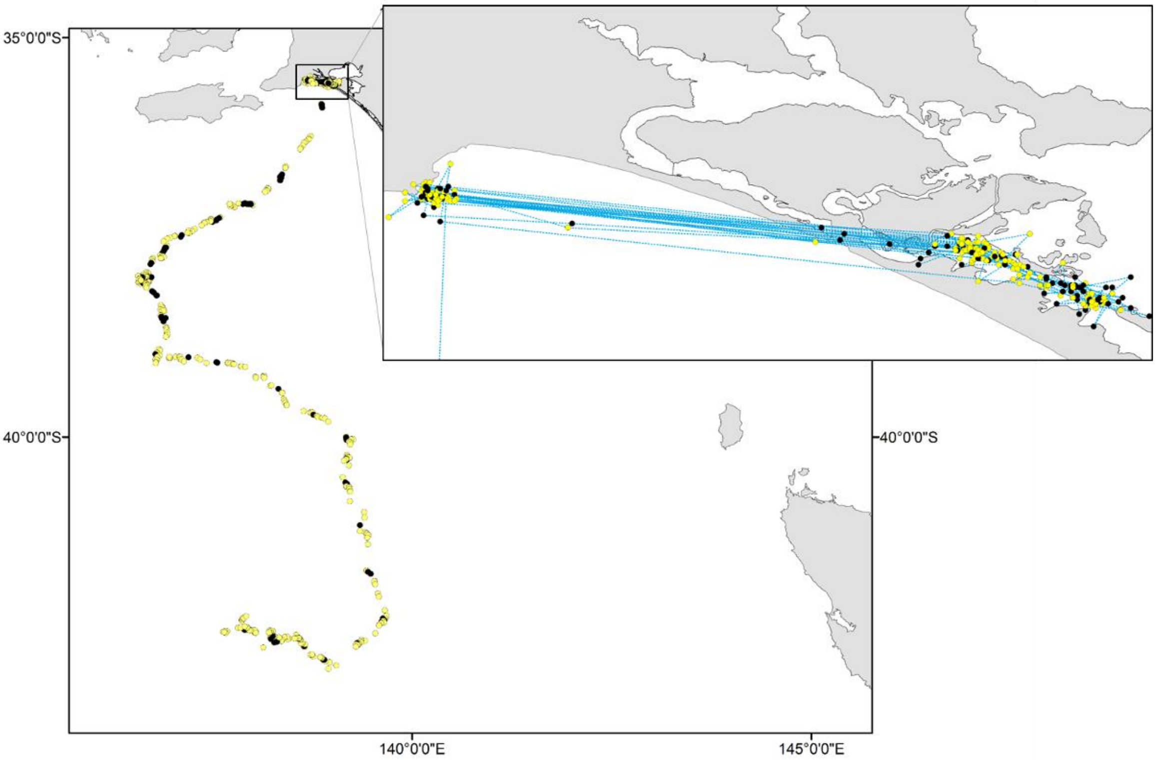


Figure 5.14. Filtered ARGOS locations (accuracy within 500 m) for juvenile male Long-nosed Fur Seal C1 between 1 September and 5 December 2015. Inset shows detail of filtered locations from 1 September to 28 October 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations.

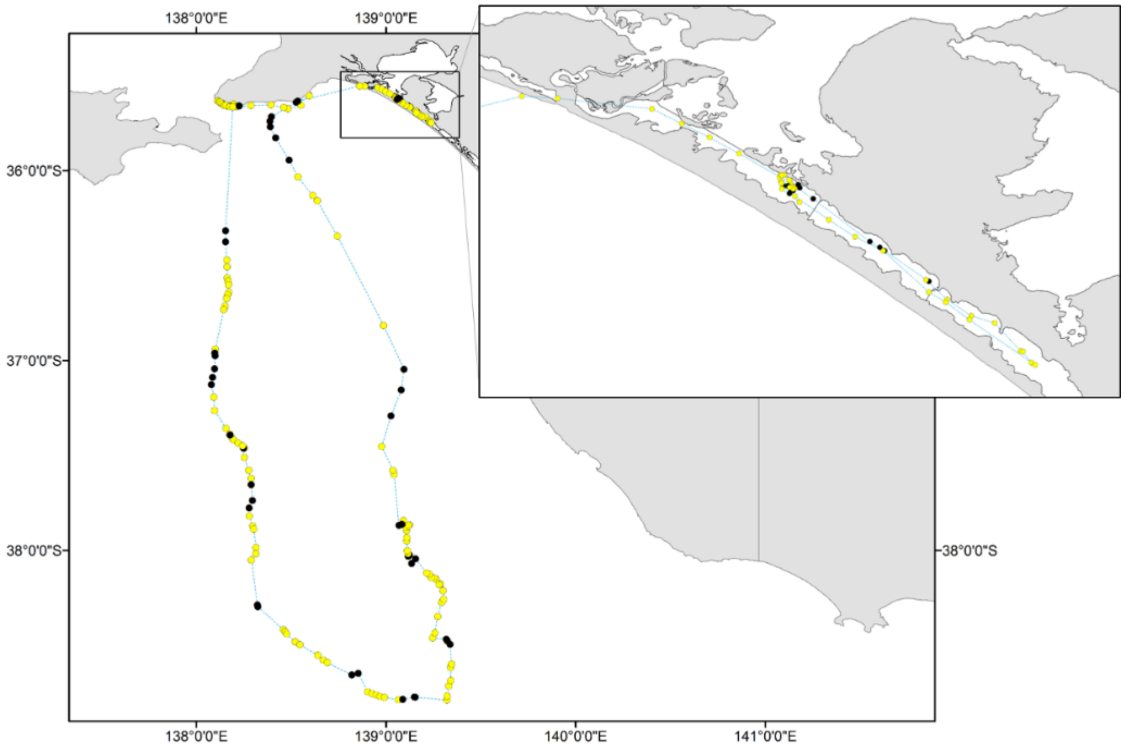


Figure 5.15. GPS locations for subadult male Long-nosed Fur Seal W1 between 28 September and 30 October 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations.

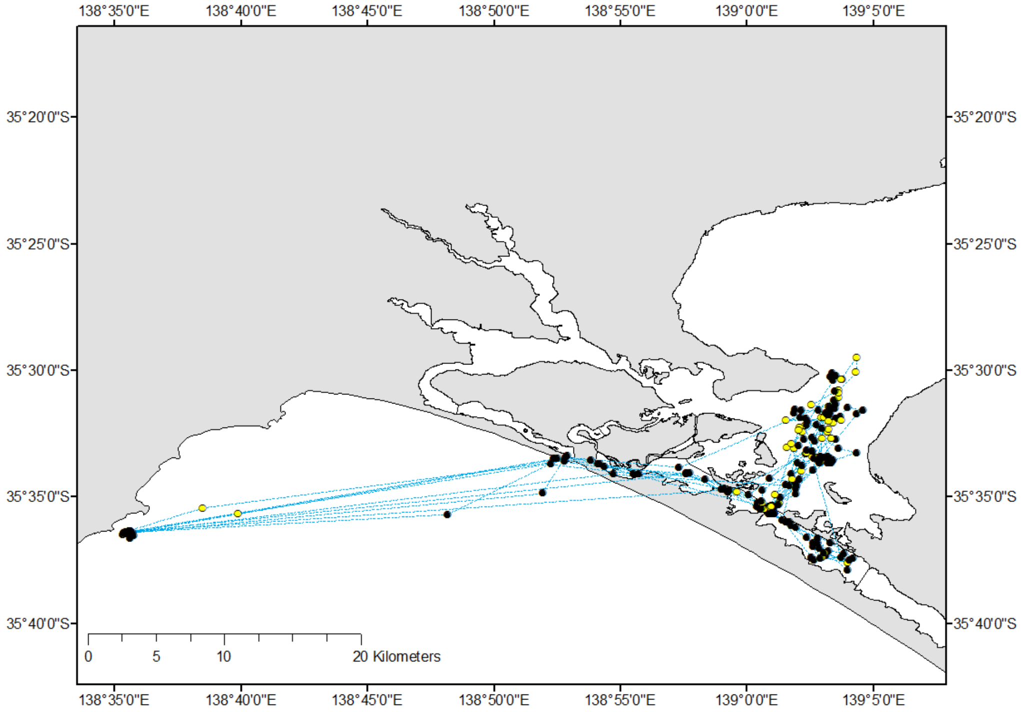


Figure 5.16. GPS locations for adult male Long-nosed Fur Seal W3 in the Coorong and Lake Alexandria between 3 and 9 October 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations.

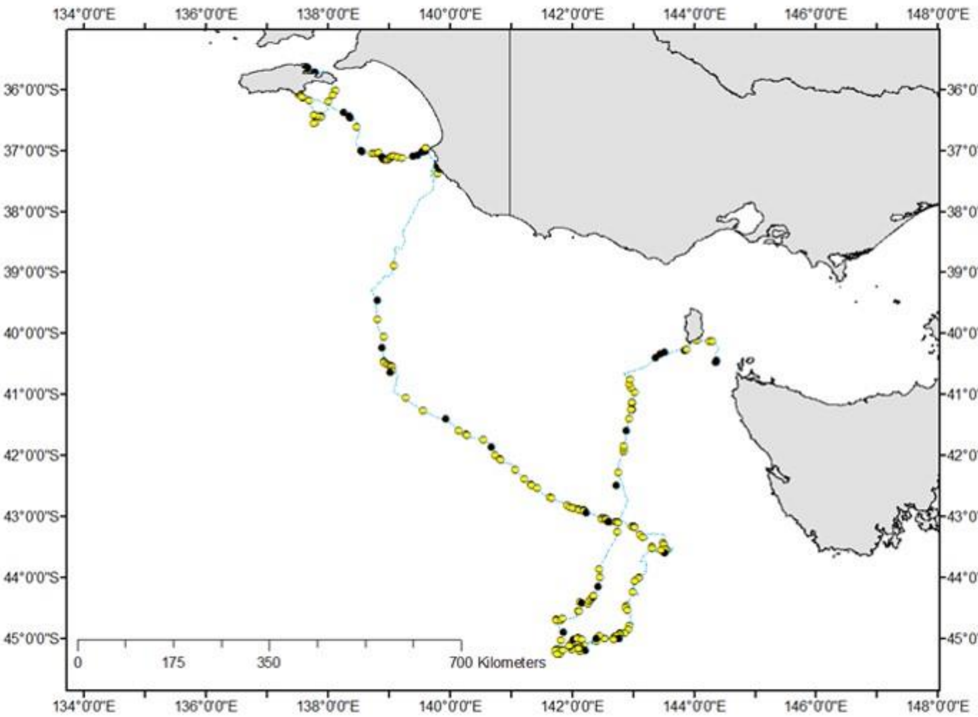


Figure 5.17. GPS locations for subadult male Long-nosed Fur Seal K1 between 9 October 2015 and 26 January 2016. Yellow circles indicate daytime locations, black circles indicate night-time locations.

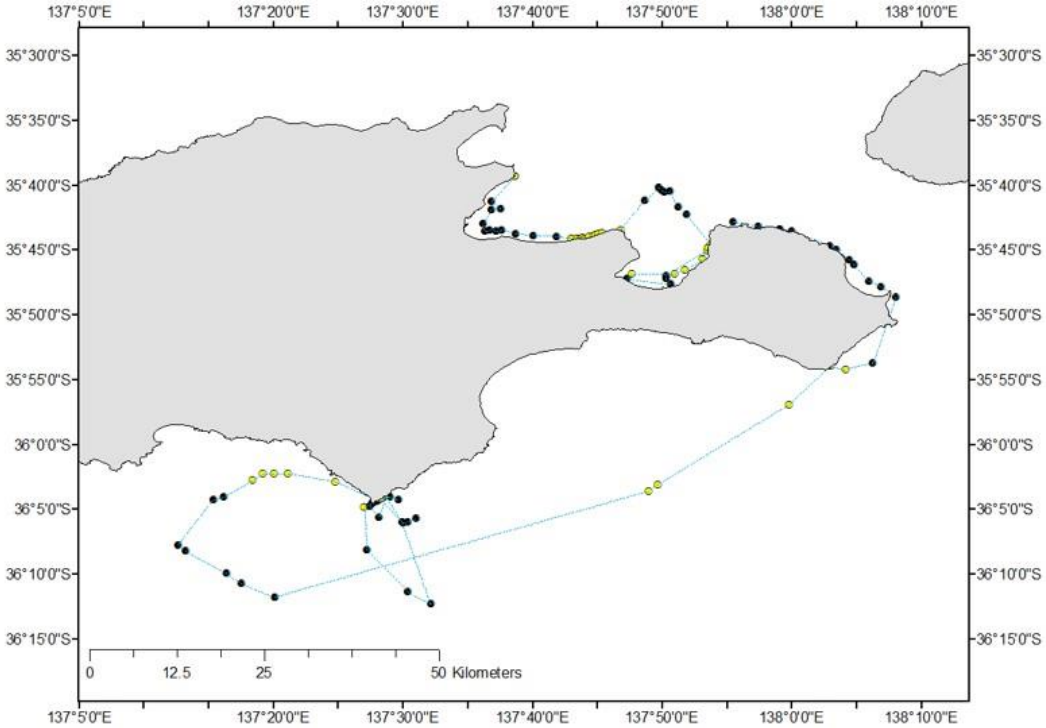


Figure 5.18. GPS locations for adult male Long-nosed Fur Seal K2 between 30 October 2015 and 7 November 2015. Yellow circles indicate daytime locations, black circles indicate night-time locations.

5.4 Discussion

This project has provided new information on the foraging behaviour and spatial distribution of juvenile, subadult and adult male LNFS from key locations in South Australia, and the spatial and temporal overlap of instrumented individuals in areas where this species directly interacts with commercial fishing and aquaculture activities. The movement data reveal high individual variation in foraging strategies and plasticity in behaviour, with some individuals switching between foraging in restricted coastal areas to the more typical offshore and shelf-break foraging trips previously described for male LNFS in South Australia (Page *et al.* 2005a, Page *et al.* 2005b).

The utilisation of GPS linked telemetry devices provided novel information on the fine-scale habitat use of tagged individuals. Movement data for the nine subadult and adult male LNFS tagged near aquaculture lease sites showed their high level of association with Southern Bluefin Tuna aquaculture pens, suggesting their presence in the area provides a means for fur seals to optimise their food intake. Although diet data of LNFS are unavailable for the period that individuals were tracked, molecular analyses of 20 LNFS scats collected at Donington Reef in July 2016 found that two farmed species, Yellowtail Kingfish and Southern Bluefin Tuna were present in 50% and 19%, respectively of scat samples. The identification of Southern Bluefin Tuna in LNFS scats at a haul-out site close to aquaculture lease areas indicates that some individuals are preying on this species; but it is not possible to determine if this represents live, injured or dead fish. Although juvenile LNFS have been recorded inside tuna pens in SG, farm managers reported that they thought individuals of that size were too small to be able to successful attack Southern Bluefin Tuna (Goldsworthy *et al.* 2009b).

The 20 scat samples from Donington Reef showed 18 fish, one shark and three cephalopod species. The most frequently occurring non-farmed prey species were Yellowtail Scad (*Trachurus novaezelandiae*) and Common Jack Mackerel (*Thrachurus declivis*) which were present in 52% and 45% of scats, respectively, followed by Sardine. Sardine is the primary baitfish used to feed farmed Southern Bluefin Tuna. Independent observers have recorded fur seals swimming freely in and out of purse seine nets during fishing operations in the South Australian sardine fishery (SARDI unpublished data). Finfish aquaculture structures attract and sustain aggregations of wild fish at higher diversity and densities than at control sites (Bacher *et al.* 2012, Dempster *et al.* 2005, Dempster *et al.* 2002, Dempster *et al.* 2010, Fernandez-Jover *et al.* 2008, Özgül and Angel 2013, Stagličić *et al.* 2017). Aquaculture pens have been proposed to act as fish aggregating devices (FADs) or artificial reefs by providing structure in the pelagic environment and access to additional nutrients in the form of waste feed (Callier *et al.* 2018, Dempster *et al.* 2010, Fernandez-Jover *et al.* 2008). Tuna pens are approximately 40 m in diameter with a net wall depth of 10 – 20 m (Fernandes *et al.* 2007a, Goldsworthy *et al.* 2009b), while Yellowtail Kingfish pens are typically 25 m in diameter with a net wall depth of 6 m (Tanner and Fernandes 2010). Irrespective of whether fur seals are depredating farmed fish, their feed or feeding off wild fish aggregations around cages, the ability to access a predictable concentrated source of prey would be highly attractive to them.

In Tasmania, nine AFS and two LNFS that were captured at salmon aquaculture farms and then equipped with telemetry devices and relocated hundreds of kilometres returned to farms within a matter of days, revealing these individuals were highly motivated to associate with the farms (Robinson *et al.* 2008a). Movement patterns of South American sea lions in relation to salmon aquaculture in southern Chile showed high variability in the degree of overlap with salmon farms. However, there was no clear relationship between the degree of spatial overlap of an individual and the proportion of salmon in its diet (Sepúlveda *et al.* 2015). Individual specialisation in accessing prey in association with fishing activities has also been shown for AFS and grey seals (Königson *et al.* 2013, Tilzey *et al.* 2006). Foraging associations of seals with other types of structures that may act as FADs or artificial reefs has also been shown, with inter-individual variability in the level of association. These include harbour seals (*Phoca vitulina*) and grey seals with underwater pipelines in the North Sea, harbour seals and offshore wind farm turbines, and between AFS and underwater pipelines and cables in Bass Strait (Arnould *et al.* 2015, Russell *et al.* 2014).

LNFS are generalist predators (Emami-Khoyi *et al.* 2016, Harcourt *et al.* 2002, Page *et al.* 2005a, Page *et al.* 2005b). Given the strong association of eight individuals with aquaculture leases in the current study, it appears that these areas provided a sufficient source of food when tuna pens were present. There were clear inter-individual differences in visitation to lease areas, with some fur seals repeatedly visiting the same sites. The majority of locations within lease sites were transmitted at night. A preference for foraging at night in association with pens may be a response to avoiding humans during daylight hours.The core foraging area of the individuals that associated with aquaculture leases were all within 20 km of Donington Reef. The tags that were still transmitting after the Southern Bluefin Tuna had been harvested and pens removed showed all three individuals switched to a more “typical” wide-ranging foraging strategy as previously described (Page *et al.* 2006), with foraging trips that extended over 800 km from haul-out locations. The temporal shift in distribution of these three individuals in relation to the end of the Southern Bluefin Tuna harvest supports previous records of the abundance of seals at Donington Reef. In 2005, LNFS were first observed at the haul-out site in April, with abundance greatest in August and it declined rapidly in September (Goldsworthy *et al.* 2009b).

Key finding: Diet analysis provides support that LNFS are attracted to aquaculture cages in part to directly feed on either live, sick or dead tuna or Yellowtail Kingfish, or on baitfish feed. However, the predominance of mackerel and trevally in the diet suggests they may also be attracted to aquaculture cages to forage on other species attracted to aquaculture operations.

Two of the three individuals that entered the Coorong also showed the ability to switch between localised foraging patterns and more wide-ranging foraging. The juvenile male tagged at Tauwitcherie Barrage (C1) undertook ten trips between West Island and the Coorong, spending up to 10 days within the Coorong, before undertaking a foraging trip off the continental shelf into pelagic waters. As this individual was not equipped with a GPS tag, the resolution of the location data in the Coorong was not good enough to determine its fine-scale movement in the estuary. The pelagic trip was similar to those previously obtained from male and female juvenile LNFS tagged at Cape Gantheaume, Kangaroo Island; they undertook pelagic foraging trips off the continental shelf in association with the subtropical front (Page *et al.* 2006) where they targeted prey such as myctophids (Page *et al.* 2005a). The subadult male tagged at West Island (W1) showed an opposite movement pattern, undertaking a number of trips along the coast, followed by a 12-day off-shelf foraging trip and then entering and remaining in the Coorong for five days until the tag stopped transmitting. In contrast, the adult male tagged at West Island (W3) appears to have exclusively foraged within the Coorong and Lake Alexandrina, with location data predominantly transmitted at night. Reports of LNFS depredating catch and damaging gear in the South Australian Lakes and Coorong Fishery have been recorded since the late 2000s (Mackay 2017). As fishing effort and the location of net sets in the Lakes and Coorong Fishery are only recorded in boat-days and fishery blocks (Earl 2018), it is not possible to determine if this individual was foraging in proximity to fishing gear.

Information on diet of LNFS in the Lakes and Coorong is limited, but analyses of hard parts in LNFS scats collected at Tauwitcherie Barrage in the Coorong in August and September 2015 indicated Tamar Goby, Bony Herring, Common Carp, Yelloweye Mullet and Mulloway were consumed (Chapter 4). Fresh water fish species were also detected in scats collected from haul-out sites at Seal Island and West Island (Chapter 4). The occurrence of fresh water fish in scats confirm that seals are foraging in the Coorong and Lower Lakes. In addition to depredation of set nets, it is likely that the barrages and associated fishways in this modified environment provide access to concentrated prey for seals. Although no quantitative assessments of the economic cost of interactions have been undertaken, questionnaire responses by commercial fishers estimated catch losses of up to 50% and more (Chapter 2 and Appendix 2.1). The Lakes and Coorong Fishery reports higher interaction rates with seals in winter months, which corresponds with a general pattern of increased abundance of seals in the region in winter (Mackay 2017). Methods trialled to mitigate interactions include the use of underwater crackers and an assessment of the potential to use more active gear in the fishery (Earl *et al.* in press).

The ability of wildlife to adapt, or otherwise, to novel anthropogenic environments has predominantly been studied for terrestrial species. Many terrestrial carnivore species display smaller home range sizes in urban compared to natural populations (e.g. Šálek *et al.* 2015). One suggestion for this pattern is that predictable and easily accessible anthropogenic food sources mean that individuals do not need to move as far to forage. In the current study, some of the LNFS showed clear plasticity in foraging behaviour, being able to switch between associations with aquaculture pens when they were present, to wide-ranging foraging behaviour once the pens had been harvested. Similarly, AFS foraged almost exclusively within the fishing grounds of the Blue Grenadier fishery until the fishing season ended after which their spatial foraging effort changed (Tilzey *et al.* 2006). Temporal switching between foraging on natural and anthropogenic food sources has also been shown in black-tailed gulls (Yoda *et al.* 2012). There is a growing body evidence that a number of marine predators show individual inter-annual fidelity to foraging sites (Arthur *et al.* 2015, Augé *et al.* 2014, Chilvers 2008, Lowther *et al.* 2011). As the duration of tag transmissions in the current study was generally in the order of months, it is not possible to determine whether the individuals that associated with aquaculture pens or barrages or fishing operations did so opportunistically, or whether they were displaying specialist foraging behaviour that is repeated annually. However, this study provides the first information on the fine-scale movement patterns of LNFS in association with key aquaculture lease areas in South Australia and within the Coorong region, improving our understanding of the temporal and spatial overlap of fur seals and fisheries and aquaculture.

6. Spatial distribution of consumption effort of Australian sea lions and Long-nosed Fur Seals, and their overlap with the main South Australian fisheries

Fred Bailleul

6.1 Introduction

The at-sea distribution of land-breeding marine predators, such as seals, varies among species, depending on their reproductive and foraging strategies. In order to estimate the potential overlap of marine predators with the core area of the main fisheries in South Australia (SA), it is critical that the spatial and temporal variation of the predators' presence in the fishing areas are understood. The most cost-effective and reliable method to assess the at-sea movements and foraging areas of seals is through tracking studies, using either satellite transmitters (platform transmitting terminals, PTTs) or GPS tags.

We use state of the art analytical methods to assess the at-sea foraging distributions of Australian sea lions (ASL, *Neophoca cinerea*) and Long-nosed Fur Seals (LNFS, *Arctocephalus forsteri*) from satellite tracking. We ask the key question: to what extent do the distributions of foraging and consumption effort of these two species in the eastern Great Australian Bight (EGAB) ecosystem overlap with the core area of the main fisheries.

The aims of this study were to estimate the spatial distribution of foraging effort of two key land-breeding marine predators and, based on dietary assessments and estimates of consumption, to determine to what extent the spatial distribution of consumption effort of key prey taxa overlaps with the spatial distribution of catch in the main SA fisheries.

The analyses were restricted to open marine environments, and did not include the Coorong estuary or freshwater lake fished in the Lakes and Coorong Fishery. As the size of the male LNFS population entering the Coorong is unknown, the degree of consumption by these animals and their overlap with the Lakes and Coorong Fishery could not be calculated.

6.2 Materials and Methods

Satellite telemetry data

Satellite telemetry data were obtained from two species: ASL and LNFS. Occurrence data were obtained from ARGOS PTTs or GPS tags from several studies over the last 15 years (Baylis *et al.* 2008a, 2008b, Baylis *et al.* 2012, Goldsworthy *et al.* 2009b, Goldsworthy *et al.* 2010, Hamer *et al.* 2013, Lowther *et al.* 2011). In addition, recent data were obtained from ARGOS linked GPS tags, for LNFS (Chapter 5). Data sources are summarised in Table 6.1. Based on the spatial extent of the tracking data, the study area was defined as the marine surface encompassed between 31 and 46°S and 124 and 146°E.

Table 6.1. Details of data sources used to determine the at-sea distribution of Australian sea lions and Long-nosed Fur Seals. Information includes: instrumentation type, time period, number of individual seals, number of breeding colonies tracked, and the resultant number of foraging trips (tracks).

Species	Instrument sources	Time period covered by data	Number of individuals	Number of colonies	Number of tracks
Australian sea lions	Argos (PTT), Fastloc (GPS)	2003-2016	221	24	3662
Long-nosed fur seals	Argos (PTT), Fastloc (GPS)	2000-2007, 2015-2016	101	5	249

Filtering and analysis of tracking data

Filtering and statistical analyses were performed using the program R (R Core Team 2017). Satellite telemetry data were obtained from ARGOS PTT tags, which transmit a message to polar orbiting satellites when an animal fitted with a tag is at the surface. ARGOS PTT data are categorised into seven quality classes (3, 2, 1, 0, A, B and Z) based on the quality of the uplinks from transmitter to satellite. Location-class Z positions were omitted due to the magnitude of their error, leaving the six other classes for filtering and subsequent analyses.

Satellite telemetry derived position estimate data were filtered using a state-space framework (Johnson *et al.* 2008, Jonsen *et al.* 2005, Patterson *et al.* 2009). The errors in satellite-derived locations provided by Argos were incorporated into estimates of likely positions. State-space models allow unobserved states and biological parameters to be estimated from location estimate data (e.g., foraging vs. transit behaviour). Models were fitted using JAGS 3.1.0 (Just Another Gibbs Sampler, http://martynplummer.wordpress.com; http://mcmc-jags.sourceforge.net) accessed from R (R Core Team 2017) using the package ‘bsam’ (Jonsen and with contributions from S. Luque 2014). Two Markov chains with a total of 50,000 simulations were computed; only one in ten samples were kept to minimise sample autocorrelation. The analyses assumed a time-step of 2h and generated 25,000 samples per chain for each position.

GPS telemetry data obtained from Fastloc-GPS tags provide a location when an animal fitted with a tag breaks the surface, even for a very short time. Calibration studies indicate that 95% of locations are accurate to ±55 m with a mean error <150 m (Bryant 2007). Given the high level of accuracy of GPS locations, we did not post-process or filter data from these tag deployments. The GPS locations were re-sampled on a time-step of 2h to be consistent with the filtered Argos satellite tracks.

Habitat model development

We used a hierarchical modelling approach to relate environmental variables to the occurrence of ASL and LNFS estimated via Argos and GPS data. We focussed on foraging location estimates identified from the state-space model process (hereafter referred as presence data). We also generated random background data used as pseudo-absence locations. Environmental data were temporally and spatially matched to the presence and background locations. Environmental variables were retrieved from the Australian Ocean Data Network Portal (AODN – IMOS https://portal.aodn.org.au) or were calculated and selected depending on their biological relevance and availability in the study area. We selected both fixed (bathymetry, bathymetry gradient) and dynamic variables (sea surface temperature, sea level anomalies, annual primary production), distance from the colony, and distance from the continental slope, because they are likely to influence foraging behaviour. These explanatory variables were standardised (centred and scaled) to improve algorithm convergence and to scale the range of the predictors. We checked for colinearity by calculating all pairwise Spearman rank correlation coefficients (rS). When pairs of predictor variables were strongly correlated (|rS| > 0.7), we ran two univariate models with each of these predictors and selected the predictor that led to the lowest Akaike Information Criteria (AIC) (Burnham and Anderson 2002). We used generalised additive models with presence/background as response variable, and non-correlated environmental parameters as explanatory variables. Models were fitted with a binomial error distribution and a logit link function. We performed all possible linear combinations of explanatory variables and ranked the models based on their AIC values. We then calculated the Akaike weight (wi) for each model, which represents the relative likelihood of candidate models (Burnham and Anderson 2002). When there was no obvious evidence of a single best model (i.e., wi > 0.90), we applied a model averaging procedure to account for uncertainties in model selection (Burnham and Anderson 2002). The best (or averaged) model was used to predict the distribution of suitable foraging habitats of the two species.

The predicted distribution of suitable foraging habitats of the seals was further weighted by estimates of colony abundance. The spatial distribution of foraging habitats was apportioned for each colony within each species based on its proportional contribution to the total estimate of its population within the region. The resultant estimates of spatial distribution of abundance using colony abundance estimates were assumed to reflect the density at-sea.

The distribution of consumption effort was based on diet summaries and population and bio-energetic models developed for the two species in the SG and Gulf St Vincent (GSV) ecosystems models (Chapter 7). Total annual consumption was apportioned for each colony using the distribution of abundance, as detailed in the paragraph above. For LNFS that only spend part of the year foraging over the continental shelf within the EGAB, we estimated the portion of total consumption that occurs over the shelf.

Data on the spatial distribution of the main fisheries catch was available for the ten-year period 2006-2016 and was averaged per Marine Fishing Area (MFA). In some instances where latitude and longitude of the catch was recorded (e.g., in the Sardine fishery), data was averaged in a 0.05° x 0.05° grid. Species considered in this study were: Blue Crab, Southern Rock Lobster, King Prawn, Southern Calamari, Garfish, King George Whiting, Snapper, Sardines and the total catch of marine scale species (excluding Sardines).

Because the fishing data used here were recorded in spatially broad MFAs, the analysis of spatial overlap with seals was conducted at that scale. Exceptions were for sardines, for which position data were available and for King Prawns, where spatial blocks were dissolved and re-scaled in a 0.05° x 0.05° grid. In consequence, the distribution of ASL and LNFS foraging and consumption effort has been re-scaled to match the MFAs and to make the overlap with fisheries data consistent. Consumption by seals and fisheries catch are presented in kg.km^{-2}.

6.3 Results

Satellite telemetry and GPS data from the two seal species were derived from deployments on 322 individual seals and involved 3911 individual foraging trips (Table 6.1). ASL have been tracked from a large proportion of the colonies (24 out of 42, Goldsworthy *et al.* 2015) (Table 6.1). LNFS have only been tracked from five colonies (Table 6.1) but those colonies account for a large percentage (97%) of the population in SA (Shaughnessy *et al.* 2015).

Distribution of consumption by seals

ASL concentrate their foraging and consumption effort over shelf waters between Eyre Peninsula and south-east of Kangaroo Island, including lower portions of SG (Figure 6.1). Four important marine scale species (Garfish, King George Whiting, Snapper and Southern Calamari) comprise only 3.79% of the estimated total prey consumed (Table 6.2). Sardine consumption was estimated to make up 0.03% of the total annual consumption of ASL, Southern Rock Lobster 0.3%, King Prawn 1.13% and

Blue Crab 0.07% (Table 6.2). No distinction has been made between male and female ASL because they both forage over the shelf and no information about the diet was available by sex for this species.

LNFS foraging and consumption effort is generally distributed over the shelf waters and in oceanic waters in the EGAB (Figure 6.2), depending on sex and age class of individuals and the time of the year.

Adult females forage over the shelf during the early breeding season (December-March), after which they start to shift toward oceanic waters (April), where they forage during the next five months (May-September) with rare incursions over the shelf. They then stay offshore without returning to the shelf during October-November (Figure 6.3).

Adult males mainly forage over the shelf and slope waters, although they sometimes forage in oceanic waters (Figure 6.4). Any other potential spatial distribution, as well as temporal variation in foraging areas for adult males, is still unknown.

Sub-adult male foraging and consumption effort is distributed over the shelf and in oceanic waters. The temporal variation in foraging location is unclear but we estimated that a larger proportion of subadult males forage over the shelf in winter (April-October) than in summer (November-March) (Figure 6.5).

A summary of the estimated total annual consumption by each LNFS age class and the proportion of the main species targeted by fisheries is presented in Table 6.2.

The distribution of foraging and consumption effort by seals of each species re-scaled to match the MFAs spatially are presented in Appendix 6.1.

Fishery catch

Averaged annual catch by species is presented in Table 6.2. The catch of marine scalefish (including Garfish, King George Whiting, Snapper and Calamari but excluding Sardine) occurs year-round (Appendix 6.2). Sardine catch mainly occurs between January and July (with the highest catches between March and May). Catch of Southern Rock Lobster mainly occurs between October and April/May. Catch of King Prawns mainly occurs in November/December and then between March and June. Blue Crab catch occurs year-round in the EGAB but only between January and April/May in the Gulfs (Appendix 6.2). Temporal variation in total annual fishery catch is presented in Appendix 6.3.

Spatial overlap between fishery catch and seals’ consumption effort

The diet of ASL is broad consisting of roughly equal proportions of fish and squid (Chapter 7). However, commercially targeted Garfish, King George Whiting, Snapper and Southern Calamari only represent <4% of the marine scale species consumed by ASL, with Calamari being the most significant, consuming a little over double that taken by fisheries (Table 6.2). Consumption of Sardine, Southern Rock Lobster, King Prawns and Blue Crab by ASL was a small fraction of that taken by fisheries (Table 6.2).

The general distribution of foraging and consumption effort of ASL covers a large part of the MFAs. ASL intake exceeds fishery catch (averaged annual fisheries catches between 2006 and 2016) in some areas of the EGAB with a maximum of 8 kg.km^{-2}, but the excess is very close to zero for most of the key fish species (Figure 6.6). On the other hand, fishery catch exceeds ASL intakes principally in SG and GSV (except for Southern Rock Lobster), with a maximum value ranging from 40 to 3000 kg.km^{-2} (Figure 6.6). Temporal variation in total annual fishery catch is presented in Appendix 6.3.

The diet composition of LNFS varies according to age classes. The key marine scale species Garfish, King George Whiting and Southern Calamari represent <5% of marine scale species consumed by subadult males (Table 6.2). Southern Calamari and Garfish were the most significantly consumed commercially targeted species (Table 6.2).

The distribution of foraging and consumption effort of LNFS only partially coincides with the MFAs, since a large part of their foraging domain is located offshore in oceanic waters, especially for adult females (Figure 6.7). Moreover, the seasonal variation in LNFS distribution (adult females and subadult males) increases or decreases the potential overlap with fisheries as a function of time of the year. From December to March, adult females spend most time over the shelf. During that time, their intake exceeds fishery catch in some locations with a maximum of 8 kg.km^{-2} when considering all marine scale species (Figure 6.7). For the three key species, Garfish, Southern Calamari and Sardine, the intake of LNFS females exceeds fishery catch, with a maximum of 1 kg.km^{-2} (Figure 6.7). On the other hand, fishery catch exceeds the intake of adult female LNFS with a maximum value ranging from 64 to 1800 kg.km^{-2} (Figure 6.7). Later in the year, the potential overlap with fisheries decreases as the females shift to forage in oceanic waters (Figures 6.8, 6.9 & 6.10).

The intake of adult male LNFS exceeds fishery catch in some locations with a maximum of 26 kg.km^{-2} when considering total marine scale species (Figure 6.11). For the three key species, Garfish, Southern Calamari and Sardine, adult males' intake exceeds the fishery catch with a maximum of 0.6 kg.km^{-2} (Figure 6.11). On the other hand, the fishery catch exceeds the intake of adult males for other species, with a maximum value ranging from 64 to 1800 kg.km^{-2} (Figure 6.11).

Subadult male LNFS forage more offshore than on the shelf in summer (November to March, Figure 6.5). During that time, the intake of subadult males exceeds fishery catch in some locations with a maximum of 8.5 kg.km^{-2} when considering total marine scale species (Figure 6.12). For the three key species, Garfish, Southern Calamari and Sardine, the intake of subadult males exceeds fishery catch with a maximum of 0.4 kg.km^{-2} (Figure 6.12). In contrast, fishery catch of other species exceeds the intake of subadult males with a maximum value ranging from 64 to 1800 kg.km^{-2} (Figure 6.12). In winter (April to October), subadult males forage more over the shelf than offshore. During that time, their intake exceeds fishery catch in some locations with a maximum of 13 kg.km^{-2} when considering all marine scale species (Figure 6.14). For the three key species, Garfish, Southern Calamari and Sardine, the intake of subadult males exceeds fishery catch with a maximum of 0.6 kg.km^{-2} (Figure 6.13). In contrast, fishery catch of other species exceeds the intake of subadult males with a maximum value ranging from 64 to 1800 kg.km^{-2} (Figure 6.13). Although King George Whiting was also a part of the diet of subadult males, no spatial overlap is presented since the resulting values were very close to 0.

6.4 Discussion

Interactions between marine predators (such as seals and seabirds) and fisheries, as a result of sharing the same resource, have been given considerable attention worldwide in recent decades (e.g. Cowx 2003, Furness 1982, Furness and Birkhead 1984, Goldsworthy *et al.* 2003, Goldsworthy *et al.* 2001, Montevecchi 2002). A number of studies have suggested that some predator populations consume significant quantities of commercially important fish species, to the extent that it has an economic impact (Furness 1982, Furness and Birkhead 1984). More recently, both the effect of fisheries activities on populations of marine predators and the impact of expanding populations of predators on fish stocks, have led to growing concerns about the conservation of marine life on the one hand and, on the other, the sustainability of both commercial and recreational fisheries (e.g. Goldsworthy *et al.* 2003, Goldsworthy *et al.* 2001, Karpouzi *et al.* 2007, Mohn and Bowen 1996). For example, some studies have shown that entanglement in fishing gear increases seabird mortality and affects their populations (e.g. Belda and Sanchez 2001, Tuck *et al.* 2003). However, human exploitation of marine resources has also provided an increased opportunity for some predators to take advantage of prey that are easier to catch or would otherwise be unavailable to them (e.g. Nolan *et al.* 2000, Roche *et al.* 2007). This form of interaction can be beneficial for predator populations but can, also impact fishery activities (Rocklin *et al.* 2009).

In South Australia, fishery bycatch and entanglement were identified as the main causes of decline in ASL populations in recent decades (Goldsworthy *et al.* 2009a, Goldsworthy and Page 2007). In contrast, LNFS populations have been recovering strongly over the last ten years after near extinction due to intensive harvesting in the 19th century (Shaughnessy *et al.* 2015). Consequently, contact of fur seals with fishers has become more frequent, and fur seals have been reported to remove fish from nets of commercial fishers and/or damage fishing gear (Goldsworthy *et al.* 2009b). The spatial and temporal overlap between the consumption effort of both ASL and LNFS, and fisheries activities, provides the first level of understanding of how predators may compete with or affect seafood industries and vice versa (Karpouzi *et al.* 2007, Reid *et al.* 2004).

The estimated distribution of foraging and consumption effort by ASL and LNFS indicates that shelf waters in the EGAB region off western and lower Eyre Peninsula, south and south-east of Kangaroo Island, along the Bonney coast and in the lower portions of SG and GSV represent critical foraging habitats for the two species (Figures 6.1 and 6.2). Potential overlap and/or competition with fisheries is expected to occur more intensely in these areas than elsewhere. However, it appears that the most intensive foraging areas for seal species do not necessarily overlap with the most intensive fishing areas (e.g., the upper portions of SG and GSV) (Figures 6.1, 6.2, and 6.6, and in Appendix 1). This is especially true for LNFS that only forage in SA shelf waters for a few months of the year, since their foraging domain also extents largely to oceanic waters. In contrast, ASL only forage over the shelf.

The diet of ASL and LNFS is largely eclectic. Although the estimated consumption by these apex predators consists of a large proportion of marine scale fish that are also targeted by SA fisheries, the key species for industry like Garfish, King George Whiting, Snapper, Sardine, Southern Calamari, Blue Crab, Southern Rock Lobster and King Prawn account for a low percentage of the estimated total prey consumed by the seals.

It is apparent that there is a spatial mismatch between areas of intensive seal foraging and fisheries catch areas. Furthermore, there are differences between the amount of fish caught by fisheries and the amount consumed by the seals. Consequently, there are MFAs where fisheries catch exceeds the take by seals, as well as MFAs where seals take more than fisheries catch.

The magnitude of the differences per MFA is important. Where seals take more than the fisheries catch, the excess never exceeded 10 kg.km^{-2} for any of the prey species considered in this study. On the other hand, fisheries catch sometimes exceeded the seals' intake by up to 3,000 kg.km^{-2} (Figure 6.7 to 6.14). The spread of the consumption effort by seals over all their foraging domain, the relatively low representation of the key species in the diet of the predators, and the spatial mismatch between intensive fishing areas and intensive seal foraging areas likely explain the magnitude of the differences. In summary, seals only took more than fisheries catch where the fisheries catch was low or non-existent. The combination of low spatial overlap in consumption and catch, and the very low consumption of key commercially fished taxa by seals, means that the actual competition between seals and the main SA fisheries is likely to be very low. However, the extent of interactions between seals and fisheries can vary markedly due to both seasonal changes in fishing activity and seal foraging distribution (Appendix 2).

The foraging distribution models for ASL and LNFS used a huge dataset of satellite tracking collected over the last 18 years to account for differences in behaviour between sex, age class, colony location and season. Although tracking effort was considerable and the modelling process based on the best of our knowledge on the biology and ecology of the two seal species, some information is still missing.

There is little information on the foraging behaviour of juveniles for each seal species and the real proportion of individuals foraging over the shelf versus in oceanic waters as a function of the seasons is still unclear, especially for subadult male LNFS. The foraging areas of seals from numerous colonies (especially for LNFS) have not been investigated because no individuals from some colonies have been satellite tracked. Clearly, additional tracking data throughout the year across a larger number of colonies of LNFS and for some specific age groups (particularly juvenile and subadult) would improve model estimates of the spatial and temporal distribution of foraging and consumption effort. Additional information on the diet of the two species, especially on the spatial and temporal variation of prey consumption relative to different colonies, would be advantageous to improve estimates of the overlap between foraging seals and the main SA fisheries, and the potential competition for fish resources.

Key finding: Analyses of the spatial overlap in seal consumption and fishery catch indicated that for both ASL and LNFS, there was a tendency for there to be a spatial mismatch between areas of intensive seal foraging and commercial catch. This is particularly noticeable in the upper gulfs which are regions of low consumption by seals, but high fishing effort.

Table 6.2. Summary of average annual fisheries catch and estimated annual consumption of these species by Australian Sea Lions (ASL) and Long-nosed Fur Seals (LNFS). Percentages refer to the average annual catch for the fisheries, and to the percentage of the estimated annual consumption for ASL and for age classes of LNFS. Estimates do not take into account the degree of spatial overlap between catch and consumption. Age classes of LNFS are adult female (AF), adult male (AM), subadult male (SAM) and juvenile (JUV).

			LNFS prey consumption (t/y)				
Key fished taxa/prey	**Average fisheries catch (t/y)**	**ASL prey consumption (t/y)**	**AF**	**AM**	**SAM**	**JUV**	**Total LNFS (t/y)**
Garfish	257 (0.7%)	45 (0.2%)	238 (0.5%)	75 (0.4%)	190 (1.1%)	215 (0.7%)	718 (0.6%)
King George Whiting	317 (0.8%)				1.7 (0%)		1.7 (0%)
Snapper	679 (1.8%)						
Southern calamari	361 (0.9%)	770 (3.6%)	35 (0.1%)	23 (0.1%)	554 (3.3%)	21 (0.1%)	633 (0.6%)
Sardine	30,698 (80.7%)	7 (0%)	545 (1.1%)	67 (0.4%)	95 (0.6%)	3 (0%)	710 (0.6%)
Southern Rock Lobster	1,748 (4.6%)	65 (0.3%)					
Western King Prawn	2,197 (5.8%)	245 (1.1%)					
Blue Crab	598 (1.6%)	15 (0.1%)					
Other	1,178 (3.1%)	20,483 (94.7%)	48,714 (98.3%)	17,659 (99.1%)	15,788 (94.9%)	29,669 (99.2%)	111,830 (98.2%)
Total catch/consumption	38,033	21,634	49,532	17,824	16,629	29,908	113,893

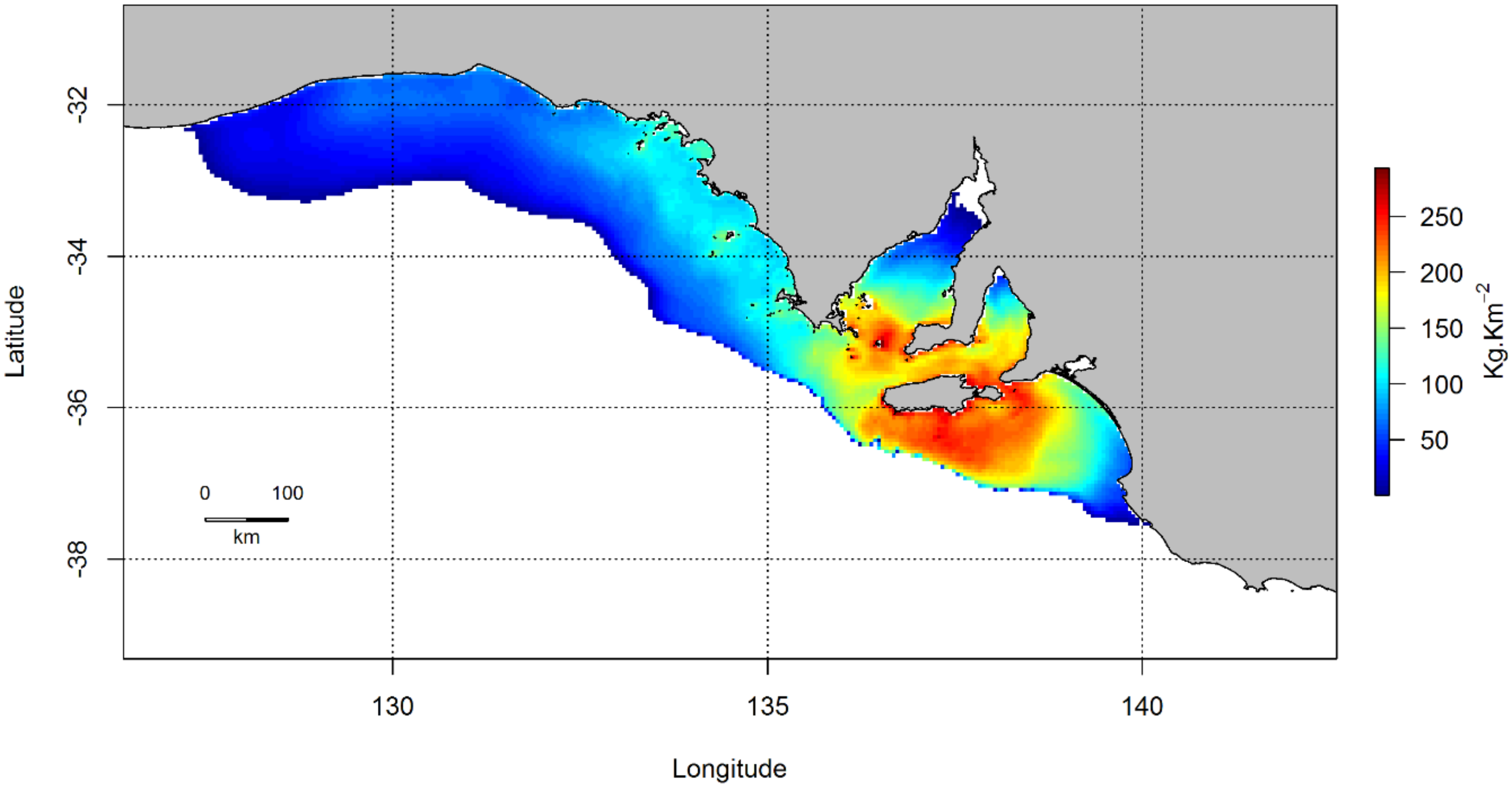


Figure 6.1. Spatial distribution of the total annual consumption of Australian Sea Lions in the eastern GAB. Warmer colours indicate a higher consumption in kg.km^{-2}.

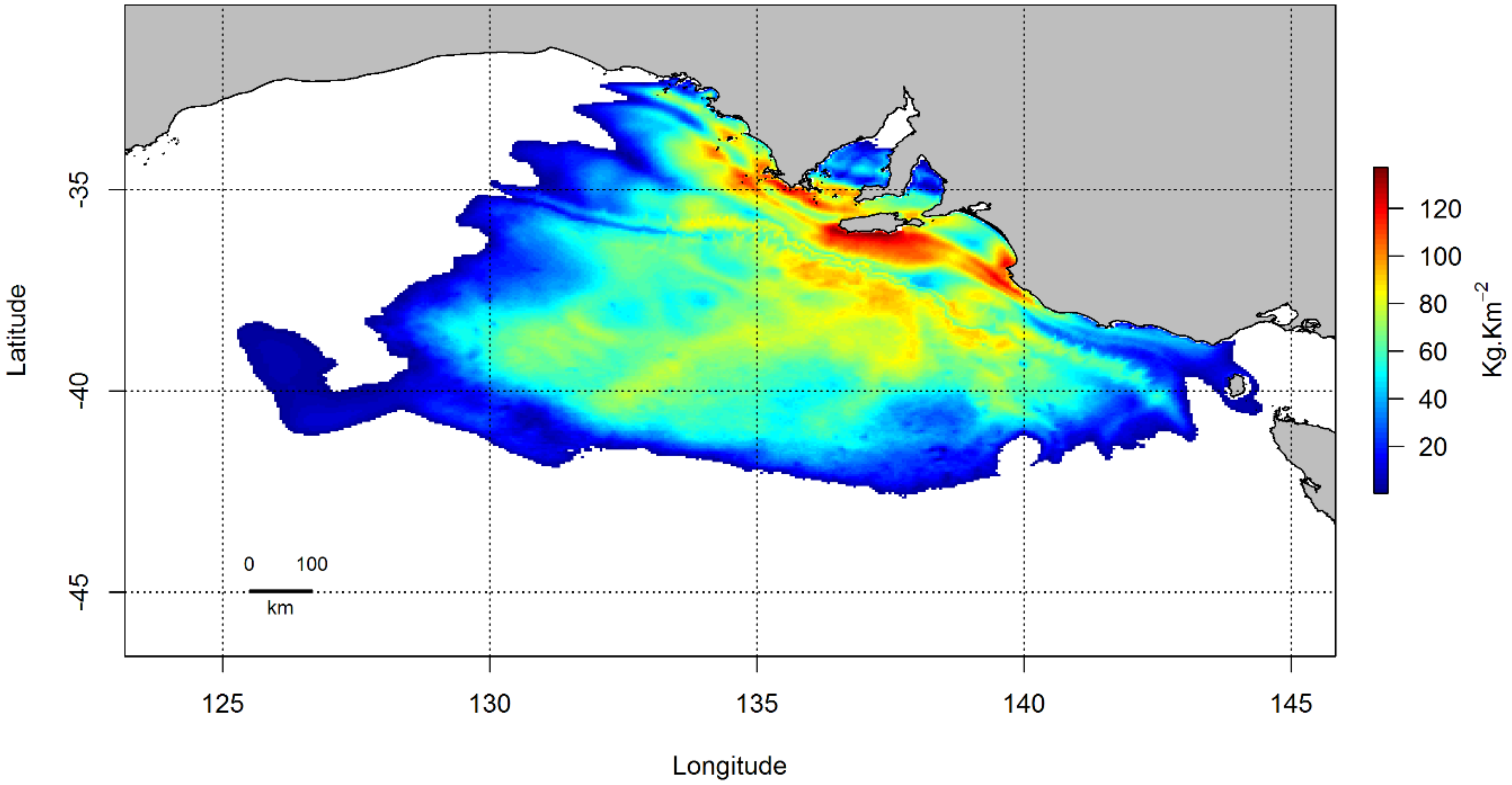


Figure 6.2. Spatial distribution of the total annual consumption of the all the age classes of Long-nosed Fur Seals in the eastern GAB. Warmer colours indicate a higher consumption in kg.km^{-2}.

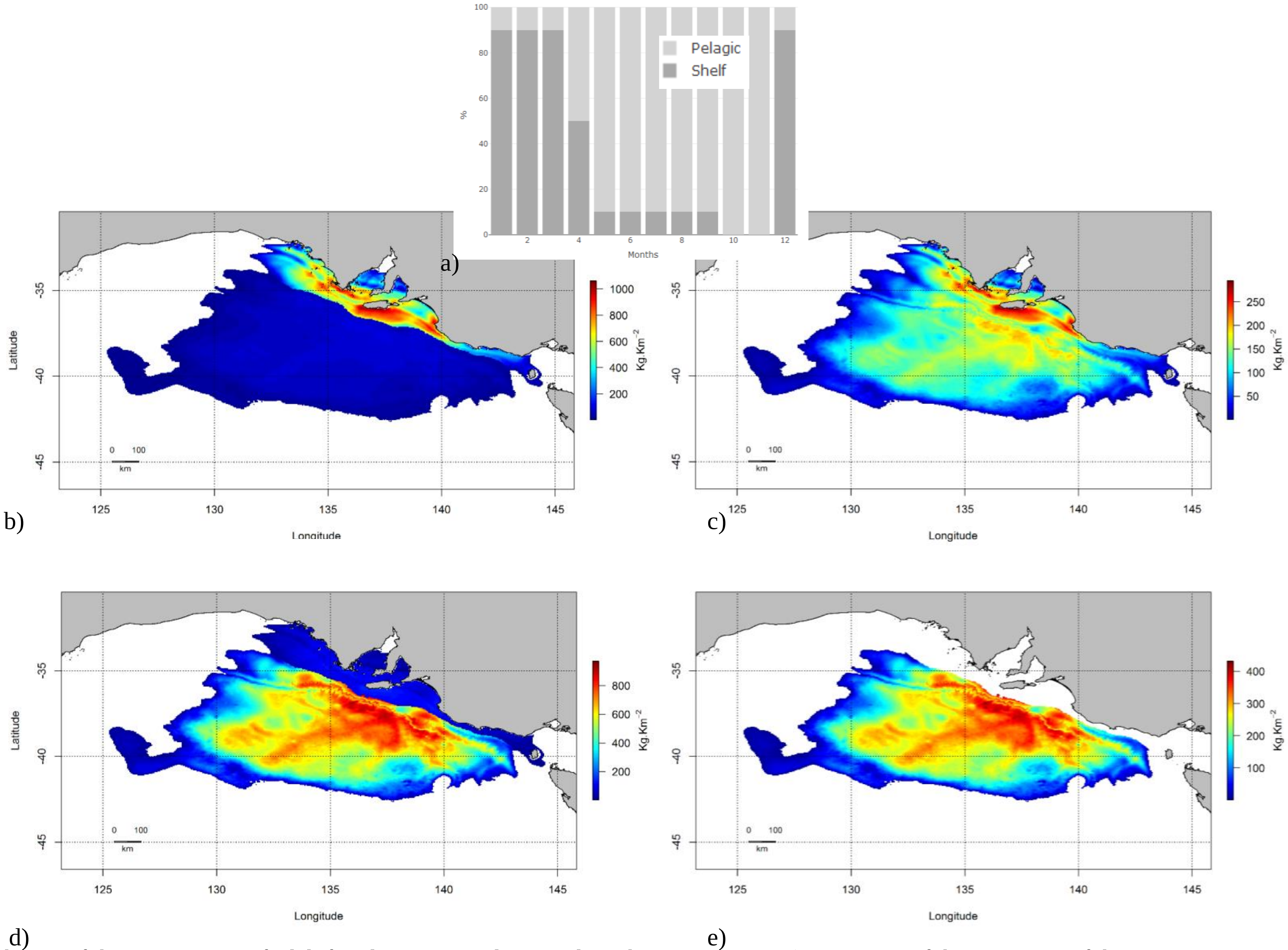


Figure 6.3. Spatial distribution of the consumption of adult female Long-nosed Fur Seals in the eastern GAB. a) Estimation of the proportion of the consumption occurring over the shelf per month. b) Spatial distribution of consumption in December-March. c) Spatial distribution of consumption in April. d) Spatial distribution of consumption in May-September. e) Spatial distribution of consumption in October-November. Warmer colours indicate a higher consumption in kg.km^{-2}.

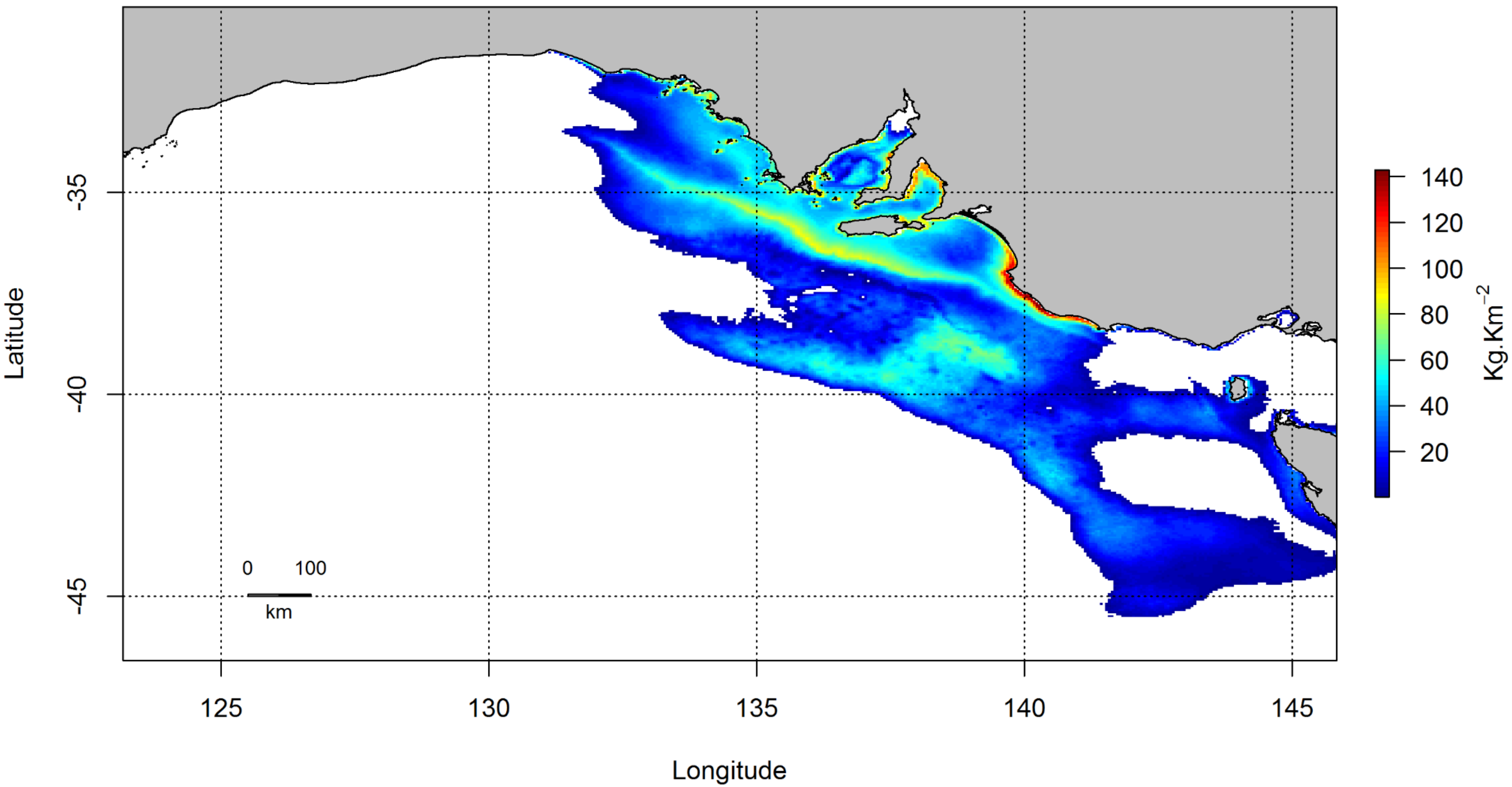


Figure 6.4. Spatial distribution of the total annual consumption of adult male Long-nosed Fur Seals in the EGAB. Warmer colours indicate a higher consumption in kg.km^{-2}.

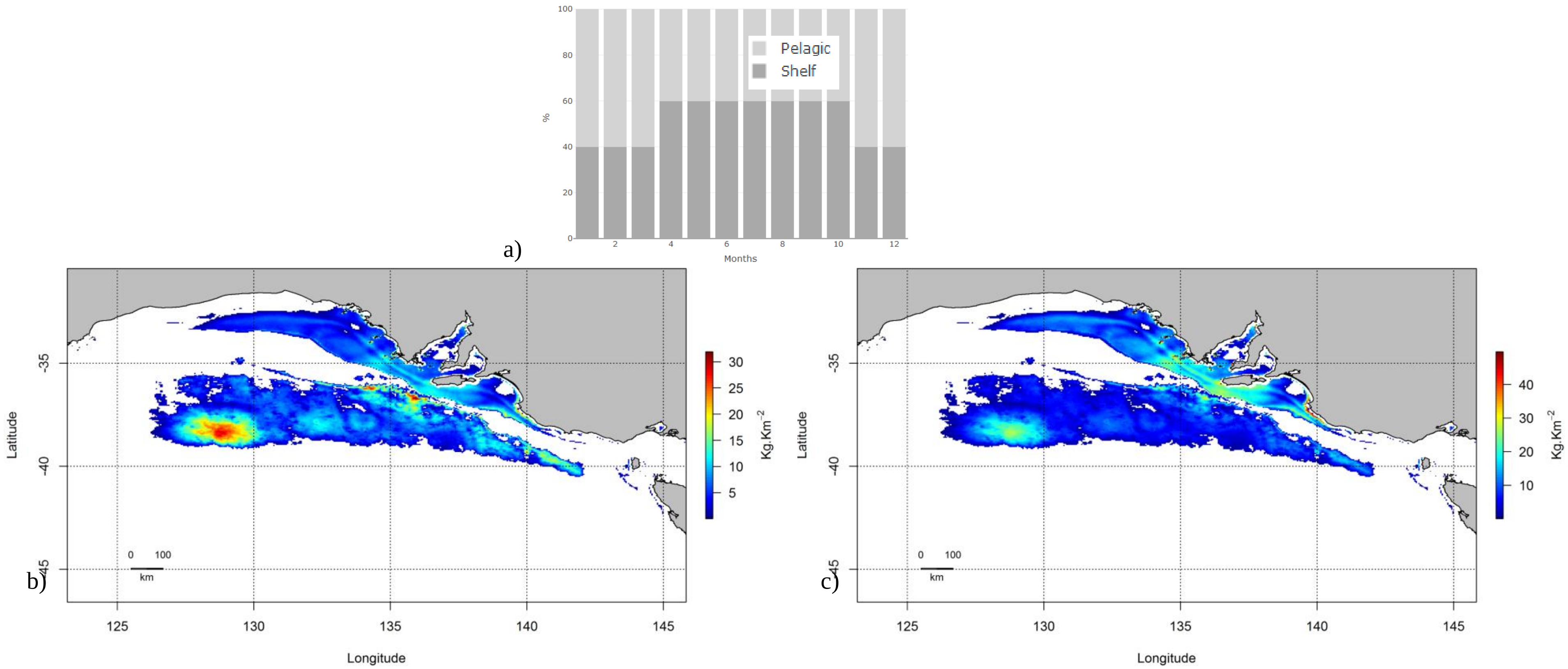
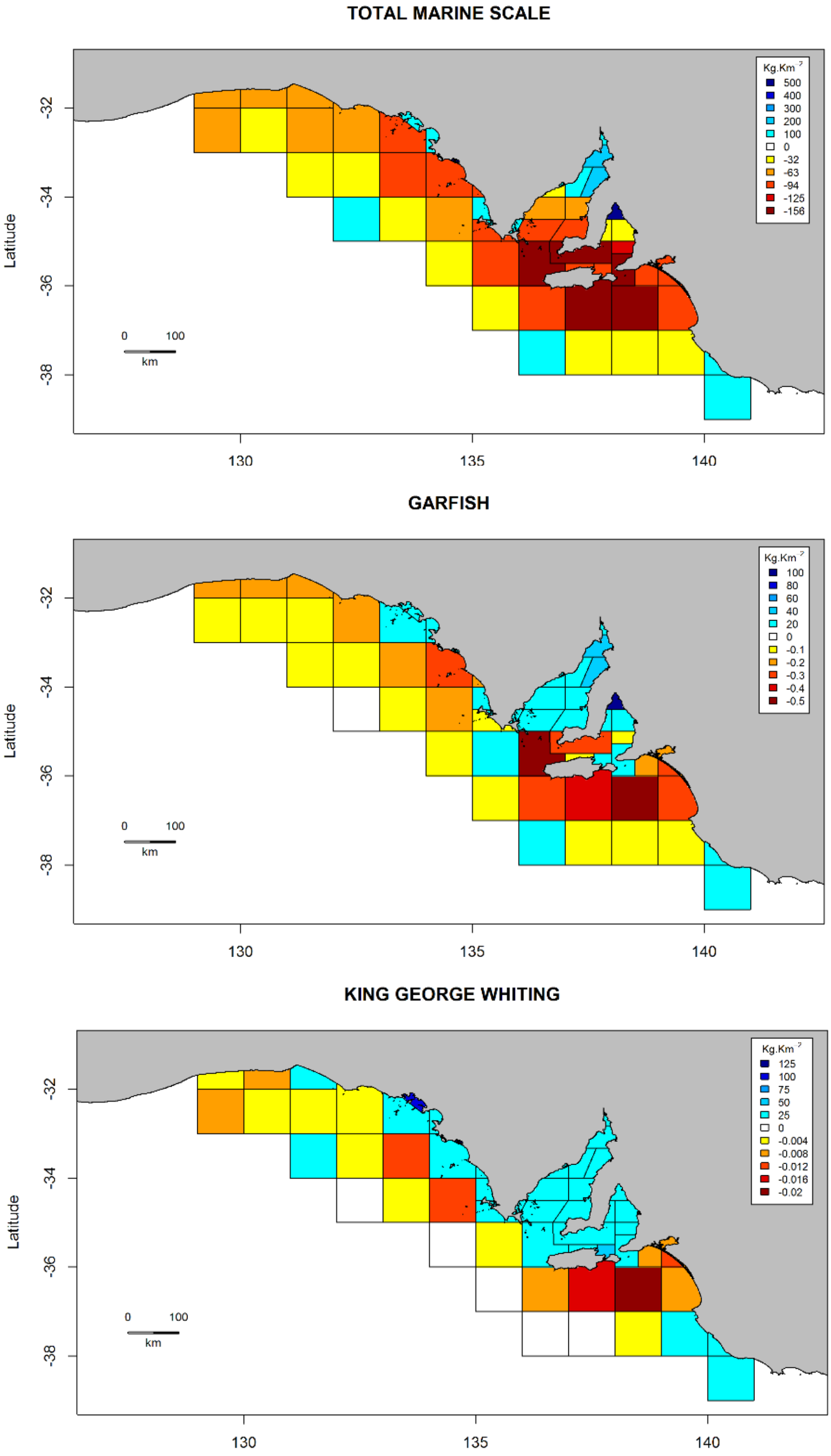


Figure 6.5. Spatial distribution of the consumption of subadult male Long-nosed Fur Seals in the eastern GAB. a) Estimation of the proportion of the consumption occurring over the shelf per month. b) Spatial distribution of consumption in November-March. c) Spatial distribution of consumption in April-October. Warmer colours indicate a higher consumption in kg.km^{-2}.


TOTAL MARINE SCALE

GARFISH

KING GEORGE WHITING

Figure 6.6. Spatial overlap in averaged annual fishery catch and Australian Sea Lion (ASL) total annual consumption. Blue scale colours indicate that fishery catch exceeds take by ASL. Other colours (yellow to red) indicate that ASL take more than the fishery catch. Values are presented in kg.km^{-2}.

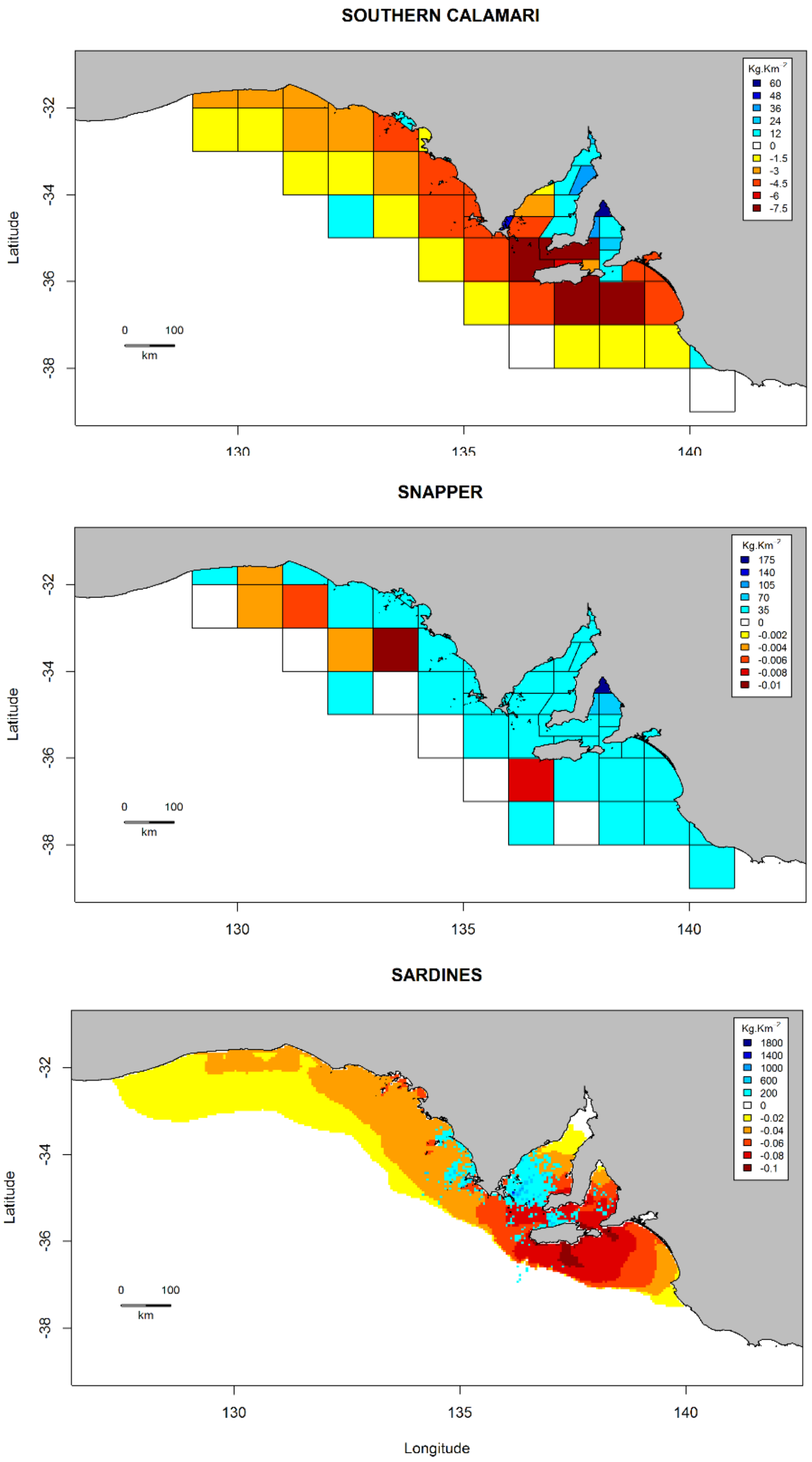


Figure 6.6 cont. Spatial overlap in averaged annual fishery catch and Australian Sea Lion (ASL) total annual consumption. Blue scale colours indicate that fishery catch exceeds take by ASL. Other colours (yellow to red)indicate that ASL take more than the fishery catch. Values are presented in kg.km^{-2}.

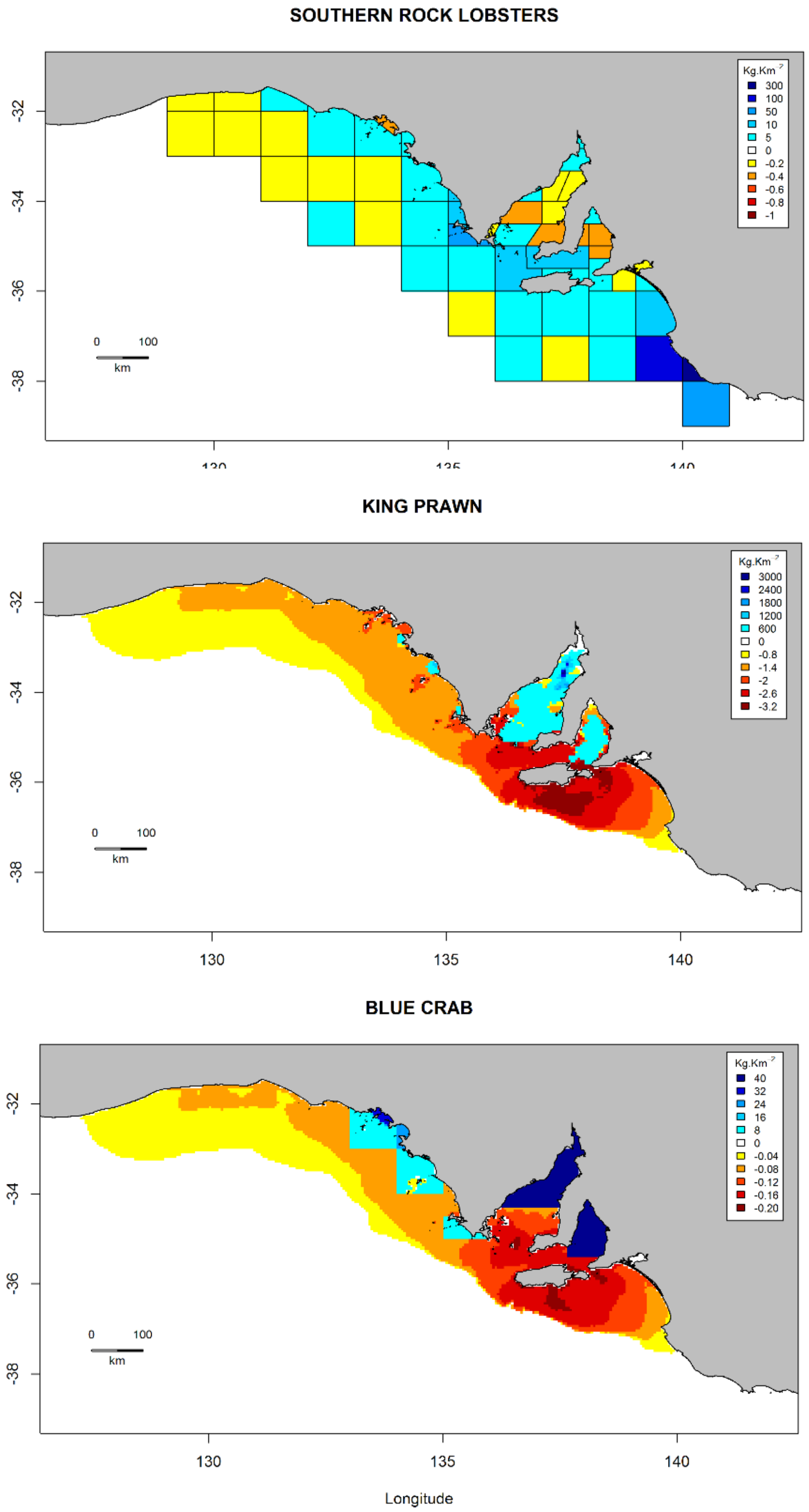


Figure 6.6 cont. Spatial overlap in averaged annual fishery catch and Australian Sea Lion (ASL) total annual consumption. Blue scale colours indicate that fishery catch exceeds take by ASL. Other colours (yellow to red) indicate that ASL take more than the fishery catch. Values are presented in kg.km^{-2}.

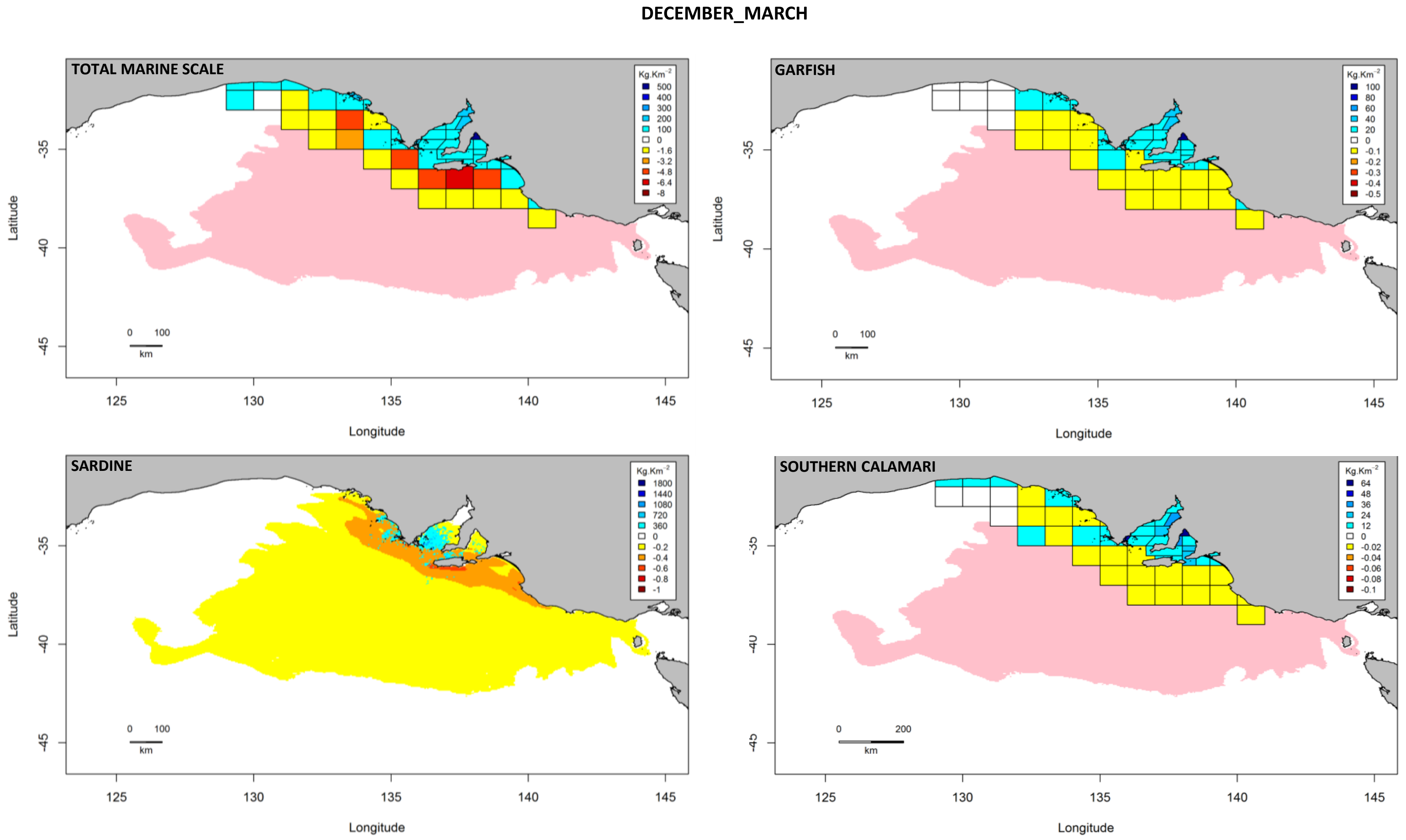


Figure 6.7. Spatial overlap in averaged annual fishery catch and adult female Long-nosed Fur Seal consumption from December to March. Blue scale colours indicate that the fishery catch exceeds consumption by LNFS. Other colours (yellow to red) indicate that LNFS take more than the fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of adult females beyond the MFAs.

APRIL

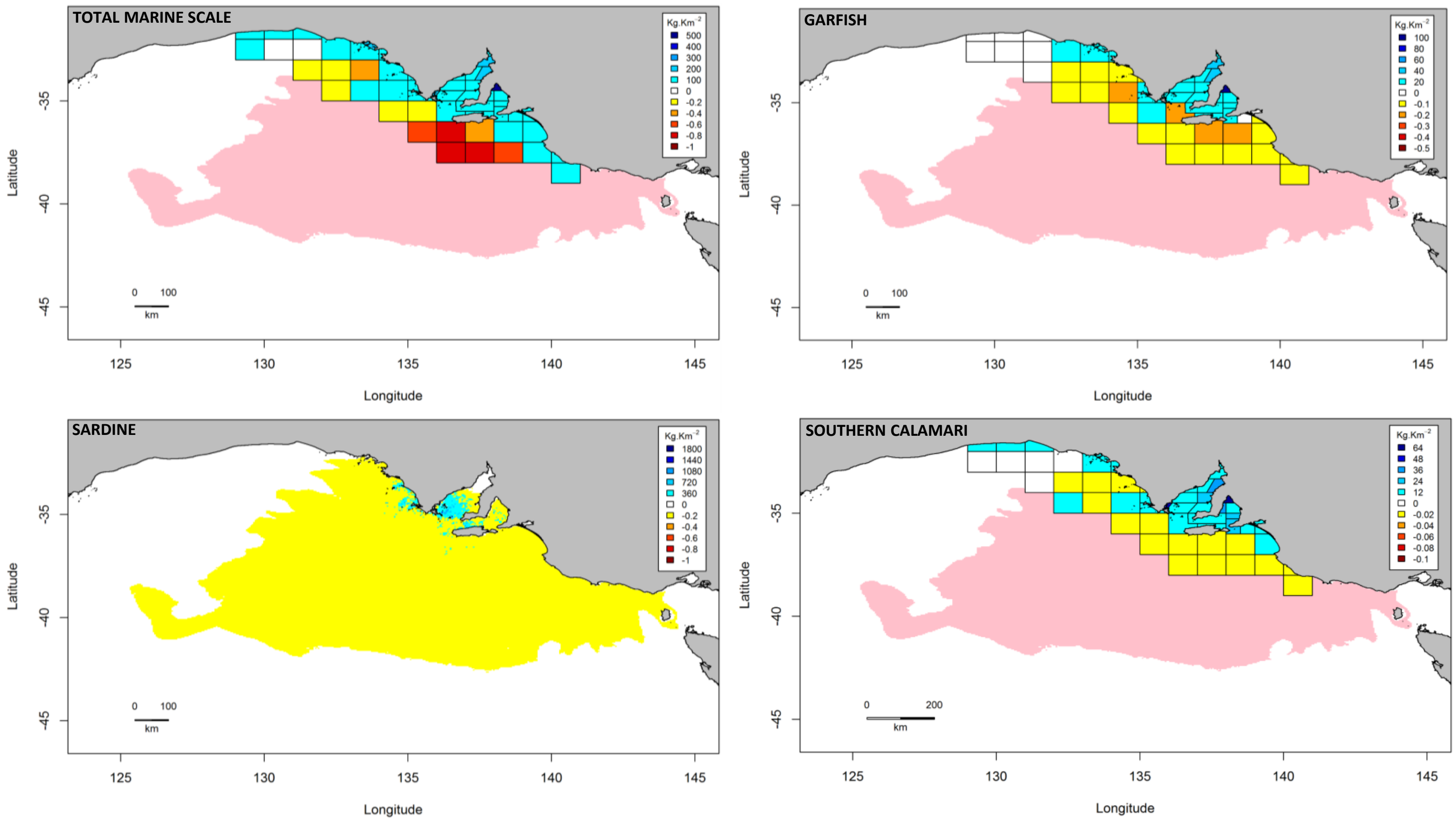


Figure 6.8. Spatial overlap in averaged annual fishery catch and adult female Long-nosed Fur Seal (LNFS) consumption in April. Blue scale colours indicate that fishery catch exceeds take by LNFS. Other colours (yellow to red) indicate that LNFStake more than the fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of adult females beyond the MFAs.

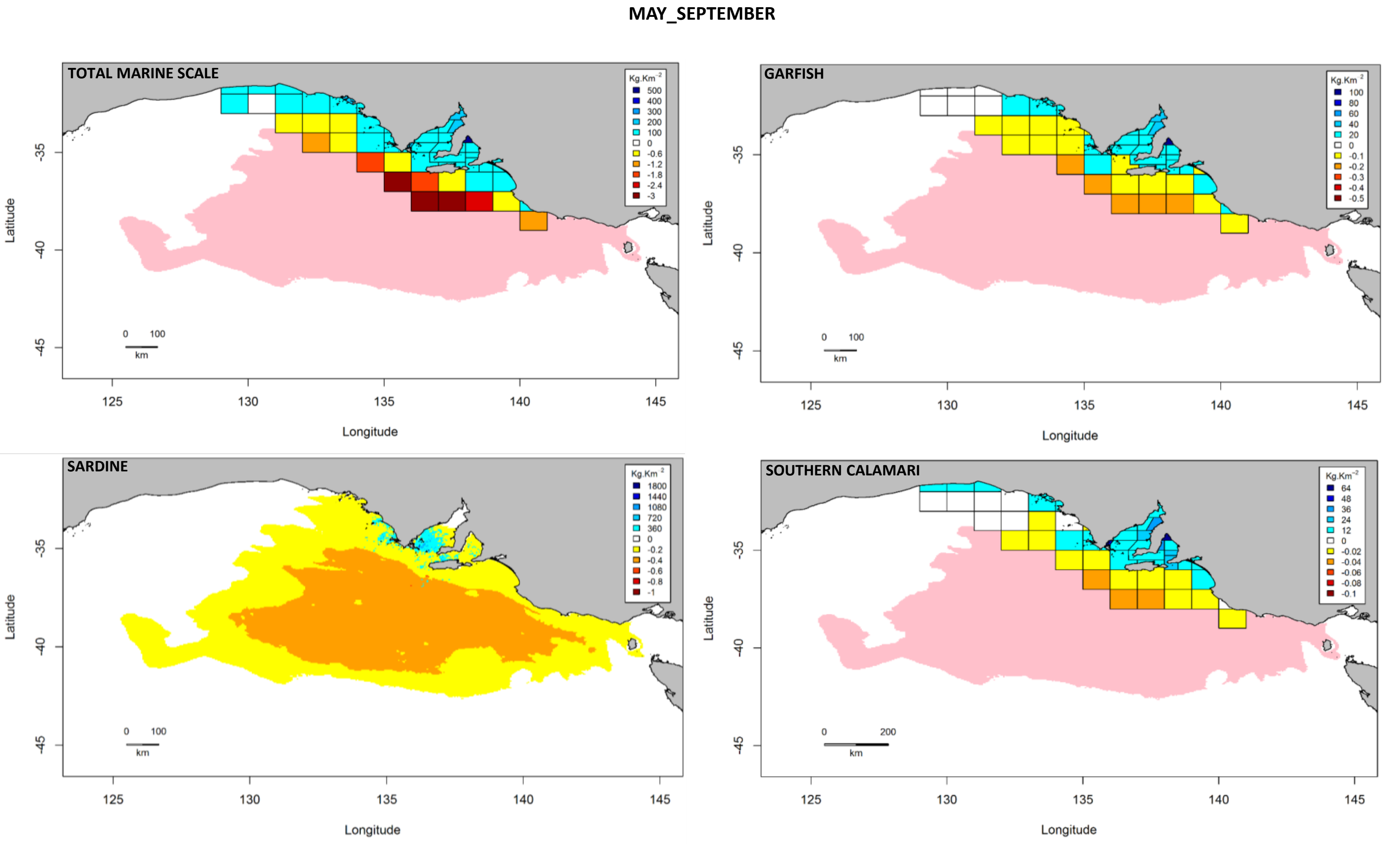


Figure 6.9. Spatial overlap in averaged annual fishery catch and adult female Long-nosed Fur Seal (LNFS)consumption from May to September. Blue scale colours indicate that fishery catch exceeds take by LNFS. Other colours (yellow to red) indicate that LNFS take more than the fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of adult females beyond the MFAs.

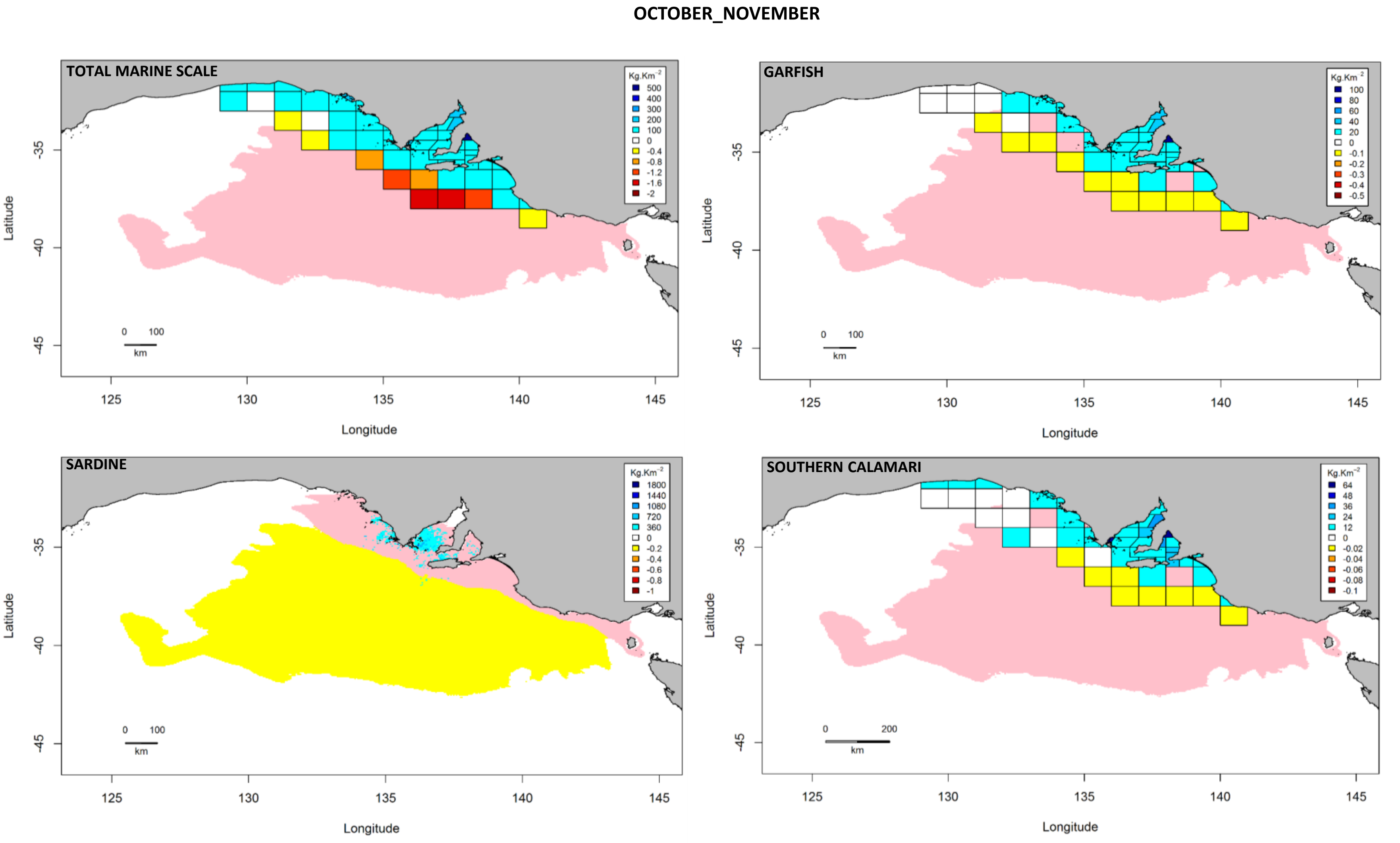


Figure 6.10. Spatial overlap in averaged annual fishery catch and adult female Long-nosed Fur Seal (LNFS) consumption in October-November. Blue scale colours indicate that fishery catch exceeds take by LNFS. Other colours (yellow to red) indicate that LNFS take more than fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of adult females beyond the MFAs.

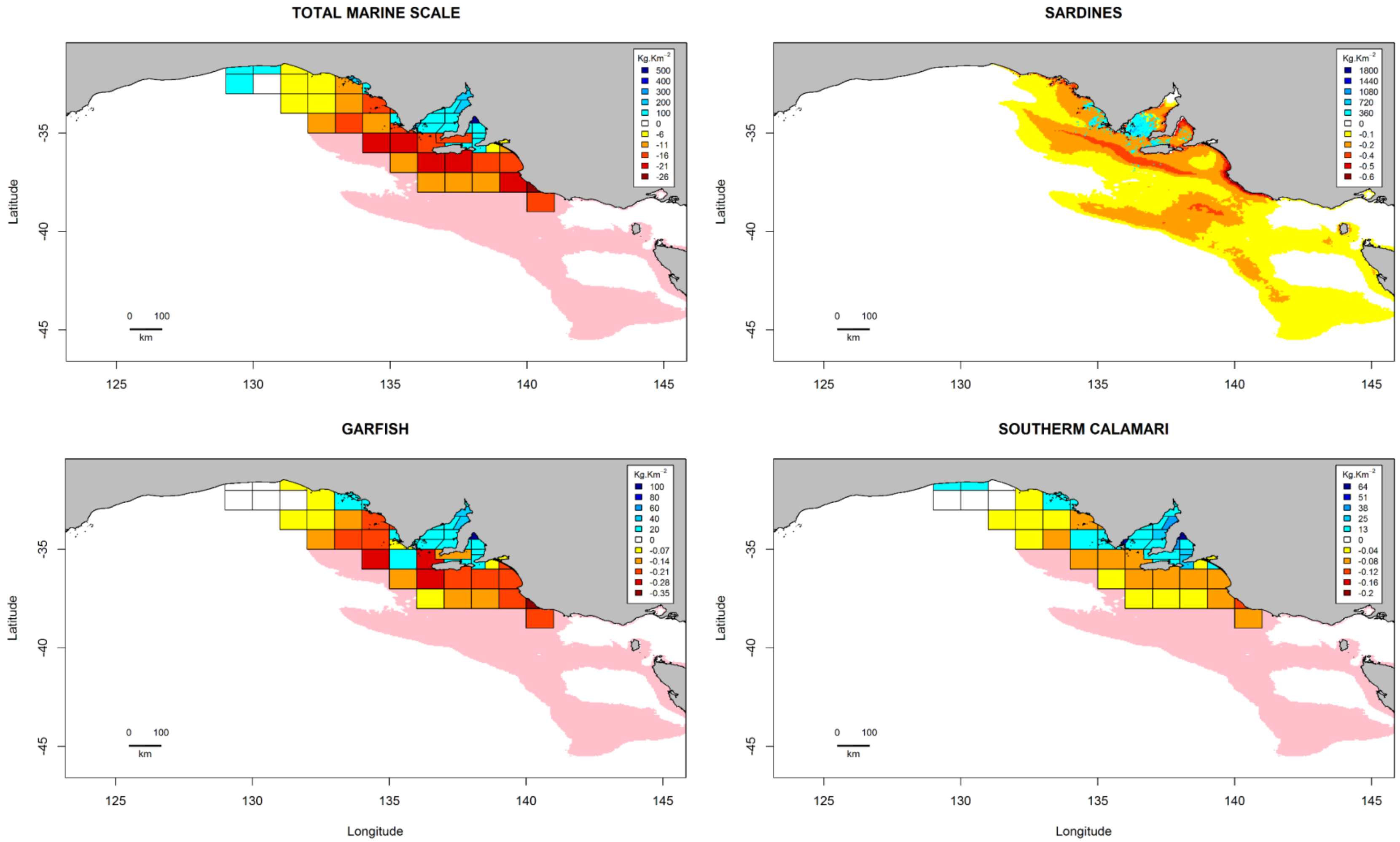


Figure 6.11. Spatial overlap in averaged annual fishery catch and adult male Long-nosed Fur Seal (LNFS)total annual consumption. Blue scale colours indicate that fishery catch exceeds take by LNFS. Other colours (yellow to red) indicate that LNFS take more than fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of adult males beyond the MFAs.

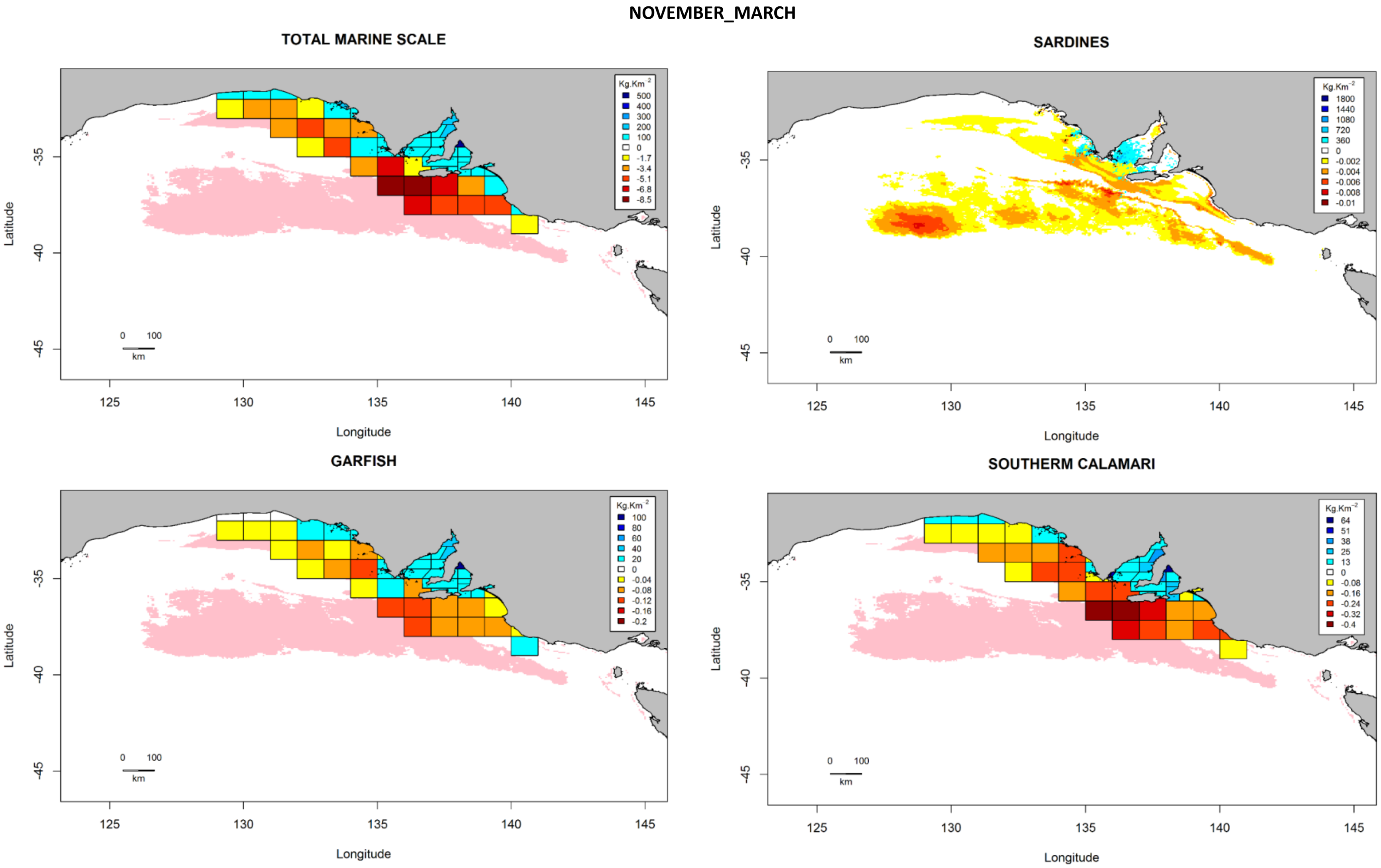


Figure 6.12. Spatial overlap in averaged annual fishery catch and subadult male Long-nosed Fur Seal (LNFS) consumption from November to March. Blue scale colours indicate that fishery catch exceeds take by LNFS. Other colours (yellow to red) indicate that LNFS take more than fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of subadult males beyond the MFAs.

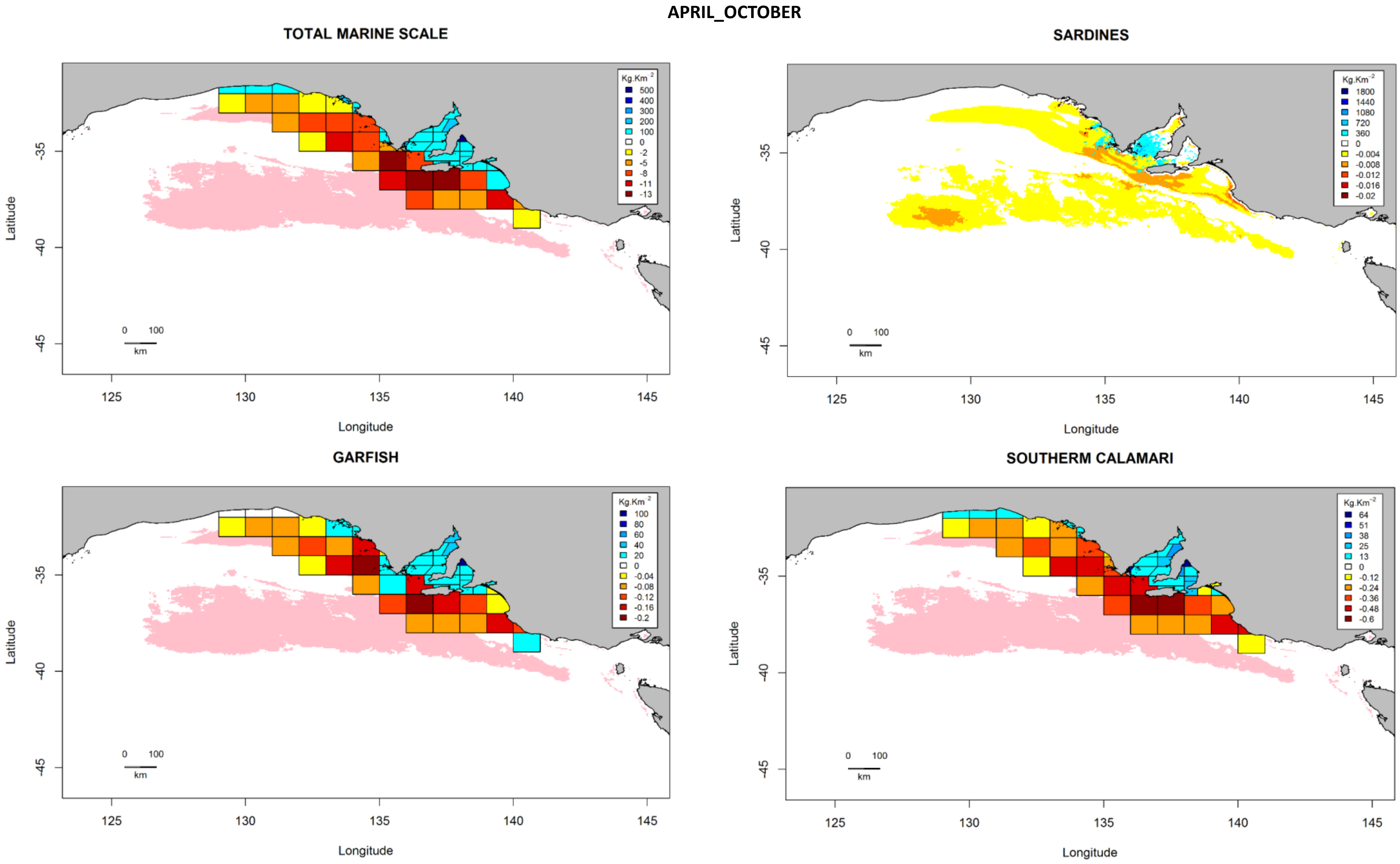
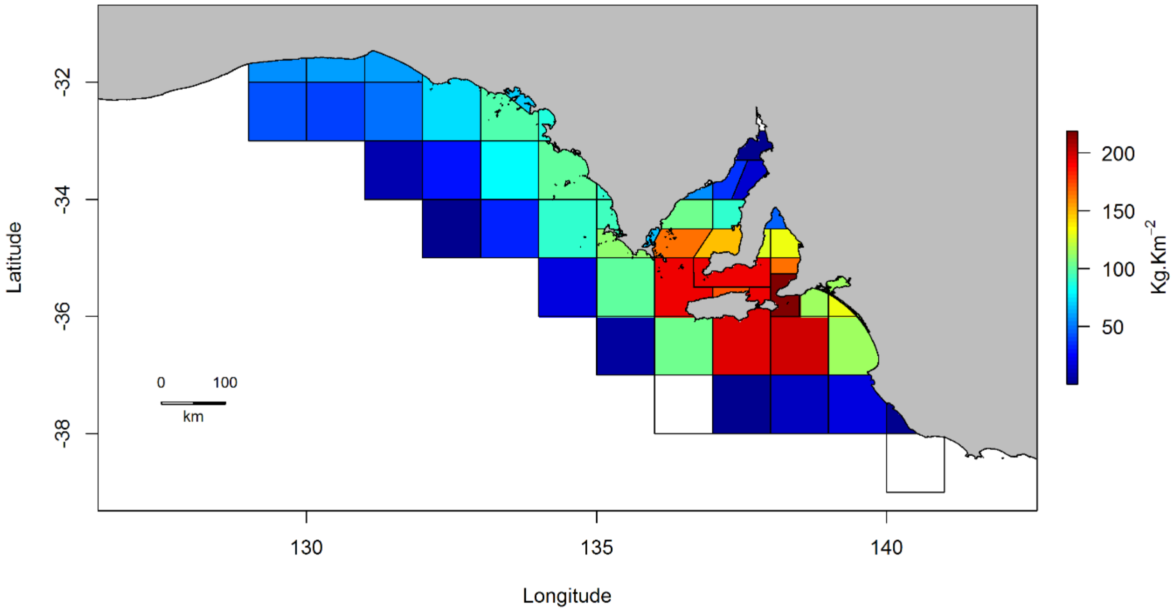


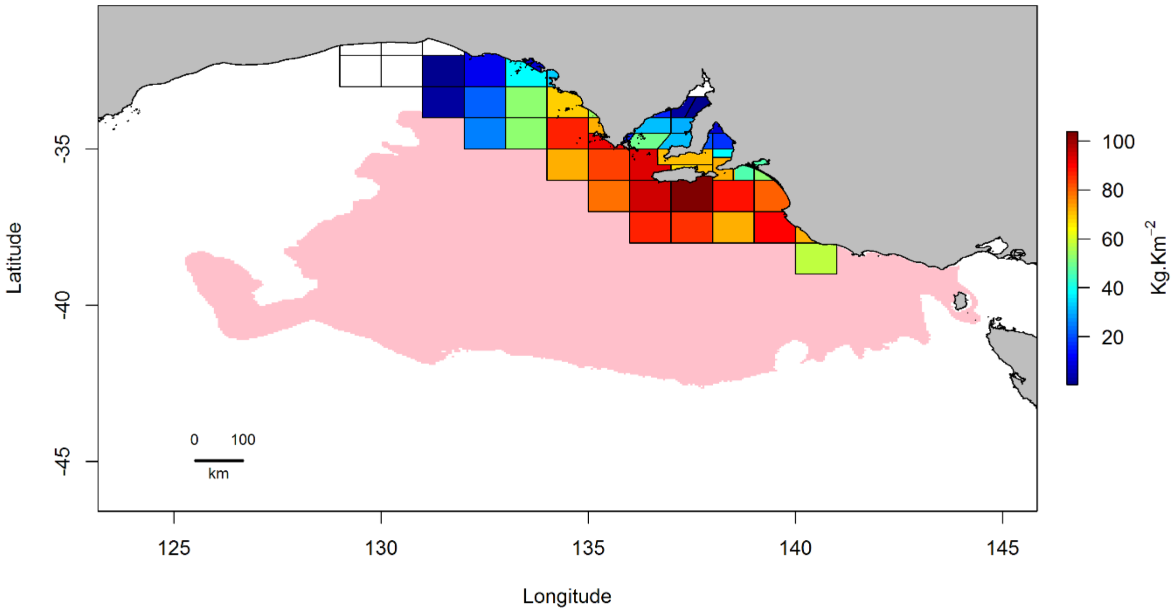
Figure 6.13. Spatial overlap in averaged annual fishery catch and subadult male Long-nosed Fur Seal (LNFS)consumption from April to October. Blue scale colours indicate that fishery catch exceeds take by LNFS. Other colours (yellow to red) indicate that LNFS take more than fishery catch. Values are presented in kg.km^{-2}. The pink area indicates the estimated foraging domain of subadult males beyond the MFAs.

Appendix 6.1. Distribution of seal consumption effort scaled to Marine Fishing Areas in South Australia

The distribution of foraging effort and consumption by Australian Sea Lions) and Long-nosed Fur Seals (LNFS) are scaled to match the Marine Fishing Areas (MFAs) in South Australia. For LNFS, the age classes and time periods are indicated for each map. Warmer colours indicate higher consumption in kg.km^{-2}.

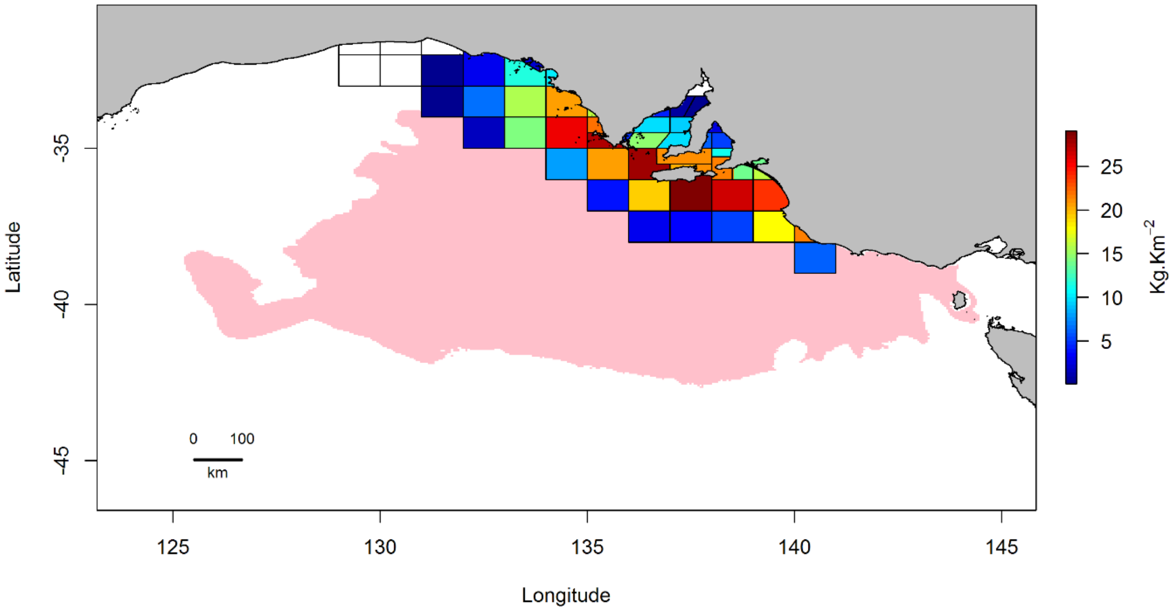


Appendix 6.1, Figure 1. Distribution of foraging and consumption effort by Australian Sea Lions.

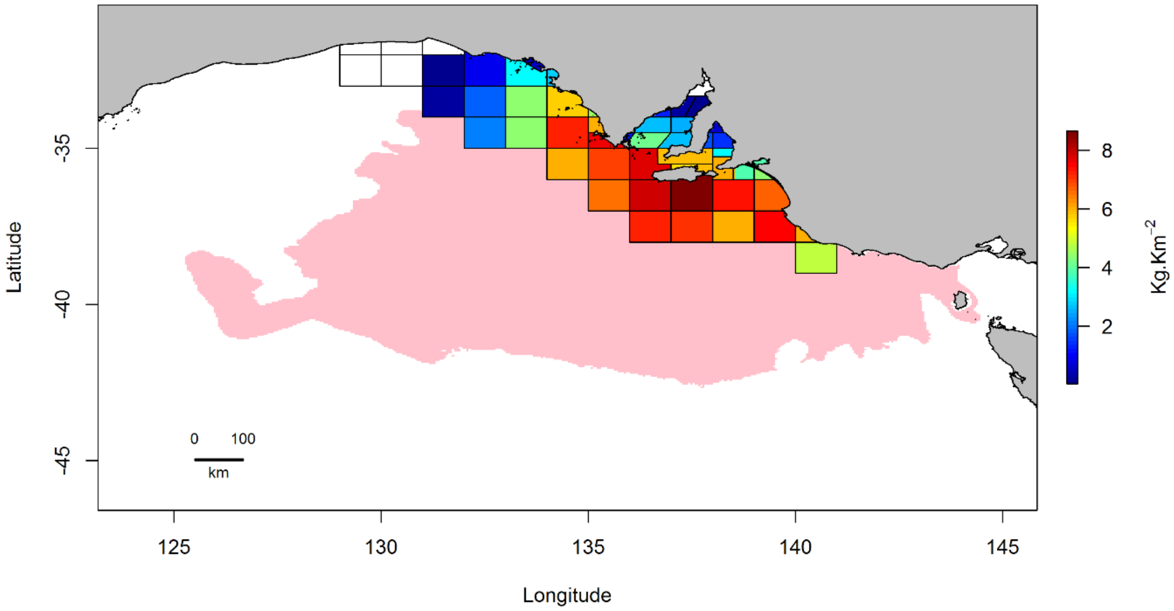


Appendix 6.1, Figure 2. Distribution of foraging and consumption effort by Long-nosed Fur Sealss,

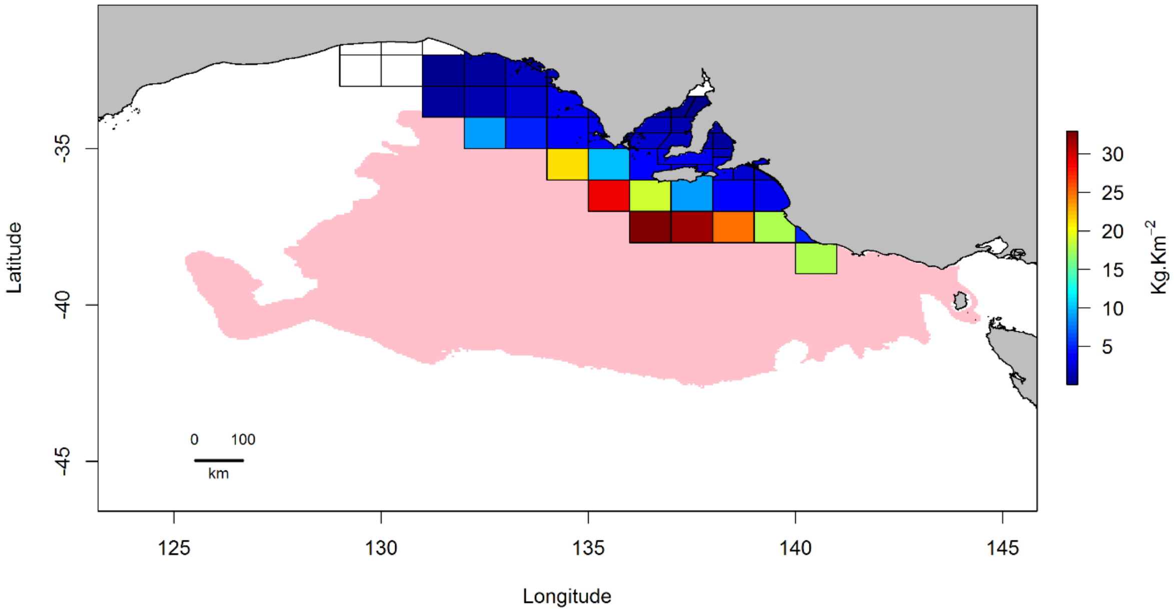
year-round and for all age and sex classes. The pink area indicates the estimated foraging domain beyond the MFAs.



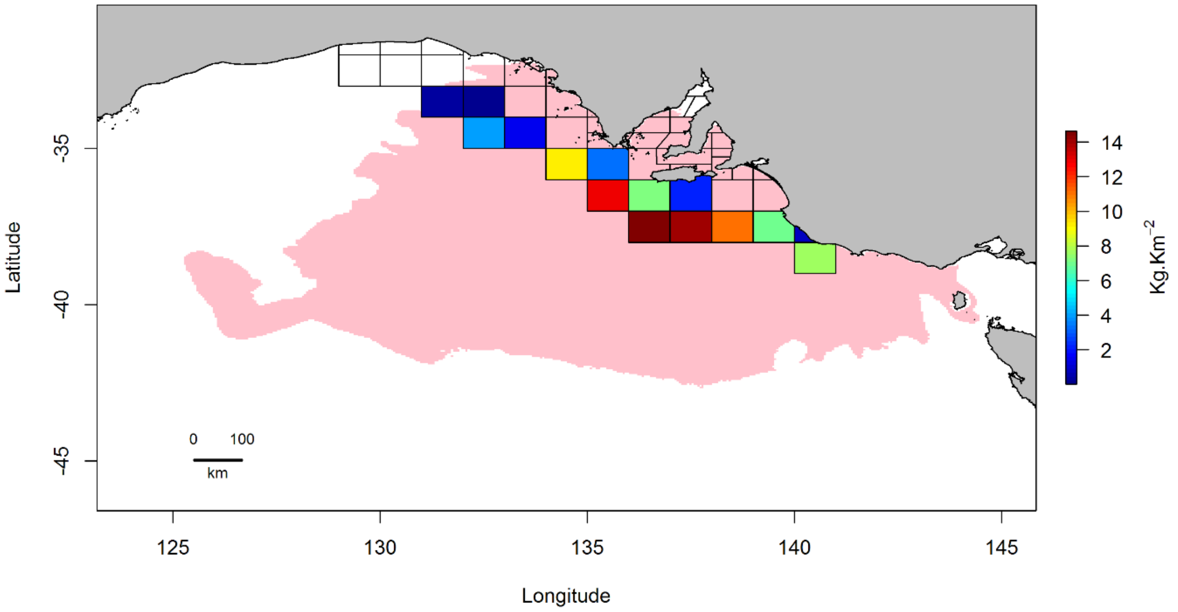
Appendix 6.1, Figure 3. Distribution of foraging and consumption effort by adult female Long-nosed Fur Seals from December to March. The pink area indicates the estimated foraging domain beyond the MFAs.



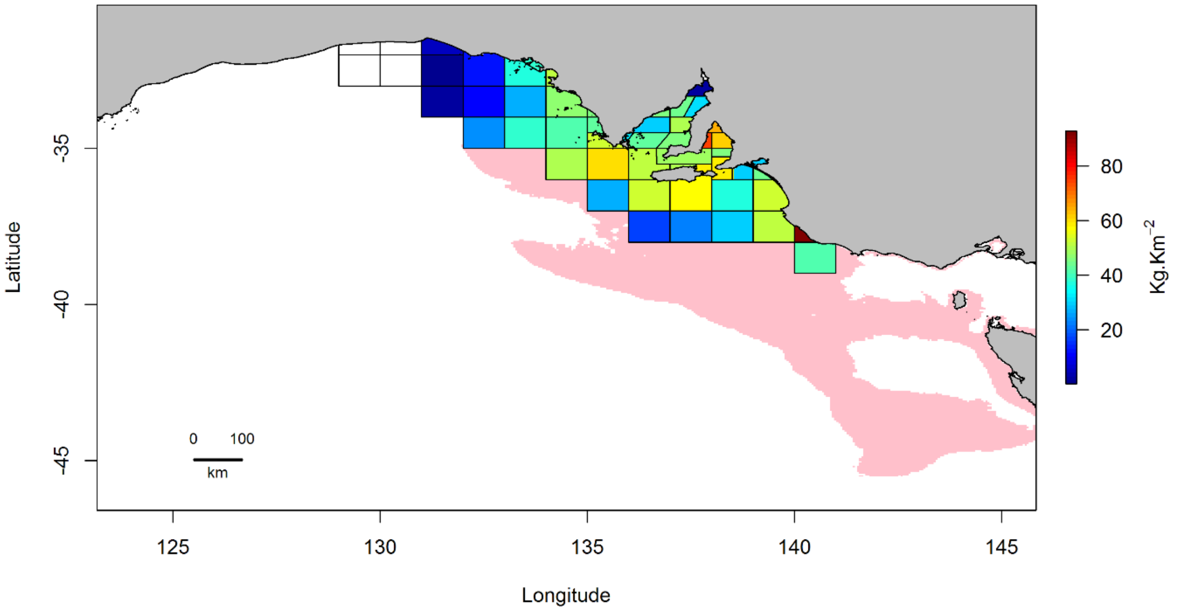
Appendix 6.1, Figure 4. Distribution of foraging and consumption effort by adult female Long-nosed Fur Seals in April. The pink area indicates the estimated foraging domain beyond the MFAs.



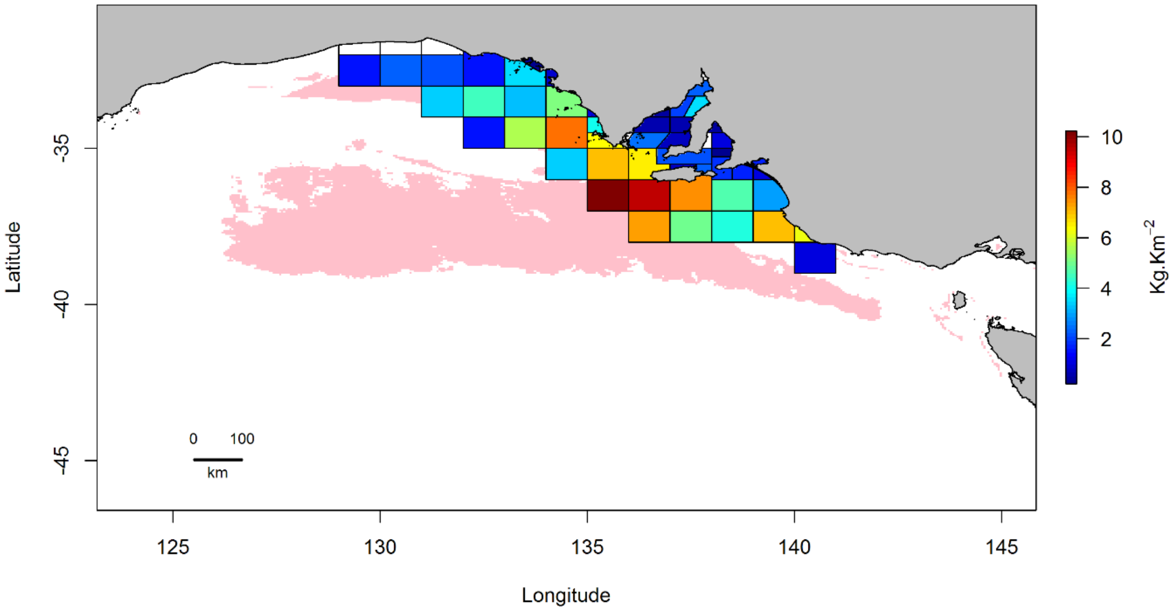
Appendix 6.1, Figure 5. Distribution of foraging and consumption effort by adult female Long-nosed Fur Seals between May and September. The pink area indicates the estimated foraging domain beyond the MFAs.



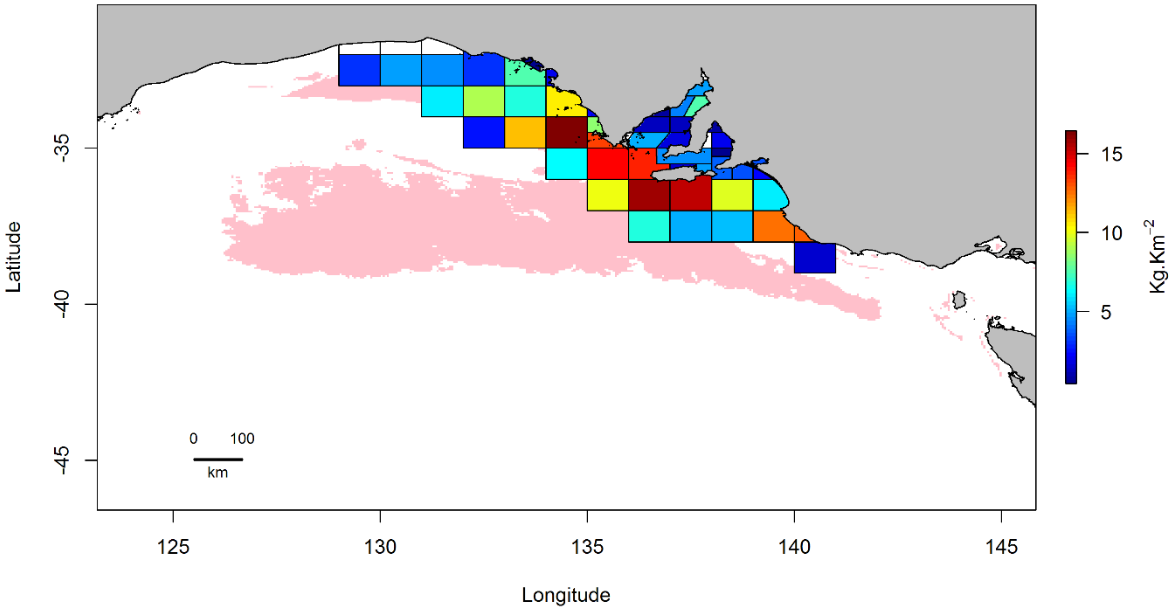
Appendix 6.1, Figure 6. Distribution of foraging and consumption effort by adult female Long-nosed Fur Seals during October and November. The pink area indicates the estimated foraging domain beyond the MFAs.



Appendix 6.1, Figure 7. Distribution of foraging and consumption effort by adult male Long-nosed Fur Seals over the whole year. The pink area indicates the estimated foraging domain beyond the MFAs.

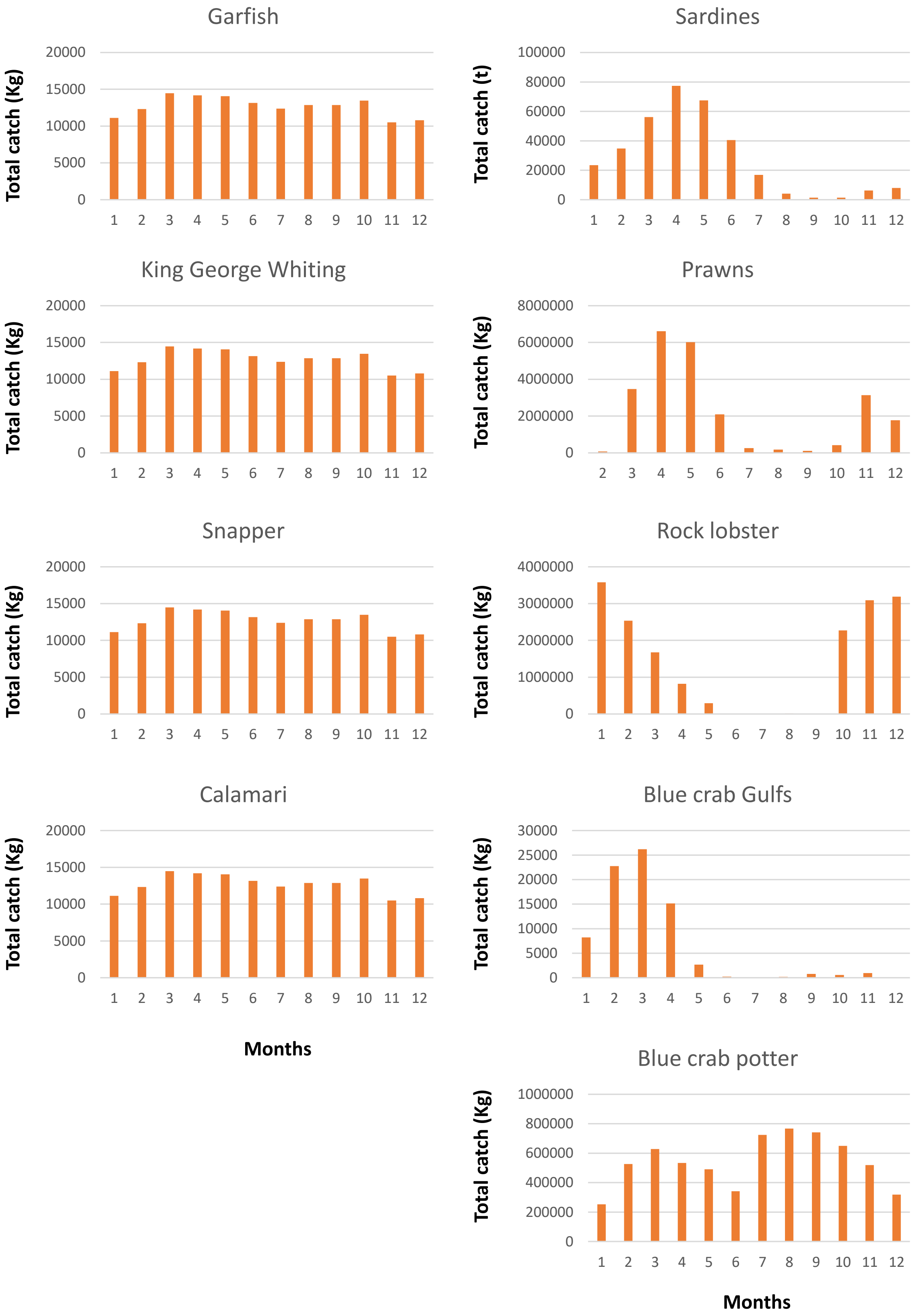


Appendix 6.1, Figure 8. Distribution of foraging and consumption effort by subadult male Long-nosed Fur Seals between November and March. The pink area indicates the estimated foraging domain beyond the MFAs.

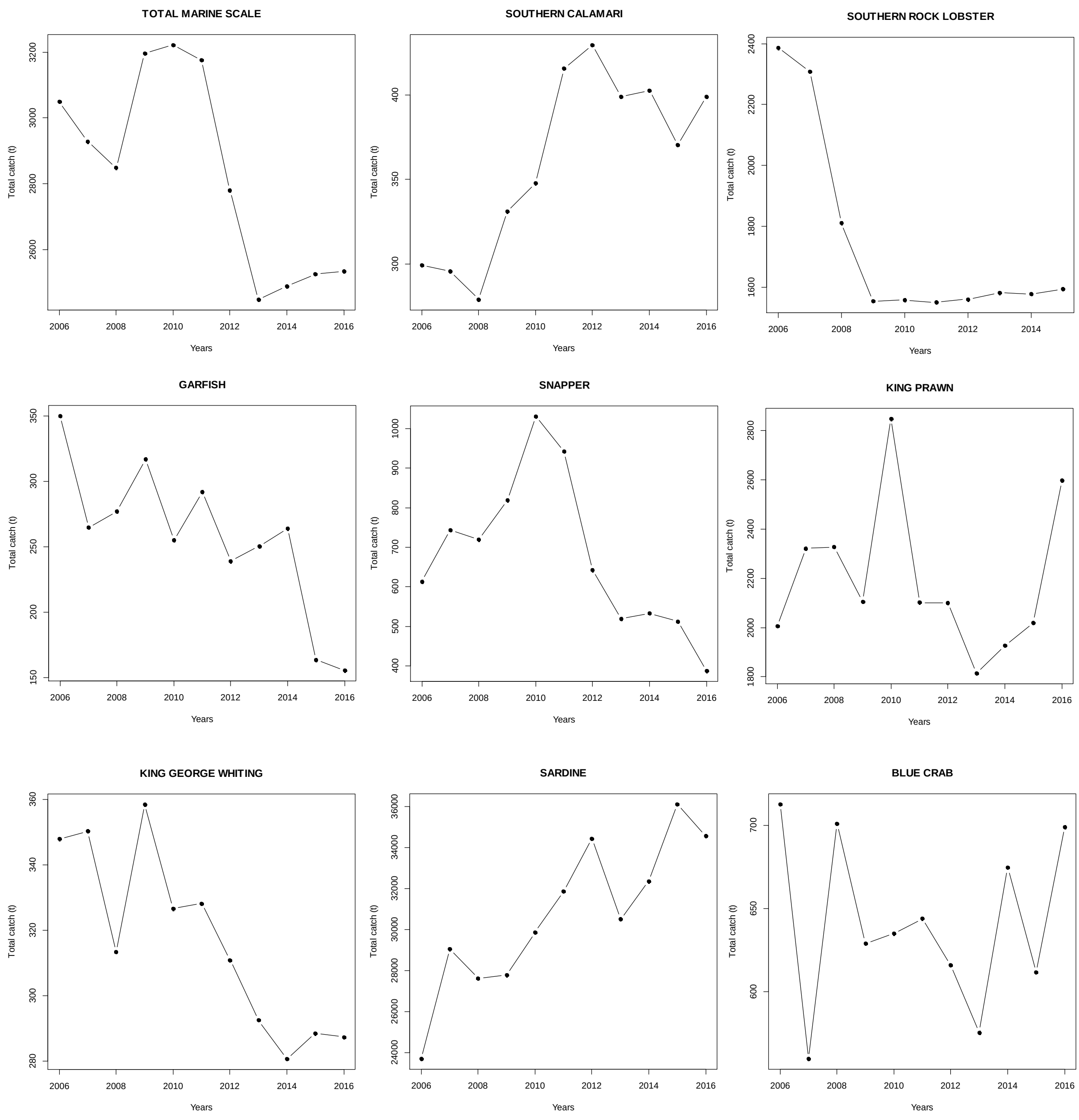


Appendix 6.1, Figure 9. Distribution of foraging and consumption effort by subadult male Long-nosed Fur Sealsbetween April and October. The pink area indicates the estimated foraging domain beyond the MFAs.

Appendix 6.2. Monthly variation in commercial fishery catches in South Australia between 2006 and 2016



Appendix 6.3. Temporal variation in total annual commercial fishery catches in South Australia between 2006 and 2016



7. Ecological modelling to assess the impacts of seals on marine ecosystems and fish production in South Australia

Simon Goldsworthy

7.1 Introduction

The aim of this Chapter was to use the Ecopath and Ecosim (EwE) trophic modelling tools to evaluate the impacts of consumption by seals, and to determine the implications of increasing seal populations on the future biomass of commercially and recreationally important marine taxa, and on the seafood and marine ecotourism industries. The seal species considered are Australian Sea Lions (ASL, *Neophoca cinerea*), Long-nosed Fur Seals (LNFS, *Arctocephalus forsteri*) and Australian Fur Seals (*A. pusillus doriferus*).

To achieve these aims, the approach taken here was to:

1. Synthesise all available data on the diets of seals in South Australia, including all historic data and new data obtained as part of this study (Chapters 3 and 4).

2. Use the full synthesis of dietary information, coupled with the most recent data available on the status and trends in abundance of seals in South Australia, to update two trophodynamic models developed for the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystems.

3. Modify the models to include multiple stanzas (juvenile and adult age-classes) for key fished species as well as for long-nosed fur seals (LNFS) so that trophic interactions can be better resolved.

4. Use the modified SG and GSV ecosystem models to:

- evaluate the importance of consumption by seals in the marine ecosystems relative to other marine predators, especially the importance of their consumption on finfish, cephalopods, crustaceans and commercially fished species;
- evaluate the sensitivity of key marine taxa to changes in LNFS and ASL biomass; and
- run scenarios to assess the potential impacts of changing biomasses of seals on the biomasses of commercially fished species and other key functional groups or species.

7.2 Methods

Spencer Gulf and Gulf St Vincent Ecopath with Ecosim models

Two recently developed Ecopath with Ecosim models for SG GSV were used as a basis to explore the trophic interactions between seal populations and commercially/recreationally valuable species in South Australia. Details on the model development and underpinning data sets are provided in Gillanders *et al*. (2015) and Goldsworthy *et al*. (2017b). The model domain areas encompass both gulfs as well as Investigator Strait; these regions account for most of South Australia’s core commercial and recreational finfish fisheries (Figure 7.1). Key modifications were made to these models to facilitate their application to better resolve and understand the trophic interactions and potential impacts of seals on South Australian marine ecosystems. The main modifications were the integration of new data on seal diets and the addition of multi-stanza groups for key seal and fished species. Details on the methodological basis to these respective modifications are provided in the following sections.

Seal dietary synthesis

All available dietary data on each of the three seal species resident in South Australia (ASL, LNFS and AFS) were compiled and synthesised (see Table 7.1 for a list of data sources). Almost all of these dietary estimations are based on indirect methods, given the difficulty in directly observing what seals eat in the wild (Bowen and Iverson 2013). Dietary data largely come from the analysis of prey hard parts and prey DNA recovered from faecal (scat) samples. An additional source was direct observation from animal-borne cameras (crittercams) deployed on Australian sea lions (Fragnito 2013). The most common data sets are from the analysis of prey hard parts recovered from faeces (scat samples), and in some instances regurgitates. The principal items recovered include fish otoliths and cephalopod beaks, which unless substantially eroded through the digestion process, can be identified to species level and allow the estimation of the size and age of the prey. Such data are commonly used to reconstruct the original biomass of prey items consumed. DNA based methods have developed markedly in recent years. In these approaches, prey DNA are extracted from faecal samples using specific polymerase chain reaction (PCR) primers to amplify DNA from one or more prey or prey groups (e.g., fish, cephalopods, crustacean). This is followed by either the cloning and sequencing of amplicons to identify individual taxa, or by using next generation sequencing (NGS) with DNA barcoding methods in combination with reference sequence databases (see Chapter 3, Pompanon *et al.* 2012).

Hard-part analyses typically calculate three measures of prey importance, the percentage frequency of occurrence (*%F*: percentage of samples containing a given prey taxa), the percentage frequency by number (*%N*: percentage of total prey items made up of a given prey taxa), and the percentage biomass contribution (*%B*). The last is estimated using regression equations from published information and from relationships between otolith and cephalopod beak measurements to fish and cephalopod mass, respectively. Most DNA based methods report prey species lists and/or frequency of occurrence (*%F*). Although the number of taxa specific sequence copies amplified could be considered the equivalent of frequency by number (*%N*), or potentially to biomass contribution (*%B*) if copy number was equivalent to the original quantity and biomass of prey DNA present in the sample, the rate of DNA degradation of different prey species (and tissues) during digestion, or the extent of degradation of prey DNA in scats in the environment prior to collection is invariably unknown.

There have been many reviews of the potential pitfalls and biases of the various dietary estimation and reconstruction methods (Bowen and Iverson 2013, Casper *et al.* 2007, Pompanon *et al.* 2012, Tollit *et al.* 2007, Tollit *et al.* 2006, Tollit *et al.* 1997, Tollit *et al.* 2009, Tollit *et al.* 2003). Key biases of hard-part analyses include inter-specific variability in digestibility of otoliths and cephalopod beaks. This leads to a biased representation of species with robust and larger otoliths/beaks, and under-representation of species not consumed entirely (e.g., larger fish eaten partially or where the head and otoliths are not consumed), or with no hard parts to be preserved (e.g., cartilaginous fishes including sharks, rays and skates). Furthermore, larger prey hard parts may be too large to pass through the digestive tract (e.g., larger cephalopod beaks) and may be differentially regurgitated relative to small prey hard parts (Gales and Cheal 1992, Kirkwood and Goldsworthy 2013). Although DNA methods typically provide a more comprehensive list of prey taxa, they may also identify more secondarily digested prey (i.e., prey items in the digestive tracts of the prey consumed), and they cannot provide a reliable estimate of the size of prey items consumed, which can be estimated from otoliths and cephalopod beaks. Finally, prey hard-parts and prey DNA obtained from scat samples usually represent the final meals consumed prior to the seal coming ashore at haul-out or breeding sites, and therefore may not be representatives of the diet of animals in their major foraging areas in the days or weeks preceding collection (Bowen and Iverson 2013). As all methods are subject to biases that can be extremely difficult to quantify, it is important to use complimentary methods (Bowen and Iverson 2013).

The key objective of the integration and synthesis of available seal diet data was to provide an estimate of the relative importance, and specifically the biomass contribution, of the various prey taxa consumed. These data are critical for integration into ecological models, and provide the basis for assessments of the impact of seal consumption on key commercially fished taxa and on the broader marine ecosystem. However, as a best approach has not been determined for combining and integrating such disparate dietary data, a method appropriate to the available data and seal taxa had to be developed.

The approach taken here was to use compound indices that enable the incorporation of all measures of prey occurrence by number, frequency and biomass. A widely used compound index using these measures is the index of relative importance (IRI, Pinkas *et al.* 1971),

$$IRI = \%F(\%N + \%B).$$

This can be expressed as a percentage, following Cortés (1997),

$$\%IRI = 100 \times \ IRI_i \div \sum_{i=1}^{n} IRI_i,$$

where IRI_i is the index of relative importance for prey item i, and n is the total number of prey taxa enumerated in the study. Our assumption is that IRI provides an index of the relative biomass and/or nutritional contribution of prey taxa. However, as few studies enumerate all three dietary measures ($\%F$, $\%N$, $\%B$) that are needed to calculate $\%IRI$, a method had to be developed to estimate missing measures when only some of them were available.

The first step was to reconcile difference in the value of $\%F$ calculated from prey hard parts ($\%F_{HP}$) and from prey DNA ($\%F_{DNA}$). Comparison of faecal hard part (HP) and faecal DNA analysis methods to enumerate prey items were undertaken on 37 randomly selected LNFS scats collected across 11 sites in South Australia in which estimates for all three dietary measures ($\%F$, $\%N$, $\%B$) of important prey taxa were available (as detailed in Chapter 4). A combined 90 prey taxa were identified using both methods, with 28% (25) detected by HP (6% by hard-parts only) and 94% (85) detected by DNA (72% by DNA only). Only 22% (20) of prey taxa were detected using both HP and DNA methods. Prey taxa that were detected using both HP and DNA methods had higher $\%F$ (18.8%), relative to those taxa only detected by HP (2.7%) or DNA (5.5%) methods, suggesting that commonly consumed prey taxa are more readily detected using either method, while uncommon prey taxa are more likely to be detected by only one method. Exceptions to this were Australian Herring, Barracouta and Giant Cuttlefish ($\%F_{DNA}$ = 18.9), Southern Dumpling Squid ($\%F_{DNA}$ = 16.2), Shorthead Eelworm ($\%F_{DNA}$ = 13.5) and Silverbelly and Blue Warehou ($\%F_{DNA}$ = 10.8). In samples where both $\%F_{HP}$ and $\%F_{DNA}$ estimates were available, the mean ratio of $\%F_{HP} : \%F_{DNA}$ was 1:3.12. Applying a multiplication factor of 2.90 to $\%F_{HP}$ values reduced the mean differences between $\%F_{HP}$ and $\%F_{DNA}$ to zero, and as such, was applied to all $\%F_{HP}$ estimates. Where both $\%F_{HP}$ and $\%F_{DNA}$ estimates were available, the mean $\%F$ for the prey taxa was estimated to be:

$$\%F = (\%F_{HP} \ \times 2.9 + \ \%F_{DNA})/2.$$

Where only the $\%F_{DNA}$ term was available, it was used as the overall $\%F$ estimate.

The second step was to estimate the $\%N + \%B$ term of the IRI equation when only an estimate of $\%F$ was available. Analyses of the same 37 LNFS scat samples (above and see Chapter 4) where estimates of $\%F_{DNA}$, $\%N$, and $\%B$ were available, determined a mean ratio of ($\%N + \%B$): $\%F_{DNA}$ to be 1:0.557. Therefore, in instances where only a $\%F_{DNA}$ was known, the value of the (%N + %B) term of the IRI equation was estimated to be $\%F_{DNA}$ x 0.45. Similar analysis for circumstances where only $\%F_{HP}$ was known, produced a mean ratio of ($\%N + \%B$): $\%F_{HP}$ of 1:1.41, and hence the ($\%N + \%B$) term was estimated to be $\%F_{HP}$ x 1.42.

Figure 7.1. Area of the Spencer Gulf and Gulf St Vincent (GSV) EwE model domains.

Table 7.1. Sources of dietary data on pinniped species (LNFS = Long-nosed Fur Seal, ASL = Australian Sea Lion, AFS = Australian Fur Seal) in South Australia used in the dietary synthesis and analysis. HP = hard part analysis; AF = adult female, AM = adult male, Sam = subadult male, JUV = juvenile; FOO = frequency of occurrence, NA = numerical abundance; BIO = biomass estimation.

Species	Data Type	Region	Sites (samples)	Age class (samples)	Year of study	FOO	NA	BIO	Source
LNFS	HP	South Coast Kangaroo Is	Cape Gantheaume (1147)	AM(476); AF(459); Juv (212)	2001-2003	Yes	Yes	Yes	Page et al. (2005)
LNFS	HP	South Coast Kangaroo Is	Cape Gantheaume (366)	AM (137); AF(186); JUV(43)	2004	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	South Coast Kangaroo Is	Cape du Couedic (136)	AF (136)	2004	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	South Coast Kangaroo Is	Cape Gantheaume (20)	AF (20)	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	South Coast Kangaroo Is	Cape du Couedic (20)	AF (20)	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	South Coast Kangaroo Is	Cape Kersaint (20)	SAM (20)	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	West Coast	Greenly Is (244)	SAM (66); AM (70)	2003-2004	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	West Coast	Four Hummocks (47)	AF (47)	2003	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	West Coast	Pearson Island (154)	SAM (154)	2003	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Donington Reef (136)	SAM (136)	2003,2006 &	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	North Islet (48)	AF & JUV (48)	2005	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Sibsey (10)	SAM (2)	2003	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Althorpe Is (109)	SAM (61)	2003-2004	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Liguanea Is (31)	SAM (31)	2003	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Neptune Is (614)	AM (223)	2003-2007	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Thistle Is (36)	JJUV & SAM (36)	2005	Yes	Yes	Yes	SARDI unpublished
LNFS	HP	Spencer Gulf	Donington Reef (32)	SAM (32)	2014	Yes	Yes	Yes	Chapter 4
LNFS	HP	North coast Kangaroo Is	Hummocky (20)	SAM (20)	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	North coast Kangaroo Is	Pissy Boy Rock (20)	SAM (20)	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	North coast Kangaroo Is	Ballast Head (20)	SAM	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	North coast Kangaroo Is	Kingscote (20)	SAM	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	North coast Kangaroo Is	Penneshaw (20)	SAM	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	Fleurieu Peninsula	Seal Is (20)	SAM	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	Fleurieu Peninsula	West Is (20)	SAM	2014	Yes	Yes	Yes	Reinhold (2015) and Chapter 4
LNFS	HP	Coorong	Tauwitcherie Barrage (64)	SAM	2015	Yes	Yes	Yes	Chapter 4
LNFS	DNA	SW Eyre	Rocky North (3)	Unknown	2014	Yes			Chapter 3
LNFS	DNA	Spencer Gulf	Liguanea Is (32)	Unknown	2014	Yes			Chapter 3
LNFS	DNA	Spencer Gulf	Donington Reef (2)	SAM	2014	Yes			Chapter 3
LNFS	DNA	Spencer Gulf	Donington Reef (20)	SAM	2016	Yes			Chapter 3
LNFS	DNA	North coast Kangaroo Is	Ballast Head (1)	SAM (1)	2014	Yes			Chapter 3
LNFS	DNA	North coast Kangaroo Is	Hummocky (4)	SAM (4)	2014	Yes			Chapter 3
LNFS	DNA	North coast Kangaroo Is	Kingscote (6)	SAM (6)	2014	Yes			Chapter 3
LNFS	DNA	North coast Kangaroo Is	Penneshaw (4)	SAM (4)	2014	Yes			Chapter 3
LNFS	DNA	South Coast Kangaroo Is	Cape du Couedic (1)	Unknown	2014	Yes			Chapter 3
LNFS	DNA	South Coast Kangaroo Is	Cape Gantheaume (7)	Unknown	2014	Yes			Chapter 3
LNFS	DNA	South Coast Kangaroo Is	Cape Kersaint (2)	Unknown	2014	Yes			Chapter 3
LNFS	DNA	South Coast Kangaroo Is	North Casuarina (1)	Unknown	2014	Yes			Chapter 3
LNFS	DNA	GSV	Outer Harbor (14)	SAM (14)	2015	Yes			Chapter 3
LNFS	DNA	Fleurieu Peninsula	Seal/Granite Is (4)	SAM (4)	2014	Yes			Chapter 3
LNFS	DNA	Fleurieu Peninsula	West Is (5)	SAM (5)	2014	Yes			Chapter 3
LNFS	DNA	The Coorong	Tauwitcherie Barrage (1)	SAM (1)	2015	Yes			Chapter 3
ASL	HP	South Coast KI	Seal Bay (20)	Unknown	2002-2005	Yes	Yes	Yes	McIntosh et al. (2007)
ASL	HP	South Coast KI	Seal Bay (176)	Unknown	2005-2007	Yes	Yes	Yes	Peters 2017
ASL	Crittercam	Spencer Gulf, West Coast	Lewis Is, Dangerous Reef, Lilliput Is	AF	2008-2012	Yes			Fragnito (2013)
ASL	DNA	South Coast KI, West Coast	Seal Bay (6), Lilliput (6)	AF	2006	Yes			Peters et al. 2015
ASL	DNA	South Coast KI	Seal Bay (6 seasons - 110 samples)	Unknown	2005-2007	Yes			Peters 2017
ASL	DNA	Nuyts Archipelago	Lilliput Is (2)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Nuyts Archipelago	Blefuscu Is (1)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Chain of Bays	Olive Is (1)	Unknown	2014	Yes			Chapter 3
ASL	DNA	SW Eyre	Rocky North Is (2)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Spencer Gulf	Liguanea Is (2)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Spencer Gulf	Albatross Is (2)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Spencer Gulf	Lewis Is (10)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Spencer Gulf	Donington Reef (9)	Unknown	2016	Yes			Chapter 3
ASL	DNA	Fleurie Peninsula/ Kangaroo Is	South Page Is (4)	Unknown	2014	Yes			Chapter 3
ASL	DNA	Fleurie Peninsula/ Kangaroo Is	North Page Is (3)	Unknown	2014	Yes			Chapter 3
AFS	HP	South Coast KI	Cape Gantheaume (128)	Unknown	2001-2002	Yes	Yes	Yes	Page et al. (2005)
AFS	DNA	South Coast KI	North Casuarina Is (7)	Unknown	2014	Yes			Chapter 3

The above synthesis approach was followed for each species to estimate overall diets. Where data sources enabled, regional estimates were also undertaken, the most relevant being for the SG and GSV regions, where regional estimates of diet were directly used for updating ecosystem models. Age-class specific assessments were only possible for LNFS by pooling data from sites and studies where the age-class source of scat samples could be determined (Table 7.1). The age-class and regional diet summaries were integrated to estimate the age-class specific diets for the SG and GSV regions. This process weighted the region (SG or GSV) and age-class (juvenile, subadult male, adult male and adult female) dietary components based on an estimate of the extent to which the regional diet reflected the age-class diet. For example, most of the scat samples collected at sites within SG and GSV are likely to have been derived from subadult and adult males, because these are the predominant age-classes observed at collection sites. Knowledge about the foraging ecology of different age-classes was also taken into account. As such, regional estimates of diet for SG and GSV were given a higher weighting (0.8) for subadult and adult males, relative age-class specific data (0.2), because it is known that most dietary data for these regions is derived from these age-classes. In contrast, dietary data for juveniles and adult females were weighted more heavily to age-class (0.8 ad 0.9, respectively) relative to regional data (0.2 and 0.1, respectively), because tracking and dietary data indicate most of their foraging takes place in outer shelf and oceanic waters, they are mostly restricted to breeding sites, and they are uncommon at haul-out sites in the SG and GSV regions.

Where seals predated on key fished species which were divided into juvenile and adult stanzas (see below), dietary proportions were allocated to juvenile and adult stanzas based on the size of prey items estimated in Chapter 4 (especially for Garfish).

Only LNFS and ASL dietary data were used to update the SG and GSV Ecopath with Ecosim models, as AFS were not considered to forage within either of these model domains (Figure 7.1).

Multi-stanza groups

Multi-stanza groups reflect different life history stages (stanzas) for species with complex trophic ontogenies, and their inclusion has been recognised as the most appropriate approach to understanding predator-prey interactions (Carl Walters, *in litt*), especially for top predators where inclusion of mutli-stanza groups makes their dynamics more realistic and provides insight into stock-recruitment relationships (EwE user guide). For the updated SG and GSV ecosystem models, multi-stanza groups were developed for LNFS and for key fished species including King George Whiting, Garfish, Snapper, Sardine, Western King Prawns, Blue Crabs and Calamari. Methodological development of multi-stanza models for each of these groups is detailed below.

The edit multi-stanza tool in Ecopath enables the user to set the parameters required to calculate the biomass and consumption within each age category. For each group, this includes an estimate of: the growth at age based on the von Bertalanffy growth rate parameter *k*; recruitment power (degree of density dependence in juvenile survival for juveniles outside the modelled area); the biomass accumulation rate (*BA/B*, the effect of the numbers at age on the population growth rate); W_m/W_∞ (weight at maturity divided by weight at infinity, assuming that body weight conforms to the von Bertalanffy growth curve with weight proportional to length–cubed); and a fixed fecundity term for species (like marine mammals) that may have a fixed number of young per breeding season (and where fecundity is not related to adult size) (EwE User Guide). For each stanza within each group, the edit multi-stanza tool also requires: an estimate of start age of each stanza (starting at age 0); their total mortality (Z, production/biomass); and consumption/biomass.

Fishes species

For Snapper, King George Whiting and Garfish, annual estimates (spanning ~30 years) of fishable biomass by age and region (estimated from regional stock assessment models, McGarvey *et al.* unpublished) were pooled to estimate the summed biomasses for each age for both SG and GSV.

Estimates of fishable biomass were used to correct the multi-stanza biomass of age-classes that have entered the fishery, as they are not intended to be an accurate estimator of pre-fishery age-classes. For the other key commercial species (Sardine, Western King Prawn, Blue Swimmer Crab and Calamari) where age-structured models to estimate fishable biomass were not available, biomass and consumption at age in the multi-stanza tool were estimated using published values. The parameters used to estimate the multi-stanza groups for each key commercial species are detailed in Table 7.2. The estimated biomass by age for Snapper, King George Whiting and Garfish, are compared to the fishable biomass estimates (based on stock assessment models) in Figure 7.2. Where necessary values of K and Z were adjusted to improve the model fit to estimates of the distribution of fishable biomass.

Long-nosed Fur Seals (LNFS)

LNFS are the most abundant seal species in South Australia, with the largest colonies on the south coast of Kangaroo Island, south of SG at North and South Neptune islands and at Liguanea Island (Shaughnessy *et al.* 2015). Estimates for the abundance of LNFS in the SG and GSV ecosystem model area were based on pup production estimates obtained from these locations between the 1993/94 and 2013/14 breeding seasons (Shaughnessy *et al.* 2015).

The life history and foraging strategies of weaned pups, juveniles, subadult males, adult males and females differ markedly. Weaned pups and juveniles largely forage in oceanic waters of the Southern Ocean. The mean maximum distance from the colony that juvenile LNFS were satellite tracked in South Australia was almost 1,100 km (B. Page, A. Baylis and S. Goldsworthy unpublished data, Page *et al.* 2006). Females commence recruiting into the breeding population at age 4 (McKenzie *et al.* 2007b). Fur seals breed annually, with most pups born over a short (6 week) breeding season between December and mid-January (Goldsworthy and Shaughnessy 1994). Females give birth to a single pup which is nursed for about 10 months prior to weaning (Goldsworthy 2006). Females alternate between shore attendance bouts lasting 1-2 days (when pups are nursed) and foraging trips to sea. The latter are generally shorter (~4 days) throughout the first 4 months (December to April) of lactation when females typically forage nearer to the breeding colony in outer shelf waters (Goldsworthy 2006, Page *et al.* 2006). From April onwards, females transition from shelf to oceanic foraging, ~400 to >1,000 km south of breeding colonies in waters associated with the subtropical front, with foraging trips lasting up to several weeks or more (Baylis *et al.* 2008a, Baylis *et al.* 2012). After pups are weaned, females leave the breeding colony and are not seen again until the they return to pup (Goldsworthy 2006, Page *et al.* 2006), suggesting that females remain in offshore foraging areas between the weaning of one pup and the birth of the next.

As male fur seals do not care for pups and are not large enough to hold breeding territories until around nine years of age (first male tenure average 9 years, McKenzie *et al.* 2007b), their foraging strategies differ markedly from females. Satellite telemetry studies have identified that adult males largely forage in continental slope waters (Page *et al.* 2006), however, the movement and foraging behaviour of subadult males is more variable. Analyses of earlier tracking data, along with those undertaken as part of this project (Chapters 5 and 6) have demonstrated that a part of the subadult male population moves into coastal waters during late autumn and throughout winter months. This is also apparent in survey data of the number of fur seals counted at Donington Reef in southern SG and at Outer Harbor breakwaters (in GSV) that demonstrates the build-up in numbers of fur seals between May and September, with a peak in August (Goldsworthy *et al.* 2009b, Shaughnessy *et al.* 2018). It is also apparent from monthly survey data of LNFS numbers in the Coorong between 2015 and 2018 (Department of the Environment, unpublished data).

In addition to marked differences in life-history and foraging behaviour, female and male fur seals also have markedly different growth strategies and adult body size, and also differ in their diets (McKenzie *et al.* 2007a, Page *et al.* 2005a). For these reasons, males and females were modelled as separate trophic groups. The female group was separated into four age-classes: foetus (-8 to 0 m), pups (0-10 m), juveniles (11 m – 3 years), and adults (4+ years); and the male group was separated into five age-classes: foetus (-8 to 0 m), pups (0-10 m), juveniles (11 m – 3 years), subadults (4- 7 years) and adults (8+ years). The foetal stage was required in order to increase pup mass at birth from 0 to 4.0 kg (females) and 4.2 kg (males), because the von Bertalanffy growth curve parameter used for multi-stanza groups in Ecopath is set to a default of -0.1 for the t_0 parameter, the hypothetical age at which growth is 0 (Guénette *et al.* 2006). For fish, t_0 is negligible but it is very important for precocial marine mammals like fur seals, where pups are 10-15% of maternal mass at birth (Trillmich 1996). Age-specific survival relationships were used to develop a population model for the species, and estimate their age and biomass distribution. For females, the relationship was $S = 0.627\text{-}0.073a + 0.003a^2\text{-}(5.91 \text{ x } 10^{-5})a^3$; for males it was males $S = 0.627\text{-}0.097a + 0.006a^2\text{-}(0.140 \text{ x } 10^{-3})a^3$, where S is survival and a is age in years) (Goldsworthy *et al.* 2003, Goldsworthy and Page 2007). The relationships used known maximum ages (23.4 year females and 16.7 years males, McKenzie 2006, McKenzie *et al.* 2007a), and age-mass relationships for females and males (McKenzie *et al.* 2007a). The curvature parameter *k*, relative biomass accumulation rate and stanza-specific mortality parameters were then adjusted so that the numbers and biomass distribution at age estimated in the edit multi-stanza groups tool matched that from the population model. To achieve the best fit, the age of the foetal groups had to be increased to 36 months to achieve an appropriate mass at birth, effectively setting age zero (birth) at 3 years, and pups were weaned 12 months later (aged 48 months). To compensate for this, the male and female groups were adjusted to live 3 years longer. Ultimately this provided a good approximation of the biomass distribution at age for both females and males (Figure 7.3). The extended foetal period did not affect consumption estimates because foetus nutrition is derived from imported energy (from their mother), as is that of pups dependent on their mothers' milk throughout the lactation period, and the period from 36 to 288 months in females, and 36 to 228 months in males is representative of the 21 and 16 years longevity in females and males, respectively.

The estimation of diet based on available data used each sex and stanza as detailed in the dietary synthesis section above.

The proportion of overall prey consumption by individual stanza's in the respective model domains (SG/GSV) was based on movement and haul-out behaviour data from satellite telemetry and surveys of haul-outs sites (Goldsworthy *et al.* 2009b, Shaughnessy *et al.* 2018). For pups and yearlings (1-2 year olds) of both sex, it was assumed that 100% of their diet came from import sources, mothers milk in pups and from the Southern Ocean in 1-2 year olds (based on tracking data and observations in colonies where yearlings are virtually absent as an age-class). For female juveniles aged 2 and 3 years, it was assumed that 70% of their foraging occurred in offshore areas and 30% within the model domain areas. For adult females, which spend most of their time raising pups, the majority of their foraging occurs in either outershelf (summer/autumn) or oceanic waters (winter/spring) (Baylis *et al.* 2008a, 2008b, Baylis *et al.* 2012). As females have to transit near coastal waters when they return to nurse their pup or depart on their next foraging trip, we have assumed that 10% of their foraging occurs within the model domain areas, while 90% occurs offshore (import). For juvenile males, we have assumed they become progressively more coastal from the ages of 2 to 3 years, acquiring 30% and 40% of their resources from coastal waters in the model domains, respectively, increasing to 50% by age 4 as subadult males, and remaining at 50% for all subadult male age classes (4-7 years old). As adult males aged 8, 9 and 10, we have assumed the proportion of resources obtained from coastal waters within the model domains decreases to 30%, 20% and 10%, as they focus foraging effort on the continental slope and oceanic waters (Page *et al.* 2006), remaining at 10% for all adult males aged >10 years.

Model balancing and time-series fitting

Following the inclusion of new dietary data and multi-stanza trophic groups, both the SG and GSV ecosystem models were re-balanced, following the approach detailed in Gillanders *et al.* (2015) and Goldsworthy *et al.* (2017b). Balanced models were then refitted to the fisheries catch and effort time series used in Gillanders *et al.* (2015) and Goldsworthy *et al.* (2017b). LNFS biomass time series used in Gillanders *et al*. (2015) and Goldsworthy *et al.* (2017b) were modified by separating them into male and female (and age-class/stanza) time-series, as the two sexes were explicitly modelled as separate trophic groups (as detailed above). Demographic and growth models were used to estimate the biomass contribution of foetal, pup, juvenile, subadult and adult stanzas.

Sensitivity and Scenario analysis

For scenarios assessing the potential impacts of seal consumption on key species, scenario biomass time series for each seal species (and multiple stanzas for LNFS) were developed. These adjusted the biomass of species (and stanzas within LNFS) so they ranged from between 10% to 10 times current biomass in the base SG and GSV ecosystem models, and then held constant for a 50-year period, while maintaining all fishing fleet efforts constant. The relative change in estimated biomass of groups under the different seal biomass scenarios was then compared to that of the base model (no change).

Table 7.2. Details of parameters used in multi-stanza groups in the Spencer Gulf and GSV EwE models. Parameters include K (von Bertalanffy growth rate parameter); Recruitment power (degree of density dependence in juvenile survival for juveniles outside the modelled area); BA/B (biomass accumulation rate); Wm/W∞ (weight at maturity divided by weight at infinity).

Group name	Age, start (months)	Tot. mort. (/year)	K	Recruitment power	BA/B	Wmat/Winf
LNFS foetus M	0	0.0400000				
LNFS pups M	36	0.6000000				
LNFS juv M	48	0.1500000				
LNFS SAM	84	0.1800000				
LNFS AM	132	0.2300000	0.1758	0.10	-0.030	0.6781
LNFS foetus F	0	0.0000001				
LNFS pups F	36	0.0000100				
LNFS juv F	48	0.0000100				
LNFS AF	72	0.0600000	0.1390	0.10	0.148	0.8864
Snapper juv	0	2.0000000				
Snapper adult	60	0.2000000	0.1150	1.00	0.000	0.0304
KGW juv	0	1.1000000				
KGW adult	36	1.5000000	0.2500	1.00	0.000	0.0420
Garfish juv	0	2.1000000				
Garfish adult	12	0.6000000	0.5000	1.00	0.000	0.0667
King Prawn juv	0	5.0000000				
King Prawn adult	12	7.5700000	0.2700	1.00	0.000	0.0900
Blue Crab juv	0	3.0000000				
Blue Crab adult	12	2.8000000	0.7000	1.00	0.000	0.0900
Calamary juv	0	8.0000000				
Calamary adult	8	1.8300000	6.0000	1.00	0.000	0.0900

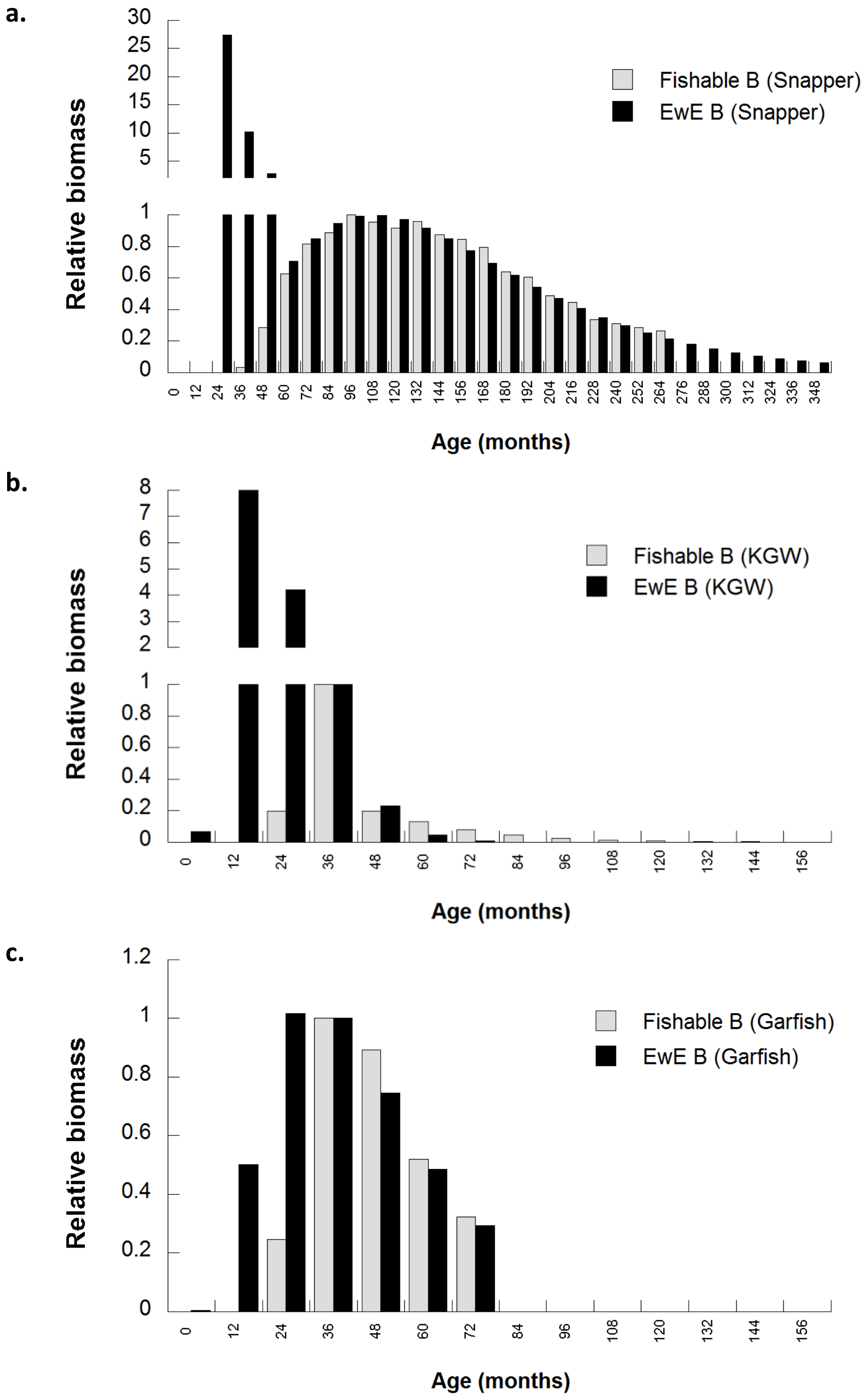


Figure 7.2. Comparison of estimated relative biomass distribution at age based on stock assessment models (Fishable B), with that estimated by the Ecopath model (EwE B) for Snapper (a), King George Whiting (KGW) (b), and Garfish (c). To aid comparison, the value of the EwE B for the peak in Fishable B was used as the relative measure (=1).

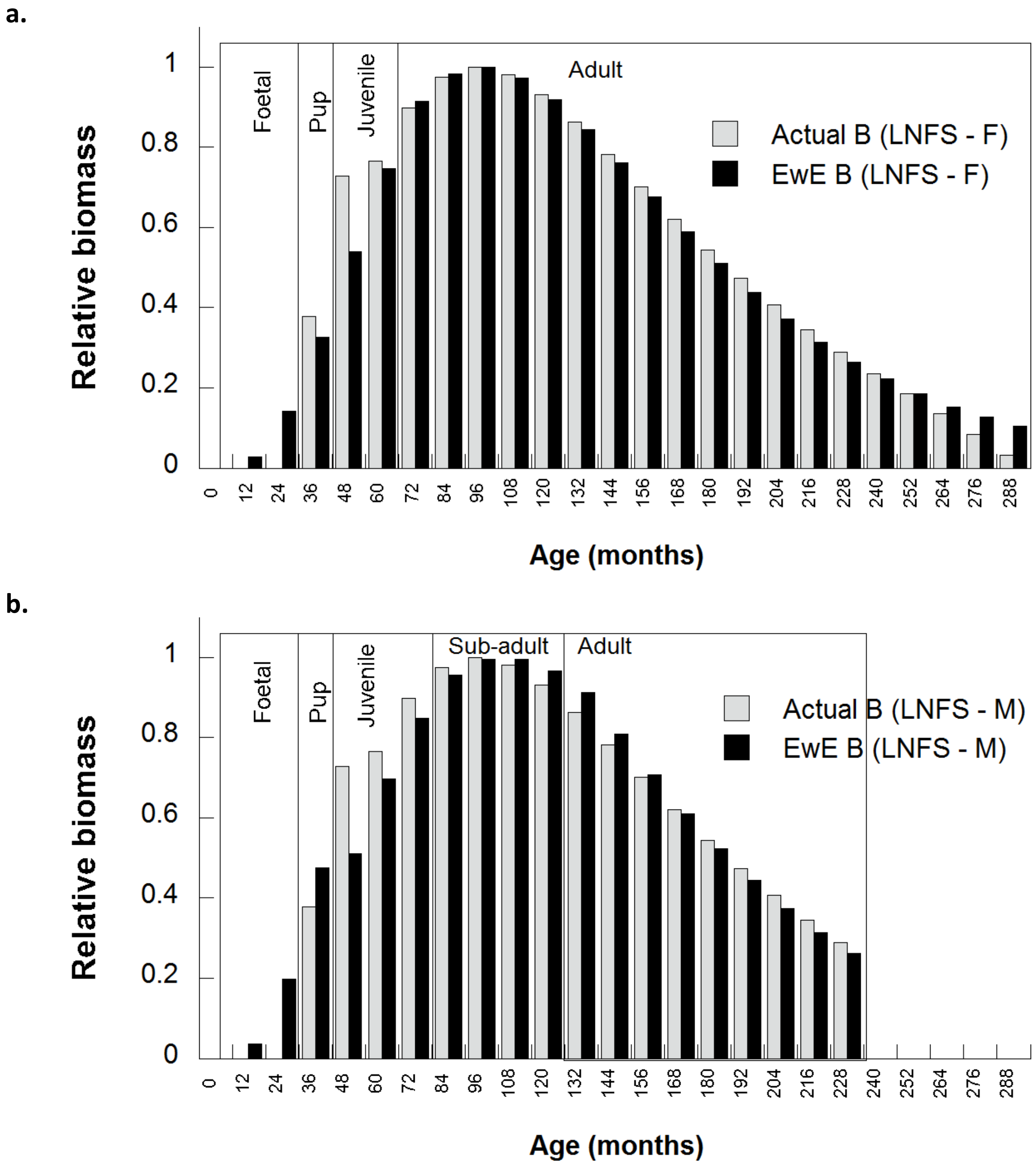


Figure 7.3. Comparison of estimated relative biomass distribution at age of Long-nosed Fur Seals, based on a population model developed for the species (Actual B), and that estimated by the Ecopath model (EwE B) for females (a) and males (b). Boxes encapsulate different stanza groups.

7.3 Results

Seal dietary synthesis

Results of the dietary synthesis estimates for ASL, AFS and LNFS in the South Australian region are presented in Appendix 7.1. Table 7.3 provides a summary of the total number of prey taxa identified through the dietary synthesis for each of the three seal species, and Table 7.4 provides the estimated prey composition by biomass.

The greatest number of prey taxa were identified for ASL (181), followed by LNFS (143) and AFS (34). The breakdown of percentage of prey taxa taken from broad prey taxa categories was very similar among the three seal species (Table 7.3). Fish (teleost) taxa accounted for between 68-70% of prey taxa among seal species, sharks and rays 4-9%, cephalopods 12-16%, crustaceans 6-8% and birds 2-5% (Table 7.3). Commercially fished taxa only made up between 4-6% of the total number consumed (Table 7.3). Although the representation of prey taxa was similar among seal species, their estimated contribution by biomass differed, especially the percentage of fish relative to cephalopods consumed (Table 7.4). In ASL, fish and cephalopods accounted for 50% and 45% respectively, while more fish and fewer cephalopods were consumed by LNFS (81% and 15%, respectively) and by AFS (95% and 1%, respectively). Crustaceans were more important in ASL (3.4%) than in AFS (1.6%) and LNFS (0.9%); and birds were more important in LNFS (3.5%) than in either AFS (0.8%) or ASL (0.2%) (Table 7.4). Key commercially fished species were more important in terms of biomass in LNFS (5% of diet) and ASL (4.3%), compared to AFS (1.6%) (Table 7.4).

Key finding: Dietary studies estimated that key commercially fished species made up just 5%, 4%, and 2% of the total prey biomass consumed by LNFS, ASL and Australian fur seals (AFS) in South Australia.

All of the key commercially fished finfish species (King George Whiting, Garfish, Snapper, Sardine, Yellow-eye Mullet and Mulloway) were found in the diet of LNFS, as were Calamari, Western King Prawns and Blue Crab, although none were significant contributors with respect to biomass in the pooled dataset (Table 7.4). Garfish (1.8%), Southern Calamari (1.7%) and Sardine (1.3%) were the most consumed of the commercially targeted species (Table 7.4). Most of the key commercially fished finfish species (King George Whiting, Garfish, Snapper, Sardine) were also found in the diet of ASL, along with Calamari, Western King Prawn, Blue Crab and Southern Rock Lobster; none were significant contributors in terms of biomass contribution except for Southern Calamari (3.6%, Table 7.4). Garfish and Blue Crab were the only commercially fished species detected in AFS diet, both being very minor prey based on estimated biomass (0.8% in both cases) (Table 7.4).

For LNFS, the diet by taxa and biomass could be enumerated by region, age-class, and by region and age-class for SG and GSV (Tables 7.3 and 7.4). Garfish, Sardine and Southern Calamari were detected in the LNFS diet in all regions, with the exception of the Coorong; King George Whiting was not detected in LNFS diet on the West Coast or the Coorong; and Snapper were only detected in LNFS diet in SG and GSV. Yellow-eye Mullet and Mulloway were detected in the diet of LNFS in the Coorong, with Yellow-eye Mullet also being detected in GSV and the south coast of Kangaroo Island. Western King Prawn were only detected in LNFS diet in GSV, and Blue Crabs were only detected in SG and the south coast of Kangaroo Island (Tables 7.3 and 7.4). The estimated biomass contribution of key commercially fished prey in the diet of LNFS was minor for the Coorong (0.1%), West Coast (0.7%) and south coast Kangaroo Island (0.7%), and of greater importance in SG (6.0%) where the largest contributor was Sardine (3.6%, Table 7.4). In SG, subadult (5.9%) and adult males (5.0%) were the main LNFS age-classes that consumed key commercial fished taxa. Those fish taxa were relatively minor contributors to the diets of juveniles (1.8%) and adult females (2.1%, Table 7.4). The standout region in terms of consumption of key commercially fished species was GSV, where they were estimated to account for 52% of LNFS diet. Key commercially fished species were significant contributors to the diets of subadult (42.9%) and adult males (42.0%); they also contributed significantly to the diet of juveniles (11.1%), but were relatively minor contributors in the diet of adult females (6.7%, Table 7.4). Calamari was the main commercial species consumed (6.0% for juvneiles, 24.4% for SAMs, 23.7% for Adult males, 3.0% for adult females), followed by Garfish (4.7% for juveniles, 16.8% for SAMs, 16.7% for Adult males, 2.5% for adult females). All other commercial species were uncommon in LNFS diet (Table 7.4).

Key finding: Regional differences in the contribution of key commercially fished species were identified in LNFS diet. They were a minor contributor to the diets on the West Coast, south coast of Kangaroo Island and The Coorong; but were more important in Spencer Gulf (6.0%) and were a major part of the diet in GSV (52.2%). Most of this consumption was by male LNFS, and the key commercially fished taxa consumed were Sardine (3% of prey biomass) in Spencer Gulf, and Calamari (24%) and Garfish (17%) in GSV.

Table 7.3. Estimated prercentage composition of prey taxa in the diets of Australian Sea Lions (ASL), Australian Fur Seals (AFS) and Long-nosed Fur Seals (LNFS) in the South Australian region. Summary of the total number of taxa and the percentage of prey taxa identified that are fish (teleosts), sharks and rays, cephalopods, other molluscs, crustaceans and birds. The percentage of prey taxa that form key commercial fisheries are also presented. The key commercially fished taxa are listed, and the presence of prey species in the diet of LNFS by region is indicated by the shaded cells. For Spencer Gulf and Gulf St Vincent, shaded cells also indicate prey of LNFS age-classes.

	ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
Prey types/species	All regions	All regions	All regions	West Coast	Kangaroo Is. (SC)	Spencer Gulf	Gulf St Vincent	Coorong	Spencer Gulf	Spencer Gulf	Spencer Gulf	Spencer Gulf	Gulf St Vincent	Gulf St Vincent	Gulf St Vincent	Gulf St Vincent
									JUV	SAM	AM	AF	JUV	SAM	AM	AF
Fish	68%	70%	68%	69%	64%	74%	68%	75%	73%	73%	69%	69%	69%	68%	65%	67%
Sharks & rays	9%	6%	4%			4%	1%	13%	4%	4%	4%	4%	1%	1%	1%	1%
Cephalopods	12%	15%	16%	24%	20%	15%	20%		16%	17%	16%	19%	20%	21%	20%	22%
Other molluscs	1%															
Crustaceans	7%	6%	8%		8%	4%	7%		4%	4%	5%	5%	6%	6%	6%	6%
Birds	2%	3%	5%	7%	8%	2%	4%	13%	2%	2%	6%	3%	4%	4%	7%	4%
Total taxa	181	34	143	29	76	94	75	8	97	101	104	101	83	84	94	96
Key commercial taxa	4%	6%	6%	10%	8%	6%	9%	25%	7%	8%	6%	6%	8%	9%	7%	7%
King George Whiting	■		■		■	■	■		■	■	■	■	■	■	■	■
Garfish	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Snapper	■		■			■	■		■	■	■	■	■	■	■	■
Sardine	■		■	■	■	■	■		■	■	■	■	■	■	■	■
Yellow-eye mullet			■		■		■	■	■	■			■	■	■	■
Mulloway			■					■		■				■		
Calamari	■		■	■	■	■	■		■	■	■	■	■	■	■	■
Western King Prawn	■		■				■						■	■	■	■
Blue crab	■	■	■		■	■			■	■	■	■				
Southern Rock Lobster	■															
Abalone																

Table 7.4. Estimated biomass contribution of prey taxa in the diets of Australian Sea Lions (ASL), Australian Fur Seals (AFS) and Long-nosed Fur Seals (LNFS) in the South Australian region. The table provides a summary of the estimated prey biomass contribution of fish (teleosts), sharks and rays, cephalopods, other molluscs, crustaceans and birds. Estimated prey biomass contribution of key commercially fished species are also presented.

	ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
Prey types/species	All regions	All regions	All regions	West Coast	Kangaroo Is. (SC)	Spencer Gulf	Gulf St Vincent	Coorong	Spencer Gulf	Spencer Gulf	Spencer Gulf	Spencer Gulf	Gulf St Vincent	Gulf St Vincent	Gulf St Vincent	Gulf St Vincent
									JUV	SAM	AM	AF	JUV	SAM	AM	AF
Fish	50.4%	95.0%	80.8%	84.5%	88.8%	85.1%	59.3%	67.1%	95.8%	84.0%	84.5%	93.5%	90.6%	63.4%	63.8%	91.0%
Sharks & rays	1.3%	1.6%	0.1%			0.2%	0.0%	32.5%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Cephalopods	44.7%	1.0%	14.7%	15.0%	6.6%	10.5%	34.7%		3.3%	9.5%	11.5%	5.9%	8.1%	28.9%	30.9%	8.3%
Other molluscs																
Crustaceans	3.4%	1.6%	0.9%		0.1%	1.0%	0.5%		0.2%	0.8%	0.8%	0.1%	0.1%	0.4%	0.4%	0.1%
Birds	0.2%	0.8%	3.5%	0.5%	4.5%	3.2%	5.5%	0.4%	0.7%	5.5%	3.0%	0.4%	1.1%	7.3%	4.9%	0.6%
King George Whiting	0.0%		0.0%		0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Garfish	0.2%	0.8%	1.8%	0.0%	0.3%	1.0%	20.7%		0.8%	1.0%	0.9%	0.5%	4.7%	16.8%	16.7%	2.5%
Snapper	0.0%		0.1%			0.0%	0.3%		0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.3%	0.0%
Sardine	0.0%		1.3%	0.4%	0.2%	3.6%	1.5%		0.7%	3.0%	3.0%	1.4%	0.3%	1.3%	1.3%	1.1%
Yellow-eye mullet			0.0%		0.0%		0.1%	0.1%	0.0%	0.0%			0.0%	0.0%	0.0%	0.0%
Mulloway			0.0%					0.0%		0.0%				0.0%		
Calamari	3.6%		1.7%	0.2%	0.2%	1.2%	29.6%		0.3%	1.8%	1.0%	0.2%	6.0%	24.4%	23.7%	3.0%
Western King Prawn	0.1%		0.0%				0.0%						0.0%	0.0%	0.0%	0.0%
Blue crab	0.1%	0.8%	0.1%		0.0%	0.1%			0.0%	0.1%	0.1%	0.0%				
Southern Rock Lobster	0.3%															
Abalone																
Sum key fished species	4.3%	1.6%	5.0%	0.6%	0.7%	6.0%	52.2%	0.1%	1.8%	5.9%	5.0%	2.1%	11.1%	42.9%	42.0%	6.7%

Table 7.5. Functional or trophic groups used in the Spencer Gulf ecosystem model as defined in Gillanders *et al.* (2015), with modified multi-stanza groups. Parameter values are indicated where P/B = production/biomass; Q/B = consumption/biomass; EE = ecotrophic efficiency. Bold values are estimated by the model. DDF = deposit detritivore feeding; ZF = zooplankton feeding; DOM = dissolved organic matter; POM = particulate organic matter.

No.	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km^2)	Biomass (t/km^2)	P/B (/year)	Q/B (/year)	EE
1	Aust sea lion	4.44	1.00	0.00636	0.00636	0.792	29.440	**0.073**
	LNFS Males							
2	LNFS foetus M	1.00	1.00	0.00043	0.00043		99.555	**0.000**
3	LNFS pups M	1.00	1.00	0.00054	0.00054		68.430	**0.000**
4	LNFS juv M	4.75	0.20	0.01225	0.00245		50.258	**0.236**
5	LNFS SAM	4.51	0.50	0.00858	0.00429		39.499	**0.187**
6	LNFS AM	4.63	0.20	0.03216	0.00643		33.412	**0.078**
	LNFS females							
7	LNFS foetus F	1.00	1.00	0.00028	0.00028		152.876	**0.000**
8	LNFS pups F	1.00	1.00	0.00041	0.00041		100.693	**0.000**
9	LNFS juv F	4.75	0.20	0.00731	0.00146		77.266	**0.197**
10	LNFS AF	4.88	0.10	0.10698	0.01070		49.860	**0.030**
11	Bottlenose dolphin	4.81	1.00	0.00354	0.00354	0.080	18.990	**0.823**
12	Common dolphin	5.15	1.00	0.03721	0.03721	0.090	20.580	**0.081**
13	Petrels	4.72	1.00	0.00293	0.00293	1.000	191.180	**0.143**
14	Australian gannet	4.88	1.00	0.00008	0.00008	1.000	124.000	**0.000**
15	Little penguin	4.93	1.00	0.00300	0.00300	1.290	85.640	**0.912**
16	Shags & cormorants	4.45	1.00	0.00020	0.00020	1.000	77.400	**0.698**
17	Terns	4.80	1.00	0.00002	0.00002	1.000	90.650	**0.946**
18	Gulls	4.18	1.00	0.00015	0.00015	1.000	126.180	**0.930**
19	White shark	5.66	1.00	**0.00167**	**0.00167**	0.100	1.730	0.950
20	Whaler sharks	5.16	1.00	**0.00630**	**0.00630**	0.095	2.610	0.950
21	Smooth hammerhead	5.11	1.00	**0.00175**	**0.00175**	0.210	3.150	0.950
22	Common thresher shark	5.08	1.00	**0.00116**	**0.00116**	0.200	2.780	0.950
23	Gummy shark	3.66	1.00	0.01849	0.01849	0.550	2.600	**0.700**
24	School shark	5.12	1.00	0.00595	0.00595	0.880	2.500	**0.780**
25	Port Jackson shark	4.13	1.00	0.09440	0.09440	0.250	1.520	**0.506**
26	Other demersal sharks	3.62	1.00	0.03900	0.03900	0.351	2.600	**0.981**
27	Rays & skates	3.65	1.00	0.35858	0.35858	0.418	1.760	**0.308**
28	SB tuna	5.25	1.00	**0.00076**	**0.00076**	0.200	1.600	0.900
29	Yellowtail kingfish	5.29	1.00	**0.00076**	**0.00076**	0.200	2.500	0.900
	Snapper							
30	Snapper juv	3.71	1.00	1.00573	1.00573		18.236	**0.636**
31	Snapper adult	3.74	1.00	0.17000	0.17000		3.800	**0.469**
32	Snook	4.86	1.00	0.04980	0.04980	0.411	3.510	**0.875**
33	Barracouta	5.32	1.00	**0.01722**	**0.01722**	0.411	3.640	0.900
34	Skipjack trevally	3.71	1.00	0.28000	0.28000	0.480	4.170	**0.940**
35	Medium pisc fish	4.51	1.00	0.42000	0.42000	0.636	1.580	**0.956**
36	Medium echino fish	3.33	1.00	0.05400	0.05400	0.625	2.340	**0.979**
37	Aust salmon	5.07	1.00	**1.30035**	**1.30035**	0.450	4.700	0.900
38	Aust herring	3.84	1.00	**1.18288**	**1.18288**	1.640	6.320	0.900
	King George Whiting							
39	KGW juv	4.27	1.00	0.14592	0.14592		4.192	**0.428**
40	KGW adult	3.57	1.00	0.06269	0.06269		2.290	**0.327**
	Garfish							
41	Garfish juv	3.34	1.00	0.00876	0.00876		13.655	**0.979**
42	Garfish adult	3.00	1.00	0.19000	0.19000		4.730	**0.424**
43	Red mullet	3.67	1.00	0.77000	0.77000	0.790	2.360	**0.989**
44	Silverbelly	3.62	1.00	0.70000	0.70000	1.100	4.400	**0.974**
45	Medium crust fish	3.69	1.00	0.50000	0.50000	0.546	2.970	**0.346**
46	Medium mollusc fish	3.27	1.00	1.82000	1.82000	0.869	2.260	**0.494**
47	Small crust fish	3.44	1.00	1.63000	1.63000	1.315	3.320	**0.951**
48	Degens/Rough leatherjacket	3.08	1.00	2.10000	2.10000	0.900	2.260	**0.610**
49	Small polychaete fish	3.23	1.00	1.20000	1.20000	0.992	2.820	**0.949**
50	Syngnathids	3.63	1.00	0.02500	0.02500	1.000	4.700	**0.691**

Table 7.5. Continued

No.	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km²)	Biomass (t/km²)	P/B (/year)	Q/B (/year)	EE
51	Blue mackerel	4.28	1.00	**3.20692**	**3.20692**	0.490	6.400	0.900
52	Jack/yellowtail mackerel	4.37	1.00	**26.70639**	**26.70639**	0.520	5.370	0.900
53	Sardine	4.28	1.00	2.25000	2.25000	1.800	5.040	**0.993**
54	Anchovy	4.05	1.00	2.06950	2.06950	0.980	5.760	**0.904**
55	Sprats	3.26	1.00	**2.90578**	**2.90578**	1.800	5.760	0.900
56	Farmed SBT	2.00	0.15	0.08196	0.01199	1.620	11.870	**0.019**
57	Farmed kingfish	2.00	0.11	0.10000	0.01107	0.486	1.180	**0.672**
58	Fish larvae	2.99	1.00	**3.88204**	**3.88204**	4.000	20.000	0.990
	Southern Calamari							
59	Calamari juv	4.28	1.00	1.53693	1.53693		26.297	**0.257**
60	Calamari adult	5.09	1.00	0.20000	0.20000		18.250	**0.327**
61	Giant cuttlefish	3.65	1.00	0.25000	0.25000	2.370	5.800	**0.912**
62	Other squids	4.58	1.00	0.73000	0.73000	1.800	17.500	**0.284**
63	Octopus	3.77	1.00	0.84000	0.84000	2.370	7.900	**0.352**
64	Rock lobster	2.86	0.50	**0.04154**	**0.02077**	0.730	12.410	0.900
	King Prawn							
65	King Prawn juv	2.39	1.00	2.92469	2.92469		82.218	**0.053**
66	King Prawn adult	2.39	1.00	0.57055	0.57055		37.900	**0.191**
	Blue Crab							
67	Blue Crab juv	2.78	1.00	2.53304	2.53304		16.566	**0.840**
68	Blue Crab adult	2.94	1.00	2.60000	2.60000		8.500	**0.501**
69	Sand crab	2.99	1.00	**4.64756**	**4.64756**	2.800	8.500	0.800
70	Other large crabs/bugs	2.01	1.00	**95.43337**	**95.43337**	2.800	8.500	0.800
71	SAO crustaceans	2.45	1.00	**101.47930**	**101.47930**	0.790	11.300	0.900
72	Hebivorous macrobenthos	2.33	1.00	**3.29495**	**3.29495**	2.800	14.000	0.900
73	Sand-zoobenthos feeders	2.02	1.00	**436.52230**	**436.52230**	0.650	7.500	0.900
74	Greenlip abalone	2.00	1.00	**0.01453**	**0.01453**	0.730	12.410	0.900
75	Black abalone	2.00	1.00	**0.00707**	**0.00707**	0.730	12.410	0.900
76	Small mobile DDF crustaceans	2.51	1.00	**4.41127**	**4.41127**	7.010	27.140	0.900
77	Small mobile ZF crustaceans	3.68	1.00	**151.13230**	**151.13230**	1.120	9.500	0.950
78	Polychaetes DDF	2.62	1.00	**60.86012**	**60.86012**	1.600	6.000	0.900
79	Sessile epifauna	2.37	1.00	**1.04841**	**1.04841**	2.800	11.800	0.900
80	Gelatinous zooplankton	2.65	1.00	0.40000	0.40000	16.500	80.000	**0.357**
81	Large carn zooplankton	3.24	1.00	**219.96430**	**219.96430**	5.000	32.000	0.800
82	Small herb zooplankton	2.24	1.00	**307.39210**	**307.39210**	29.500	55.000	0.800
83	Meiofauna	2.57	1.00	**3.20656**	**3.20656**	35.000	125.000	0.990
84	Benthic microflora	1.66	1.00	0.70000	0.70000	9500.000	12000.000	**0.329**
85	Planktonic microflora	1.45	1.00	17.50000	17.50000	571.000	985.000	**0.995**
86	Macroalgae	1.00	0.06	12915.10000	774.90590	2.780	0.000	**0.192**
87	Seagrass	1.00	0.18	12748.80000	2231.04000	2.430	0.000	**0.019**
88	Phytoplankton	1.00	1.00	32.00000	32.00000	500.000	0.000	**0.467**
89	Detritus DOM	1.00	1.00	20.40000	20.40000			**0.942**
90	Detritus POM	1.00	1.00	18.50000	18.50000			**0.998**
91	Fish farm feed	1.00	0.22	1.91000	0.41600			**0.081**
92	Discards	1.00	1.00	0.44164	0.44164			**0.022**

Table 7.6 Functional or trophic groups used in the GSV ecosystem model as defined in Goldsworthy *et al*. (2016), with modified multi-stanza groups. Parameter values are indicated where P/B = production/biomass; Q/B = consumption/biomass; EE = ecotrophic efficiency. Bold values are estimated by the model. DDF = deposit detritivore feeding; ZF = zooplankton feeding; DOM = dissolved organic matter; POM = particulate organic matter.

No.	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km^2)	Biomass (t/km^2)	P/B (/year)	Q/B (/year)	EE
1	Australian sea lion	4.63	1.00	0.00627	0.00627	0.792	29.440	**0.0004**
	LNFS Males							
2	LNFS Foetus M	1.00	1.00	0.00014	0.00014		99.555	**0.000**
3	LNFS Pups M	1.00	1.00	0.00018	0.00018		68.430	**0.000**
4	LNFS Juv M	4.87	0.20	0.00406	0.00081		50.258	**0.009**
5	LNFS SAM	4.71	0.50	0.00284	0.00142		39.499	**0.004**
6	LNFS AM	4.86	0.20	0.01065	0.00213		33.412	**0.000**
	LNFS Females							
7	LNFS Foetus F	1.00	1.00	0.00003	0.00003		152.907	**0.000**
8	LNFS Pups F	1.00	1.00	0.00004	0.00004		100.714	**0.000**
9	LNFS Juv F	4.90	0.20	0.00073	0.00015		77.282	**0.000**
10	LNFS AF	4.93	0.10	0.01070	0.00107		49.860	**0.000**
11	Bottlenose dolphin	4.75	1.00	0.00354	0.00354	0.080	18.990	**0.042**
12	Common dolphin	5.09	1.00	0.02210	0.02210	0.090	20.580	**0.005**
13	Petrel	4.66	1.00	0.00514	0.00514	1.000	191.180	**0.514**
14	Australian gannet	5.41	1.00	0.00003	0.00003	1.000	125.330	**0.064**
15	Little penguin	4.86	1.00	0.00148	0.00148	1.290	85.640	**0.877**
16	Shags & commorants	4.40	1.00	0.00051	0.00051	1.000	77.410	**0.580**
17	Terns	4.84	1.00	0.00003	0.00003	1.000	90.230	**0.875**
18	Gulls	3.90	1.00	0.00203	0.00203	1.000	129.350	**0.069**
19	White shark	5.72	1.00	0.00001	0.00001	0.100	1.730	**0.000**
20	Whaler shark	5.16	1.00	**0.03000**	**0.03000**	0.095	2.610	0.950
21	Smooth hammerhead	5.60	1.00	**0.00001**	**0.00001**	0.210	3.150	0.950
22	Common thresher shark	5.00	1.00	**0.00001**	**0.00001**	0.200	2.780	0.950
23	Gummy shark	3.68	1.00	0.07472	0.07472	0.550	2.600	**0.289**
24	School shark	5.10	1.00	**0.00205**	**0.00205**	0.880	2.500	0.900
25	Port Jackson shark	4.16	1.00	0.02529	0.02529	0.250	1.520	**0.723**
26	Other demersal shark	3.59	1.00	0.03622	0.03622	0.351	2.600	**0.563**
27	Ray & skate	3.56	1.00	0.16777	0.16777	0.418	1.760	**0.334**
28	Southern bluefin tuna	5.17	1.00	**0.00258**	**0.00258**	0.200	1.600	0.900
29	Yellowtail kingfish	5.21	1.00	**0.00984**	**0.00984**	0.200	2.500	0.900
	Snapper							
30	Snapper juv	3.63	1.00	0.76909	0.76909		18.236	**0.037**
31	Snapper adult	3.52	1.00	0.13000	0.13000		3.800	**0.356**
32	Snook	4.77	1.00	**0.04718**	**0.04718**	0.411	3.510	0.900
33	Barracouta	5.24	1.00	**0.32654**	**0.32654**	0.411	3.640	0.900
34	Skipjack trevally	3.64	1.00	0.21971	0.21971	0.480	4.170	**0.936**
35	Medium piscivore fish	4.24	1.00	**0.70741**	**0.70741**	0.636	1.580	0.900
36	Medium echinoderm fish	3.31	1.00	**0.01625**	**0.01625**	0.625	2.340	0.900
37	Australian salmon	4.95	1.00	**0.61249**	**0.61249**	0.450	4.700	0.900
38	Australian herring	3.76	1.00	**0.95124**	**0.95124**	0.450	4.700	0.900
	King George whiting							
39	KGW juv	4.16	1.00	0.18339	0.18339		4.192	**0.089**
40	KGW adult	3.49	1.00	0.07879	0.07879		2.290	**0.205**
	Garfish							
41	Garfish juv	3.29	1.00	0.00352	0.00352		17.377	**0.755**
42	Garfish adult	2.95	1.00	0.14984	0.14984		4.730	**0.548**
43	Red mullet	3.61	1.00	**0.11978**	**0.11978**	0.790	2.360	0.900
44	Silverbelly	3.54	1.00	**0.76860**	**0.76860**	1.100	4.400	0.900
45	Medium crustacean fish	3.65	1.00	**0.05515**	**0.05515**	0.546	2.970	0.900
46	Medium molluscan fish	3.29	1.00	**0.39917**	**0.39917**	0.869	2.260	0.900
47	Small crustacean fish	3.40	1.00	1.40000	1.40000	1.315	3.320	**0.969**
48	Degens/Rough leatherjacket	3.05	1.00	**1.88536**	**1.88536**	0.900	2.260	0.900
49	Small polychaete fish	3.18	1.00	**1.30490**	**1.30490**	0.992	2.820	0.900
50	Syngnathids	3.57	1.00	**0.23486**	**0.23486**	1.000	4.700	0.900

Table 7.6 continued

No.	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km²)	Biomass (t/km²)	P/B (/year)	Q/B (/year)	EE
51	Blue mackerel	4.20	1.00	**1.38318**	**1.38318**	0.490	6.400	0.900
52	Jack/yellowtail mackerel	4.28	1.00	**4.13649**	**4.13649**	0.520	5.370	0.900
53	Sardine	4.20	1.00	1.79589	1.79589	1.000	5.040	**0.935**
54	Anchovy	3.98	1.00	**3.45755**	**3.45755**	0.980	5.760	0.900
55	Sprats	3.23	1.00	**1.98498**	**1.98498**	1.000	5.760	0.900
56	Fish larvae	2.99	1.00	**1.97078**	**1.97078**	4.000	20.000	0.990
	Souhtern Calamari							
57	Calamari juv	4.03	1.00	0.68163	0.68163		26.297	**0.000**
58	Calamari adult	5.02	1.00	0.08870	0.08870		18.250	**0.939**
59	Giant cuttlefish	3.58	1.00	**0.29467**	**0.29467**	2.370	5.800	0.900
60	Other squids	4.50	1.00	0.20000	0.20000	1.800	17.500	**0.951**
61	Octopus	3.60	1.00	**1.18061**	**1.18061**	2.370	7.900	0.900
62	Rock lobster	2.84	0.50	0.05881	0.02941	0.730	12.410	**0.325**
	Western king prawn							
63	Western king prawn juv	2.36	1.00	0.42162	0.42162		82.218	**0.068**
64	Western king prawn adult	2.36	1.00	0.08225	0.08225		37.900	**0.992**
	Blue crab							
65	Blue crab juv	2.77	1.00	0.42629	0.42629		16.566	**0.961**
66	Blue crab adult	2.77	1.00	0.43756	0.43756		8.500	**0.966**
67	Sand crab	2.99	1.00	**2.25215**	**2.25215**	2.800	8.500	0.900
68	Other large crabs/bugs	2.01	1.00	**38.84204**	**38.84204**	2.800	8.500	0.900
69	Sand associated omnivore crustac	2.42	1.00	**63.45197**	**63.45197**	0.790	11.300	0.900
70	Herbivorous macrobenthos	2.31	1.00	**41.53827**	**41.53827**	2.800	14.000	0.900
71	Sand zoobenthos feeder	2.13	1.00	**264.02580**	**264.02580**	0.650	7.500	0.900
72	Greenlip abalone	2.00	0.20	0.60000	0.12000	1.500	15.000	**0.002**
73	Blacklip abalone	2.00	0.20	**0.01696**	**0.00339**	1.500	15.000	0.900
74	Small mobile DDF crustacean	2.43	1.00	**2.37626**	**2.37626**	7.010	27.140	0.900
75	Small mobile ZF crustacean	3.55	1.00	**55.11633**	**55.11633**	1.120	9.500	0.900
76	Polychates DDF	2.53	1.00	**16.36532**	**16.36532**	1.600	6.000	0.900
77	Sessile epifauna	2.38	1.00	1.10000	1.10000	2.800	11.800	**0.929**
78	Gelatinous zooplankton	3.47	1.00	0.20000	0.20000	16.500	80.000	**0.185**
79	Large carnivorous zooplankton	3.09	1.00	**65.94096**	**65.94096**	5.000	32.000	0.990
80	Small herbivorous zooplankton	2.23	1.00	**60.93745**	**60.93745**	29.500	55.000	0.990
81	Meiofauna	2.51	1.00	**2.10037**	**2.10037**	35.000	125.000	0.990
82	Microphytobenthos	1.51	1.00	0.50000	0.50000	9500.000	12000.000	0.214
83	Planktonic microflora	1.51	1.00	**3.56480**	**3.56480**	571.000	1028.000	0.990
84	Macroalgae	1.00	0.01	12900.00000	154.80000	10.000	0.000	**0.295**
85	Seagrass	1.00	0.20	3306.30000	667.87260	0.938	0.000	**0.068**
86	Phytoplankton	1.00	1.00	22.00000	22.00000	190.000	0.000	**0.404**
87	Detritus DOM water column	1.00	1.00	20.40000	20.40000			**0.989**
88	Detritus POM sediment	1.00	1.00	18.50000	18.50000			**0.999**
89	Discards	1.00	1.00	0.10490	0.10490			**0.000**

Figure 7.4. Flow diagram expression of trophic flows and trophic levels in the Spencer Gulf ecosystem. Functional groups are represented by a circle; the size of the circle is proportional to its biomass (colour of circles is unrelated to any parameter). The location of the five Long-nosed Fur Seals (LNFS) age-classes (stanza: LNFS juv F, LNFS juv M, LNFS SAM, LNFS AM, LNFS AF) and Australian Sea Lion (ASL) are highlighted.

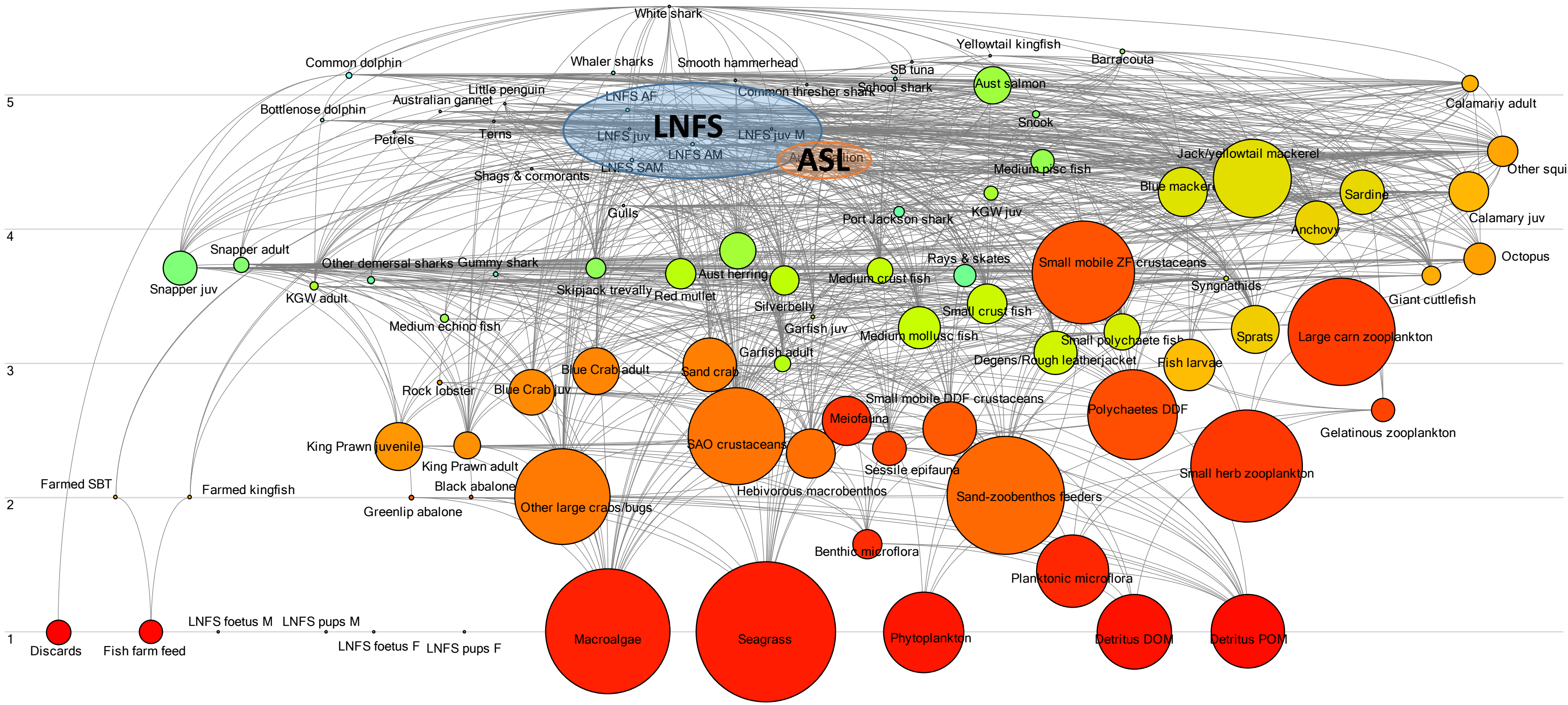
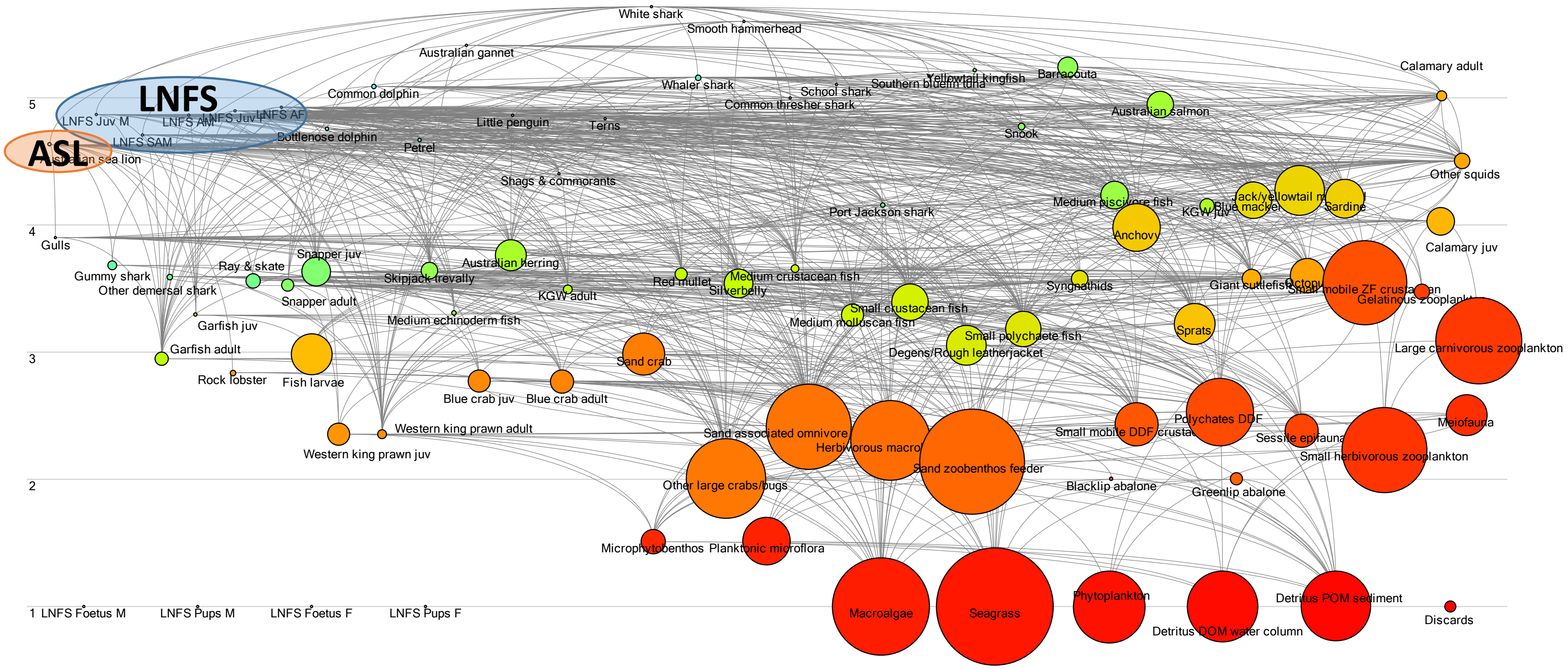


Figure 7.5. Flow diagram expression of trophic flows and trophic levels in the GSV ecosystem. Functional groups are represented by a circle; the size of the circle is proportional to its biomass (colour of circles is unrelated to any parameter). The location of the five Long-nosed Fur Seals (LNFS) age-classes (stanza: LNFS juv F, LNFS juv M, LNFS SAM, LNFS AM, LNFS AF) and Australian Sea Lion (ASL) are highlighted.



Balanced Ecopath Models

The basic parameters used to inform the functional groups within the SG and GSV ecosystem *Ecopath* models are presented in Tables 7.5 and 7.6, respectively. The balancing procedure required adjustment to parameter estimates for some groups where ecotrophic efficiencies (EE) were initially >1. EE is the proportion of production that is either harvested or predated upon by higher trophic levels and cannot exceed 1. Some of these adjustments could be achieved by slight changes to dietary proportions for some functional groups, others required changes to estimated biomass, P/B and Q/B estimates.

The trophic flows between the functional groups in the SG and GSV ecosystem models estimated by *Ecopath* are presented in Figures 7.4 and 7.5. The trophic level of ASL was 4.44 and 4.63 in the SG and GSV ecosystems, respectively (Tables 7.5 and 7.6). The trophic level of LNFS juveniles (4.75 and 4.87), subadults (4.51 and 4.71) and adult males (4.63 and 4.86) in SG and GSV ecosystems, respectively, was similar to that of juvenile females (4.75 and 4.90) and adult females (4.88 and 4.93) (Tables 7.5 and 7.6).

Consumption of finfish and cephalopods

Total annual consumption of finfish and cephalopods by all marine predators was estimated in both the SG and GSV ecosystem models. The proportional breakdown of estimated consumption by key predator groups for each of these models excluding and including fisheries catches, is presented in Table 7.7. Figures 7.6 and 7.7 present total estimated consumption of by key predator groups inclusive of fisheries catches. The overall consumption of crustaceans was not estimated as many of the trophic groups that contained crustaceans also included other invertebrate taxa groups (e.g., molluscs). Cephalopods were the largest consumers of finfish in both the SG (72%) and GSV ecosystems (49%), followed by finfish (24% and 45%, respectively)(excluding fisheries catches). Collectively, finfish and cephalopods consumed 96% and 94% of all finfish consumed (excluding fisheries catches) in the SG and GSV ecosystems, respectively (Table 7.7, Figure 7.6). In comparison, top marine predator groups (seals, dolphins, seabirds, and sharks and rays), consumed just 3.7% and 5.7% of the total finfish consumed in the SG and GSV ecosystems (excluding fisheries catches) (Table 7.7, Figure 7.6).

Seals (LNFS and ASL) consumed an estimated 1.2% and 0.8% of the total finfish consumed in the SG and GSV ecosystems excluding fisheries catches, respectively (Table 7.7); and 1.1% and 0.8% inclusive of fisheries catches, respectively (Table 7.7, Figure 7.6). Most of the finfish consumed by seals in SG was by LNFS (0.8%, compared to 0.3% ASL, excluding fisheries catches), while in the GSV ecosystem most of the finfish consumed by seals was by ASL (0.5%, compared to 0.3% by LNFS, excluding fisheries catches) (Table 7.7).

Estimated consumption of finfish by LNFS increased by about 60% between 1991 and 2010 in SG (or from 0.51 to 0.83% relative consumption), and by about 10% in GSV between 1994 and 2013 (or from 0.25 to 0.27% relative consumption) (Figure 7.8). In contrast, consumption of finfish by ASL in SG was estimated to have decreased by 15% between 1991 and 2010 (or from 0.40 to 0.35% relative consumption), and to have declined by 3% in GSV between 1994 and 2013 (or from 0.53 to 0.51% relative consumption) (Figure 7.8).

Fisheries catches accounted for 2.8% and 0.4% of the total combined estimates of consumption and catch of finfish in the SG and GSV ecosystems, respectively (Table 7.7, Figure 7.6). Comparatively, seals were estimated to consume 1.1% and 0.8% of the total combined estimates of consumption and catch of finfish in the SG and GSV ecosystems, respectively(Table 7.7, Figure 7.6).

Finfish were the dominant consumers of cephalopods in both SG (79%) and GSV (74%), followed by cephalopods (15% and 16%, respectively) (Table 7.7, Figure 7.7). Collectively, cephalopods and finfish consumed 93% and 91% of all cephalopods consumption in the SG and GSV ecosystems, respectively (Table 7.7, Figure 7.7). The top marine predator groups (seals, dolphins, seabirds and sharks and rays), accounted for the remaining 7% and 9% of cephalopod consumption, respectively (Table 7.7, Figure 7.7). Seals (LNFS and ASL) consumed an estimated 2.1% and 2.7% of the total cephalopod consumption in the SG and GSV ecosystems, respectively (Table 7.7, Figure 7.7). Most of the cephalopod consumption by seals in SG was by LNFS (1.2%, compared to 0.9% ASL); while in the GSV ecosystem most cephalopod consumption was by ASL (2.1%, compared to 0.6% by LNFS) (Table 7.7).

Estimated consumption of cephalopods by LNFS increased by about 58% between 1991 and 2010 in SG (or from 0.76 to 1.18% relative consumption), but decreased by about 5% in GSV between 1994 and 2013 (or from 0.61 to 0.59% relative consumption) (Figure 7.8). Consumption of cephalopods by ASL in SG was estimated to have decreased by 19% between 1991 and 2010 (or from 1.16 to 0.93% relative consumption), and to have decreased by 8% in GSV between 1994 and 2013 (or from 2.30 to 2.14% relative consumption) (Figure 7.8).

Consumption of commercially targeted finfish, cephalopods and crustaceans

Commercially targeted ‘key finfish’ species included Snapper, King George Whiting, Garfish, and Sardine. Commercially targeted cephalopods included Southern Calamari, while commercially targeted ‘key crustaceans’ included Western King Prawns, Southern Rock Lobster and Blue Crab. Annual consumption of key finfish, Southern Calamari and key crustaceans by all marine predators was estimated for both the SG and GSV ecosystem models (Table 7.7, Figures 7.6, 7.7 and 7.8.)

Cephalopods were the largest consumers of key finfish species in both the SG (59%) and GSV ecosystems (29%), followed by finfish (36% and 61%, respectively, excluding fisheries catches) (Table 7.7). These estimates were similar when fisheries catches were excluded or included (Table 7.7, Figure 7.6). Collectively, cephalopods and finfish consumed 95% and 90%, of all key finfish consumed in the SG and GSV ecosystems, respectively, when fisheries catches were excluded; and 81% and 89%, respectively, when fisheries catches were included (Table 7.7, Figure 7.6). In comparison, top marine predator groups (seals, dolphins, seabirds, and sharks and rays), consumed 5% and 10% of the total key finfish consumption in the SG and GSV ecosystems, when fisheries catches were excluded; and 4% and 9.5%, respectively when fisheries catches were included (Table 7.7, Figure 7.6).

Seals (LNFS and ASL) accounted for an estimated 0.4% and 0.6% of the total key finfish consumption in the SG and GSV ecosystems, respectively, when fisheries catches were excluded; and 0.3%% and 0.6%, respectively when fisheries catches were included (Table 7.7). Most of this consumption was by LNFS (0.4% in SG and 0.5% in GSV, excluding fisheries catches; 0.3% and 0.5%, respectively, when including fisheries catches) (Table 7.7). Estimated consumption of key finfish by LNFS in SG increased by about 24% between 1991 and 2010 (or from 0.23 to 0.38% relative consumption, excluding fisheries catches); and by 19% in GSV between 1994 and 2013 (or from 0.46 to 0.55% of all key finfish consumed, excluding fisheries catches) (Figure 7.8). In contrast, consumption of finfish by ASL in SG was estimated to have decreased by 21% between 1991 and 2010 (from 0.01 to 0.01% relative consumption, excluding fisheries catches), and to have increased by about 8% in GSV between 1994 and 2013 (from 0.02 to 0.02% relative consumption, excluding fisheries catches) (Figure 7.8).

Finfish were the largest consumers of Southern Calamari in SG (92%) followed by cephalopods (4.2%) (when fisheries catches were excluded; and 92%% and 4.1%, respectively when fisheries catches were included; Table 7.7, Figure 7.7). Both groups collectively accounted for most Southern

Calamari consumption (96%, excluding and excluding fisheries catches) (Table 7.7, Figure 7.7). In contrast, the major Southern Calamari consumers in the GSV ecosystem were cephalopods (25%) and dolphins (25%), followed by sharks and rays (21%) and finfish (15%), excluding fisheries catches (cephalopods 22%, and dolphins 22%, sharks and rays 19%, finfish 14% inclusive of fisheries catches; Table 7.7, Figure 7.7). Fisheries accounted for an estimated 0.2% and 9.2% of the total estimated Southern Calamari consumption in the SG and GSV ecosystems, respectively. Comparatively, seals were estimated to consume 0.4% and 13.3% of the total combined estimates of consumption and catch of Southern Calamari in the SG and GSV ecosystems, respectively(Table 7.7, Figure 7.7). In SG, consumption levels were similar for ASL (0.3%) and LNFS (0.2%); whereas in GSV, most was by LNFS (9.6%, compared to 3.8% in ASL (inclusive of fisheries catches, Table 7.7). Estimated consumption of Southern Calamari by LNFS increased by about 58% between 1991 and 2010 in SG (and from 0.11 to 0.17% in terms of relative consumption, excluding fisheries catches); and decreased by about 6% in GSV between 1994 and 2013 (from 11.7 to 10.5% relative consumption, excluding fisheries catches) (Figure 7.8). Consumption of Southern Calamari by ASL in SG was estimated to have declined by about 20% between 1991 and 2010 (from 0.33 to 0.27% relative consumption, excluding fisheries catches); and to have declined by about 11% in GSV between 1994 and 2013 (from 4.9 to 4.1% relative consumption, excluding fisheries catches) (Figure 7.8).

Most key crustacean consumption was split between finfish, cephalopods and crustaceans, but in different proportions in the SG (37%, 26% and 21%, respectively, when fisheries catches were included or excluded) and GSV ecosystems (25%, 15% and 56%, respectively, when fisheries catches were included or excluded) (Table 7.7). Seals (LNFS and ASL) accounted for an estimated 0.5% and 0.03% of the total estimated consumption of key crustaceans in the SG and GSV ecosystems, respectively (when fisheries catches were included or excluded), with almost all of this consumption attributable to ASL (Table 7.7). Estimated consumption of key crustacea by ASL decreased by about 13% between 1991 and 2010 in SG (and from 0.71 to 0.51% relative consumption, excluding fisheries catches); and decreased by about 3% in GSV between 1994 and 2013 (from 0.03 to 0.03% relative consumption, excluding fisheries catches) (Figure 7.8). Consumption of key crustaceans by LNFS in SG was estimated to have increased by about 66% between 1991 and 2010 (from 0.02 to 0.03% of relative consumption, excluding fisheries catches); and to have increased by about 15% in GSV between 1994 and 2013 (from 0.001 to 0.001% relative consumption, excluding fisheries catches) (Figure 7.8).

Key finding: Ecosystem models identified that more than 90% of the finfish and cephalopods consumed in the SG and GSV ecosystems, were consumed by other finfish and cephalopods. Seals only consumed about 1% of all finfish and 2-3% of all cephalopods, and only accounted for around 0.5% of the total consumption of commercially targeted finfish, most of which was consumed by LNFS.

Sensitivity analysis

Sensitivity analyses were undertaken to assess the sensitivity of various taxa groups in the SG and GSV ecosystem models to changes in the biomass of LNFS and ASL. This was achieved by running scenarios where the relative change in the biomass of selected functional groups to either a 10% decrease (B=0.9) or a 10% increase (B=1.1) in either LNFS or ASL biomass could be compared to the base model SG (2010) and GSV (2013) output, run over a 50-year period. Results of these analyses are provided in Figures 7.9 to 7.12. Note that the x-axis scale varies between figures to make the magnitude of change more apparent.

Sensitivity analysis for Long-nosed Fur Seals

In general, the majority of groups were relatively insensitive to changes in fur seal biomass. For example the biomass of 79% (62) and 90% (70) of the trophic groups in the SG and GSV ecosystem models responded by <0.1% to a 10% increase in LNFS biomass, respectively. Of those that responded by >0.1%, 17% had a negative response, and 4% had a positive response in the SG ecosystem; while in the GSV ecosystem, 9% responded negatively and 1% positively. Similarly, 81% (63) and 90% (70) of the trophic groups in the SG and GSV ecosystem models responded by <0.1% to a 10% decrease in LNFS biomass, respectively. Of those that responded by >0.1%, 15% had a positive response, and 4% had a negative response in the SG ecosystem; while in the GSV ecosystem, 9% responded positively and 1% responded negatively.

The greatest negative response to a 10% increase in LNFS biomass in the SG ecosystem model was by Little Penguins (-2.8%), followed by Barracouta (-2.6%), whaler sharks (-0.9%), Bottlenose Dolphin (-0.8%), Common Thresher Shark (-0.7%), Smooth Hammerhead (-0.5%), Yellowtail Kingfish (-0.3%), Petrels (-0.2%), juvenile Garfish (-0.2%), small polychaete eating fish (-0.2%), medium piscivorous fish (-0.2%), ASL (-0.1%), and School Shark (-0.1%) (the larger changes are illustrated in Figures 7.9 and 7.11). Similarly, in the GSV ecosystem model, the greatest negative response to a 10% increase in LNFS biomass was by Little Penguins (-1.5%), followed by Smooth Hammerhead (-0.7%), Common Thresher Shark, juvenile Garfish (-0.3%), Shags and Cormorants (-0.2%), Australian Gannet (-0.1%) and adult Garfish (-0.1%) (Figures 4.7, 4.9). The greatest positive response to a 10% increase in LNFS biomass in the SG ecosystem model was by White Shark (3.2%), followed by Anchovy (0.1%) and Gulls (0.1%) (Figures 7.9 and 7.11). Similarly, the greatest positive response to a 10% increase in LNFS biomass in the GSV ecosystem model was by White Shark (3.1%) (Figures 7.9 and 7.11).

The greatest positive response to a 10% decrease in LNFS biomass in the SG ecosystem model was by Little Penguins (3.4%), followed by Barracouta (3.1%), whaler sharks (0.8%), Bottlenose Dolphin (0.7%), Common Thresher Shark (0.5%), Smooth Hammerhead (0.4%), Yellowtail Kingfish (0.3%), Petrels (0.2%), juvenile Garfish (0.2%), small polychaete feeding fish (0.2%), medium piscivorous fish (0.2%), and ASL (0.2%) (larger changes are illustrated in Figures 7.9 and 7.11). Similarly, in the GSV ecosystem model, the greatest positive response to a 10% decrease in LNFS biomass was by Little Penguins (1.8%), followed by Smooth Hammerhead (0.07), Common Thresher Shark (0.5%), juvenile Garfish (0.3%), Shags and Cormorants (0.2%), Australian Gannet (0.1%), and adult Garfish (0.1%) Figures 4.7, 4.9). The greatest negative response to a 10% decrease in LNFS biomass in the SG ecosystem model was by White Shark (-3.1%), followed by Anchovy (-0.2%) and Gulls (-0.1%) (Figures 7.9 and 7.11). Similarly, the greatest negative response to a 10% decrease in LNFS biomass in the GSV ecosystem model was by White Shark (-3.1%) (Figures 7.9 and 7.11).

The majority of commercially important species were also relatively insensitive to changes in LNFS biomass (Figures 7.9 and 7.11). Garfish were the most sensitive to changes in LNFS biomass, but even these were minor. A 10% increase in LNFS biomass resulted in a 0.18% and 0.26% decline in the biomass of juvenile Garfish, and a 0.01% and 0.11% decline in the biomass of adult Garfish in SG and GSV ecosystem models, respectively (Figure 7.9). In contrast, a 10% decrease in LNFS biomass resulted in a 0.22% and 0.32% increase in the biomass of juvenile Garfish, and a 0.01% and 0.13% increase in the biomass of adult Garfish in SG and GSV ecosystem models, respectively (Figure 7.9.

Of the remaining commercially important species, those that responded negatively to a 10% increase in LNFS biomass in the SG ecosystem model included juvenile King George Whiting (-0.003%); Sardine (-0.010%) and juvenile (-0.005%) and adult (-0.009%) Southern Calamari. In the GSV ecosystem model, they included Sardine (-0.010%); adult Southern Calamari (-0.015%) and juvenile (-0.017%) and adult (0.003%) Western King Prawns. Commercially important species that responded positively to a 10% increase in LNFS biomass in the SG ecosystem model included adult King George Whiting (0.002%); juvenile (0.020%) and adult Snapper (0.010%); juvenile (0.001%) and adult Blue Crab (0.0003%); Southern Rock Lobster (0.028%); and juvenile (0.001%) and adult

Western King Prawns (0.001%). In the GSV ecosystem model, these included juvenile (0.004%) and adult King George Whiting (0.009%); juvenile (0.002%) and adult Snapper (0.003%); juvenile Southern Calamari (0.003%); and juvenile (0.004%) and adult Blue Crab (0.004%). Most of these responses were too small to illustrate on Figure 7.9.

Sensitivity analysis for Australian sea lions

As with LNFS, the majority of groups were relatively insensitive to changes in ASL biomass. The biomass changes of 65% (50) and 62% (48) of the trophic groups in the SG and GSV ecosystem models responded by <0.1% to a 10% increase in ASL biomass, respectively. Of those that responded by >0.1%, 29% had a negative response, and 6% had a positive response in the SG ecosystem; while 27% responded negatively and 10% positively in the GSV ecosystem.

The greatest negative response to a 10% increase in ASL biomass in the SG ecosystem model was by Gulls (-14.6%), followed by Shags and Cormorants (-9.4%), other demersal sharks (-7.1%), Southern Rock Lobster (-3.5%), Barracouta (-2.3%), Common Thresher Shark (-1.2%), Bottlenose Dolphin (-1.0%), Smooth Hammerhead (-0.6%), Red Mullet (-0.6%), whaler sharks (-0.5%), medium piscivorous fish (-0.5%), Giant Cuttlefish (-0.3%), Yellowtail Kingfish (-0.3%), Australian Gannet (-0.3%), Snook (-0.2), Gummy Shark (-0.2%), School Shark (-0.2%), juvenile Garfish (-0.1%), Common Dolphin (-0.1%), Octopus (-0.1%), other squid (-0.1) and Skipjack Trevally (-0.1%) (Figures 7.10 and 7.12). In the GSV ecosystem model, the greatest negative response to a 10% increase in ASL biomass was by Yellowtail Kingfish (-7.6%), Shags and Cormorants (-3.7%), Red Mullet (-2.7%), Australian Gannet (-0.8%), Gulls (-0.8%), Little Penguins (-0.7%), Smooth Hammerhead (-0.5%), other demersal sharks (-0.5%), Southern Bluefin Tuna (-0.2), other squids (-0.2%), medium piscivorous fish (-0.2), rays and skates (-0.2%), Bottlenose Dolphin (-0.2%), Southern Rock Lobster(-0.2%), Port Jackson Shark (-0.2%), whaler sharks (-0.2%), juvenile Garfish (-0.1%), Octopus (-0.1%), Common Thresher Shark (-0.1%), Gummy Shark (-0.1%) and Giant Cuttlefish (-0.1%) (Figures 7.10 and 7.12).

The greatest positive response to a 10% increase in ASL biomass in the SG ecosystem model was by Terns (13.3%), followed by White Shark (3.3%), Petrels (0.9%), Black Abalone (0.1%), and medium echinoderm feeding fish (0.1%) (Figures 4.8, 4.10). Similarly, the greatest positive response to a 10% increase in ASL biomass in the GSV ecosystem model was by Terns (0.8%), followed by medium crustacean feeding fish (0.5%), Petrels (0.5%), White Shark (0.4%), Black Abalone (0.3%), Skipjack Trevally (0.3%), School Shark (0.1%), and Australian Salmon (0.1%) (Figures 4.8, 4.10).

The greatest positive response to a10% decrease in ASL biomass in the SG ecosystem model was by Gulls (15.7%), followed by Shags and Cormorants (9.8%), other demersal sharks (7.6%), Southern Rock Lobster (3.6%), Barracouta (2.3%), Common Thresher Shark (1.0%), Bottlenose Dolphin (0.9%), Smooth Hammerhead (0.6%), Red Mullet (0.6%), medium piscivorous fish (0.5%), whaler sharks (0.4%), Giant Cuttlefish (0.3%), Australian Gannet (0.3%), Yellowtail Kingfish (0.3%), Snook (0.2), Gummy Shark (0.2%), juvenile Garfish (0.1%), School Shark (0.1%), Common Dolphin (0.1%), Octopus (0.1%), other squid (0.1%) and Skipjack Trevally (0.1%) (Figures 7.10, 7.12). In the GSV ecosystem model, the greatest positive response to a 10% decrease in ASL biomass was by Yellowtail Kingfish (7.7%), Shags and Cormorants (3.7%), Red Mullet (2.7%), Australian Gannet (0.9%), Gulls (0.8), Little Penguins (0.7%), Smooth Hammerhead (0.5%), other demersal sharks (0.5%), Southern Bluefin Tuna (0.2), other squids (0.2%), medium piscivorous fish (0.2), rays and skates (0.2%), Bottlenose Dolphin (0.2%), Southern Rock Lobster(0.2%), whaler sharks (0.2%), Port Jackson Shark (0.2%), juvenile Garfish (0.1%), Octopus (0.1%), Common Thresher Shark (0.1%), Gummy Shark (0.1%) and Giant Cuttlefish (0.1%) (Figures 7.10, 7.12

The greatest negative response to a 10% decrease in ASL biomass in the SG ecosystem model was by Terns (-13.2%), followed by White Shark (-2.4%), Petrels (-0.9%), Black Abalone (-0.3%), and medium echinoderm feeding fish (-0.1%) (Figures 7.10, 7.12). Similarly, the greatest negative response to a 10% decrease in ASL biomass in the GSV ecosystem model was by Terns (-0.8%), followed by medium crustacean feeding fish (-0.5%), Petrels (-0.5%), White Shark (-0.3%), Black Abalone (-0.3%), Skipjack Trevally (-0.3%), School Shark (-0.1%), and Australian Salmon (-0.1%) (Figures 7.10, 7.12).

The majority of commercially important species were relatively insensitive to changes in ASL biomass (Figure 7.10). Southern Rock Lobster were the most sensitive to changes in ASL biomass. A 10% increase in ASL biomass resulted in a 3.5% and 0.17% decrease in the biomass of Southern Rock Lobster in SG and GSV ecosystem models, respectively (Figure 7.10). Of the remaining commercially important species, those that responded negatively to a 10% increase in ASL biomass in the SG ecosystem model included juvenile (-0.14%) and adult Garfish (-0.027%), adult Snapper (-0.035%), juvenile (-0.016%) and adult Southern Calamari (-0.030%), juvenile (-0.054%) and adult Blue Crab (-0.021%) (Figure 7.10). In the GSV ecosystem model, they included juvenile (-0.144%) and adult Garfish (-0.002%), juvenile (-0.069%) and adult Snapper (-0.036%), juvenile King George Whiting (-0.12%), adult Southern Calamari (-0.074%), and adult Blue Crab (-0.002%) (Figure 7.10).

Commercially important species that responded positively to a 10% increase in ASL biomass in the SG ecosystem model included juvenile Snapper (0.014%), juvenile (0.007%) and adult King George Whiting (0.002%), Sardine (0.001%), and juvenile (0.002%) and adult Western King Prawn (0.005%) (Figure 7.10). In the GSV ecosystem model, these included adult King George Whiting (0.036%); Sardine (0.003%); juvenile Southern Calamari (0.010%); and juvenile (0.008%) and adult Western King Prawns (0.005%), and juvenile Blue Crab (0.005%) (Figure 7.10).

Impact of changes in seal biomass on total fish and cephalopod production

The biomass response of all combined finfish and cephalopod groups to changes in seal biomass was examined by undertaking scenarios where the biomass of seals was reduced and increased incrementally from 0.1 to 10 times the current biomass levels. Such scenarios can be informative as they provide some insight into the how different parts of the marine ecosystem respond to changes in seal biomass, at what biomass levels different trophic groups are most responsive, and the extent to which response relationships are linear and non-linear. Figures 7.13 and 7.14 plot the response relationships for two groups: total finfish and total cephalopods to different scenarios of LNFS and ASL biomass in the (SG and GSV ecosystem models. A total crustacean group could not be created because many crustacean taxa form part of taxa groups that included non-crustacean invertebrates.

Four general observations are apparent:

- the magnitude of change in relative biomass of key groups to major changes in seal biomass (from 0.1 to 10 fold current levels) is very small, ranging from just 1.27% to -1.05% current biomass levels (i.e. < ±1.5%);
- the response relationships are typically non-linear, and their direction (+ve or –ve) may change under low and high seal biomass scenarios (especially in response to changes in LNFS biomass);
- some of the response relationships differ between the SG and GSV ecosystem models; and
- the magnitude and range of the response relationship is typically greatest at low seal biomasses, and least at high seal biomasses.

The LNFS scenarios undertaken in the SG ecosystem identified that between low and current biomass scenarios (0.1 to 1.0 times current biomass), there was a negative relationship between seal biomass and total finfish and cephalopod biomass (Figure 7.13a and b). However, in the GSV ecosystem, these relationships were reversed for total finfish (Figure 7.13a), and the relation for total cephalopods was fairly flat (Figure 7.13b). In contrast, under higher LNFS biomass scenarios (1 to 10 times current biomass), the response relationships of total finfish and cephalopod groups were similar in both gulf models, with the biomass of groups tending to increase with increasing seal biomass, although the magnitude of responses was very small (Figures 7.13a, b).

The ASL scenarios undertaken in the SG ecosystem identified that for lower to higher biomass scenarios (0.1 - 10 times current biomass), there was generally a negative relationship between ASL biomass and the biomass of finfish and cephalopods (Figures 4.14a, b). In the GSV ecosystem scenarios, the negative relationship between ASL and cephalopod biomass was similar to that for SG, but the relationship between ASL and finfish biomass was positive (Figures 4.14a, b).

Impact of changes in seal biomass on overall commercial fish production

The impacts of changes in seal biomass on the productivity of commercially fished species was examined by undertaking scenarios where the biomass of seals was reduced and increased incrementally from 0.1 to 10 times the current biomass levels. These scenarios examined the response of the total pooled biomass of key commercial fish (Snapper, King George Whiting, Garfish and Sardine), cephalopods (Southern Calamari) and crustaceans (Western King Prawns, Blue Crabs, Southern Rock Lobster) to changes in LNFS (Figure 7.15) and ASL biomass (7.16) in the SG and GSV ecosystem models.

As with the scenarios undertaken for total fish and cephalopod production above, those undertaken for key commercially fished groups also showed that the magnitude of change in relative biomass of key groups to major changes in seal biomass (from 0.1 to 10 fold current levels) was small (<±1%); the response relationships were non-linear; the direction (+ve or –ve) and magnitude of change varied under low, current and high seal biomass scenarios with the greatest magnitude of response at low seal biomasses; and there were some differences in the response relationships between the SG and GSV models (Figures 7.15, 7.16).

The LNFS scenarios undertaken in the SG model identified that between low and current biomass scenarios (0.1 to 1.0 times current biomass), there was a weak negative relationship between seal biomass and commercial fish and cephalopod biomass (Figure 7.15a), and a weak positive relationship with commercial crustaceans (Figure 7.15a). These relationships were very similar in the GSV model, except that there was no apparent relationship for commercial cephalopods (Figure 7.15b). All these response relationships attenuated as seal biomass approached current biomass levels. However, under increasing LNFS biomass the production in all commercially targeted groups remained stable or increased slightly, especially with further increases in LNFS biomass. The exception to this pattern was the response of commercial cephalopods in the SG model, that showed a weak negative response, but this also attenuated as LNFS biomass increased (Figures 7.15a and b).

The ASL scenarios for the SG model identified a negative relationship between ASL and commercial crustacean biomass, but for commercial fish and cephalopods the response relationships were weaker, especially under increasing ASL biomass scenarios and marginally positive for commercial fish (Figure 7.16a). The response relationships between ASL biomass ands commercial fished groups were much weaker in the GSV model (Figure 7.16b).

Impact of changes in seal biomass on production of key commercially caught fish species

The impact of changes in seal biomass on the biomasses of individual key commercially fished species was estimated following the approach detailed above, for each of the SG and GSV ecosystem models. Estimated changes in both the absolute and relative biomass changes of key commercially fished species under difference scenarios of seal biomass ranging from 0.1 to 10 fold the current levels are presented in Figures 7.17 to 7.20. Plots for individual species by regions are presented in Figures 7.21 and 7.22.

The key observation from these analyses is that the absolute changes in biomass of commercially fished species to very significant changes in seal biomass (from 0.1 to 10 fold current levels) are almost imperceptible (Figure 7.17a, 7.18a, 7.19a, 7.20a). The magnitude and nature of the response relationships to changes in seal biomass are only apparent when biomass changes are plotted as a relative change (Figure 7.17b, 7.18b, 7.19b, 7.20b).

Other key observations include:

- the magnitude of change in relative biomass of commercially fished groups to major changes in seal biomass (from 0.1 to 10 fold current levels) is generally very small. For most groups these range < ±1.5%. The major exceptions are Garfish (increasing by almost 12% under a 0.1 LNFS biomass scenario in GSV) and Southern Rock Lobster (increasing by almost 35% under a 0.1 ASL biomass scenario in SG) (Figures 7.21 and 7.22);
- some commercially fished species are directly or indirectly negatively, positively or neutrally impacted by increases or decreases in LNFS and ASL biomass, but as indicated above, for most species the magnitude of impact is very small (<1%);
- the response relationships are often non-linear and their direction (+ve or –ve) and degree of influence (slope) may change under low and high seal biomass scenarios;
- some of the response relationships differ between LNFS and ASL, and within species the response relationships often differ between the two Gulf model regions;
- the magnitude and range of the response relationship is typically greatest at low seal biomasses, and least at high seal biomasses.

Summaries of the species and regional response relationships are provided below.

Snapper
Snapper biomass responded positively to increases in LNFS biomass and negatively to increases in ASL biomass in both Gulf models (Figure 7.21a).

King George Whiting
King George Whiting biomass in the SG model showed a weak negative response to increasing LNFS biomass at low biomasses (0.1 to 1.0 current biomass), but a weak positive relationship to increasing LNFS biomass at high biomasses (1.0 to 10 current biomass) (Figure 7.21b). In the GSV model, King George Whiting biomass responded positively to increases in LNFS biomass (Figure 7.21b). King George Whiting biomass also responded positively to increases in ASL biomass in both Gulf models (Figure 7.21b).

Garfish
In the SG model, Garfish showed a weak positive response to increasing LNFS biomass at low biomasses, and a weak negative relationship thereafter (Figure 7.21c). In contrast, Garfish biomass responded negatively to increasing LNFS in the GSV model, especially at low biomasses (<1.0 current biomass), but the effect was reduced at higher biomasses (>1.0 current biomass) (Figure 7.21c). Garfish biomass responded negatively to increases in ASL biomass in both Gulf models, with the relationship being stronger in the SG model (Figure 7.21c).

Southern Calamari
In the SG model, Southern Calamari biomass responded negatively to increasing LNFS biomass at low biomasses (<1.0 current biomass), and then weakly positively at increasing LNFS biomasses (>1.0 current biomass) (Figure 7.21d). The pattern was similar for the GSV ecosystem, but with a weaker positive response at greater LNFS biomasses (Figure 7.21d). Southern Calamari biomass responded negatively to increasing ASL biomass in both Gulf models, however the relationship was weaker in the SG model at higher ASL biomasses (Figure 7.21d).

Sardine

In both Gulf models, Sardine biomass responded negatively to increasing LNFS biomass at lower biomasses (<1.0 current biomass) (although the relationship was much stronger for the SG model), and then weakly positive at higher LNFS biomasses (>1.0 current biomass) (Figure 7.21e). Sardine biomass showed a weak negative responses to increasing ASL biomass at low biomasses, and a strong positive response to increasing ASL biomass at higher biomasses (>1.0 current biomass) in both Gulf models (Figure 7.21e).

Western King Prawn

In the SG model, Western King Prawn biomass showed a weak positive response to increasing LNFS biomass, but showed a negative response at lower LNFS biomasses (<1.0 current biomass) and weak positive response at higher LNFS biomasses in the GSV ecosystem model (Figure 7.22a). Western King Prawn biomass showed a positive response to increasing ASL biomass in both Gulf models, and the relationship was stronger at higher ASL biomass in the GSV ecosystem model (Figure 7.22a).

Blue Crab

Blue Crab biomass generally responded positively to increasing LNFS biomass in both Gulf models, but the relationship was weaker in the SG ecosystem model at higher LNFS biomasses (Figure 7.22b). In contrast, Blue Crab biomass responded negatively to increasing ASL biomass in both Gulf models, but the relationship was weaker in the GSV ecosystem model (Figure 7.22b).

Southern Rock Lobster

Southern Rock Lobster biomass showed a variable and weak response at lower LNFS biomasses (<1.0 current biomass), but a strong positive response to LNFS biomass at higher biomasses (>1.0 current biomass) (Figure 7.22c). There was no discernible relationship between Southern Rock Lobster biomass at LNFS biomass in the GSV ecosystem model (Figure 7.22c). In contrast, Southern Rock Lobster biomass responded negatively to increasing ASL biomass in both Gulf models, but the relationship was weaker in the GSV ecosystem model (Figure 7.22c). The negative relationship between Southern Rock Lobster and ASL biomass in the SG ecosystem model was the strongest response relationship detected among all commercially fished species, with a ~35% increase in Southern Rock Lobster biomass at low ASL biomass levels (0.1 current biomass), and a ~20% decrease in biomass at high ASL biomass (10 times current biomass) (Figure 7.22c).

Key finding: Scenarios of the potential impacts of increasing seal populations on commercially fished species found no evidence that further increases in seal biomass would result in significant impacts on future fish production. Outputs from both the SG and GSV models indicated a less than 1% change in biomass of key commercially targeted finfish, cephalopod and crustacean taxa in response to LNFS biomass increasing from 0.1 to current biomass levels. Under increasing LNFS biomass scenarios (from current up to 10-fold current biomass levels), the biomass of key commercially fished taxa tended to increase as the biomass of LNFS increased.

Key finding: The study found that most key fished species responded non-linearly to changes in seal biomass, indicating that the indirect predation effects of seals on other predators or competitors of commercially fished species were more important than their direct predation on these species. In this way, seals are important in mediating predator-prey interactions that affect the biomass of many taxa, including those targeted by commercial fishers.

Impact of changes in seal biomass on other apex predators

The impact of changes in seal biomass on the biomasses of other apex predator groups (dolphins, seabirds, and sharks and rays) was estimated for the SG and GSV ecosystem models (Figure 7.23). As with the fish, cephalopod and crustacean groups, the responses by apex predator groups to changes in seal biomass were generally small, most were non-linear and the direction of response often changed under low and high seal biomass scenarios.

In the SG ecosystem model, dolphin biomass responded positively to increasing LNFS biomass at lower biomasses (<1.0 current biomass), but negatively to increasing LNFS biomass at higher biomasses (>1.0 current biomass) (Figure 7.23a). There was no discernible relationship between dolphin biomass and LNFS biomass in the GSV ecosystem model (Figure 7.23a). In contrast, dolphin biomass responded negatively to increasing ASL biomass in the SG ecosystem model, but positively to increasing biomass in the GSV ecosystem model (Figure 7.23a).

Seabirds as a group showed a variable response to LNFS biomass at low biomasses (<1.0 current biomass), but a negative response at higher biomasses (>1.0 current biomass) in the SG ecosystem model (Figure 7.23b). In the GSV ecosystem model, seabirds showed a negative response to LNFS at low biomasses which became weaker at high biomass (>1.0 current biomass) (Figure 7.23b). Seabirds showed a strong negative response to ASL at low biomass (<1.0 current biomass), and a weakly positive response at higher biomasses (>1.0 current biomass) in the SG ecosystem model, and a weakly negative response to ASL biomass in the GSV ecosystem model (Figure 7.23b).

Sharks and rays responded negatively to LNFS biomass at low biomasses, but positively at higher biomasses in the SG ecosystem model (Figure 7.23c). There was no discernible relationship between the biomass of sharks and rays and LNFS in the GSV ecosystem model, except for a weak positive response at very high biomasses (Figure 7.21c). The biomass of sharks and rays responded negatively to ASL biomass in both Gulf models, but the relationship was stronger for the SG ecosystem model (Figure 7.23c).

Some individual species response scenarios were also undertaken for species of conservation and/or ecotourism importance, including ASL response to changing LNFS biomass, and the response of Little Penguins and Giant Cuttlefish to changes in biomass of both seal species (Figure 7.24). A scenario examining the potential impact of changing ASL biomass on LNFS biomass could not be undertaken because female and male LNFS were modelled as separate trophic groups in both Gulf ecosystem models.

ASL biomass responded negatively to increasing LNFS biomass in the SG ecosystem model, and the relationship was stronger at lower biomasses, with a ~7% decline in ASL as LNFS biomass increased from 0.1 to 1.0 current biomass (Figure 7.24a). There was no discernible relationship between ASL and LNFS biomass in the GSV ecosystem model.

Little Penguin biomass showed a strong negative relationship with LNFS biomass in both Gulf models. The relationship was stronger at low LNFS biomasses (especially in the SG ecosystem model), and became weaker at higher biomass (>1.0 current biomass) (Figure 7.24b). The response relationship was the strongest of any of the scenarios undertaken in this study. The magnitude of decline in Little Penguin biomass as LNFS biomass increased from 0.1 to current biomass levels, was ~80% and ~60% in the SG and GSV ecosystem models, respectively (Figure 7.24b). Little Penguin biomass also showed a negative relationship to ALS biomass in the GSV ecosystem model, but it was much weaker than that for LNFS. There was no discernible relationship between Little Penguin and ASL biomass in the SG ecosystem model (Figure 7.24b).

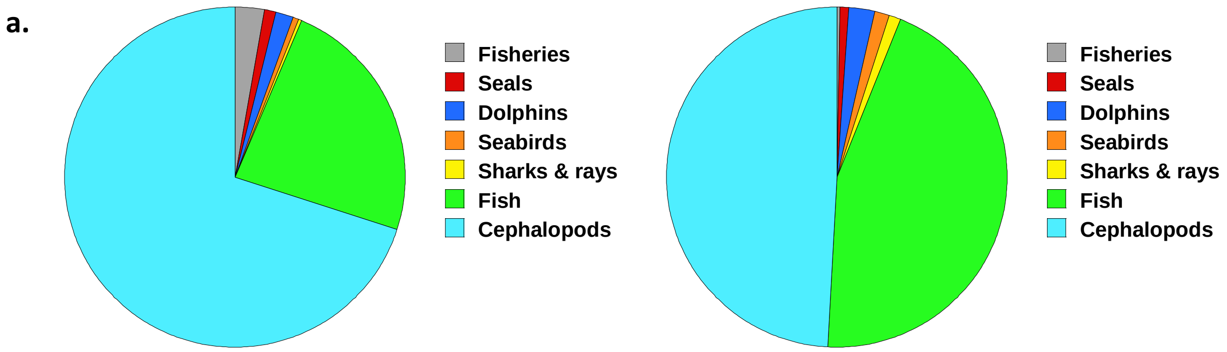
In the SG ecosystem model, Giant Cuttlefish biomass responded negatively to LNFS at low biomasses (<1.0 current biomass), and positively (but more weakly) at higher LNFS biomasses (between 1.0 to

10 fold current biomasses). In contrast, Giant Cuttlefish biomass in GSV showed a weak positive relationship with LNFS biomass at low and high LNFS biomasses (Figure 7.24c). Giant Cuttlefish responded negatively to ASL biomass in both Gulf models, although the relationship was stronger in the SG ecosystem (Figure 7.24c).

Key finding: Scenario modelling of increasing LNFS biomass in both the SG and GSV provided the first quantitative evidence that recovering LNFS populations may have contributed to declines in Little Penguin populations. However, the impact from other predators, such as sharks, may be underestimated in these models.

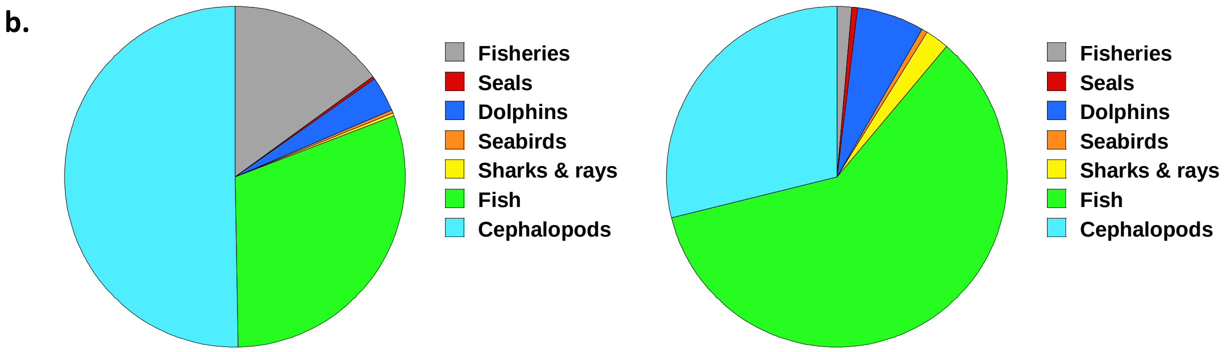
Table 7.7. Breakdown of the total estimated consumption by percentage of all finfish, all cephalopods, and commercially targeted key finfish (Snapper, King George Whiting, Garfish and Sardine), Southern Calamari and key crustaceans (Western King Prawns, Blue Crabs, Southern Rock Lobster) by all marine predator groups in the Spencer Gulf and Gulf St Vincent ecosystem models. Comparative estimates of consumption are provided excluding and including fisheries catches. The percentage consumed by Long-nosed Fur Seal (LNFS) and Australian Sea Lion (ASL) is also presented. Percentage consumption is based on total biomass consumed in the final year of Spencer Gulf (2010) and Gulf St Vincent models (2013).

	Taxa Group	Model region	Fisheries	Crustaceans	Cephalopods	Finfish	Sharks & rays	Seabirds	Dolphins	Seals	LNFS	ASL
Excluding fisheries catch	Finfish	SG			72.1%	24.2%	0.3%	0.5%	1.7%	1.2%	0.8%	0.3%
		GSV			49.2%	45.0%	1.1%	1.3%	2.6%	0.8%	0.3%	0.5%
	All cephalopods	SG			14.6%	78.9%	1.8%	0.2%	2.5%	2.1%	1.2%	0.9%
		GSV			16.4%	74.4%	3.6%	0.5%	2.4%	2.7%	0.6%	2.1%
	Key finfish	SG			59.1%	36.0%	0.3%	0.3%	3.9%	0.4%	0.4%	0.0%
		GSV			29.2%	61.1%	2.1%	0.6%	6.5%	0.6%	0.5%	0.0%
	Calamari	SG			4.2%	92.3%	1.4%	0.0%	1.6%	0.4%	0.17%	0.27%
		GSV			24.5%	15.2%	21.0%	0.2%	24.5%	14.7%	10.5%	4.1%
	Key crustaceans	SG		21.4%	25.7%	37.4%	14.9%	0.0%	0.0%	0.5%	0.0%	0.5%
		GSV		55.9%	15.3%	24.8%	3.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Including fisheries catch	Finfish	SG	2.8%		70.1%	23.5%	0.3%	0.5%	1.7%	1.1%	0.8%	0.3%
		GSV	0.4%		49.1%	44.9%	1.1%	1.3%	2.5%	0.8%	0.3%	0.5%
	All cephalopods	SG	0.2%		14.6%	78.7%	1.8%	0.2%	2.5%	2.1%	1.2%	0.9%
		GSV	0.4%		16.3%	74.1%	3.6%	0.4%	2.4%	2.7%	0.6%	2.1%
	Key finfish	SG	15.0%		50.2%	30.6%	0.3%	0.3%	3.3%	0.3%	0.3%	0.0%
		GSV	1.5%		28.8%	60.2%	2.0%	0.6%	6.4%	0.6%	0.5%	0.0%
	Calamari	SG	0.2%		4.1%	92.1%	1.4%	0.0%	1.6%	0.4%	0.2%	0.3%
		GSV	9.2%		22.2%	13.8%	19.0%	0.2%	22.2%	13.3%	9.6%	3.8%
	Key crustaceans	SG	0.9%	21.2%	25.5%	37.1%	14.8%	0.0%	0.0%	0.5%	0.0%	0.5%
		GSV	0.3%	55.7%	15.3%	24.8%	3.8%	0.0%	0.0%	0.0%	0.0%	0.0%



Finfish consumption - Spencer Gulf

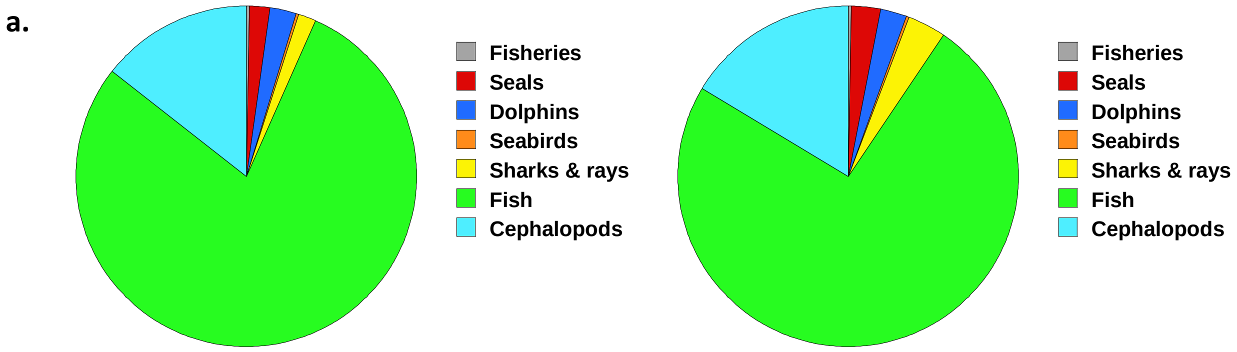
Finfish consumption - GSV



Key finfish consumption - Spencer Gulf

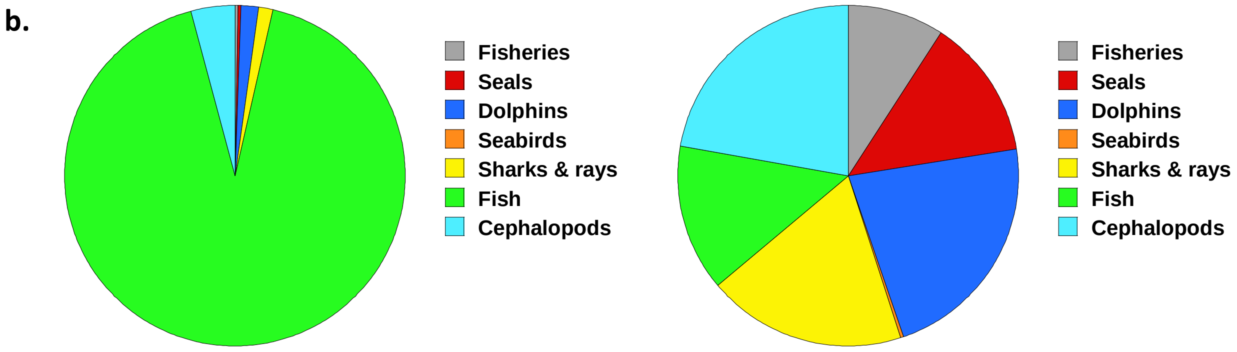
Key finfish consumption - GSV

Figure 7.6 Proportional breakdown of total consumption by predator groups and fisheries catches (landings and discards) of (a) all finfish, and (b) key finfish species (Snapper, King George Whiting, Garfish, Sardine), by all marine predator groups in the Spencer Gulf (left) and (GSV, right) ecosystem models.



Cephalopod consumption - Spencer Gulf

Cephalopod consumption - GSV



Calamari consumption - Spencer Gulf

Calamari consumption - GSV

Figure 7.7. Proportional breakdown of total consumption by predator groups and fisheries catches (landings and discards) of (a) all cephalopods, and (b) Southern Calamari, by all marine predator groups in the Spencer Gulf (left) and Gulf St Vincent (GSV, right) ecosystem models.

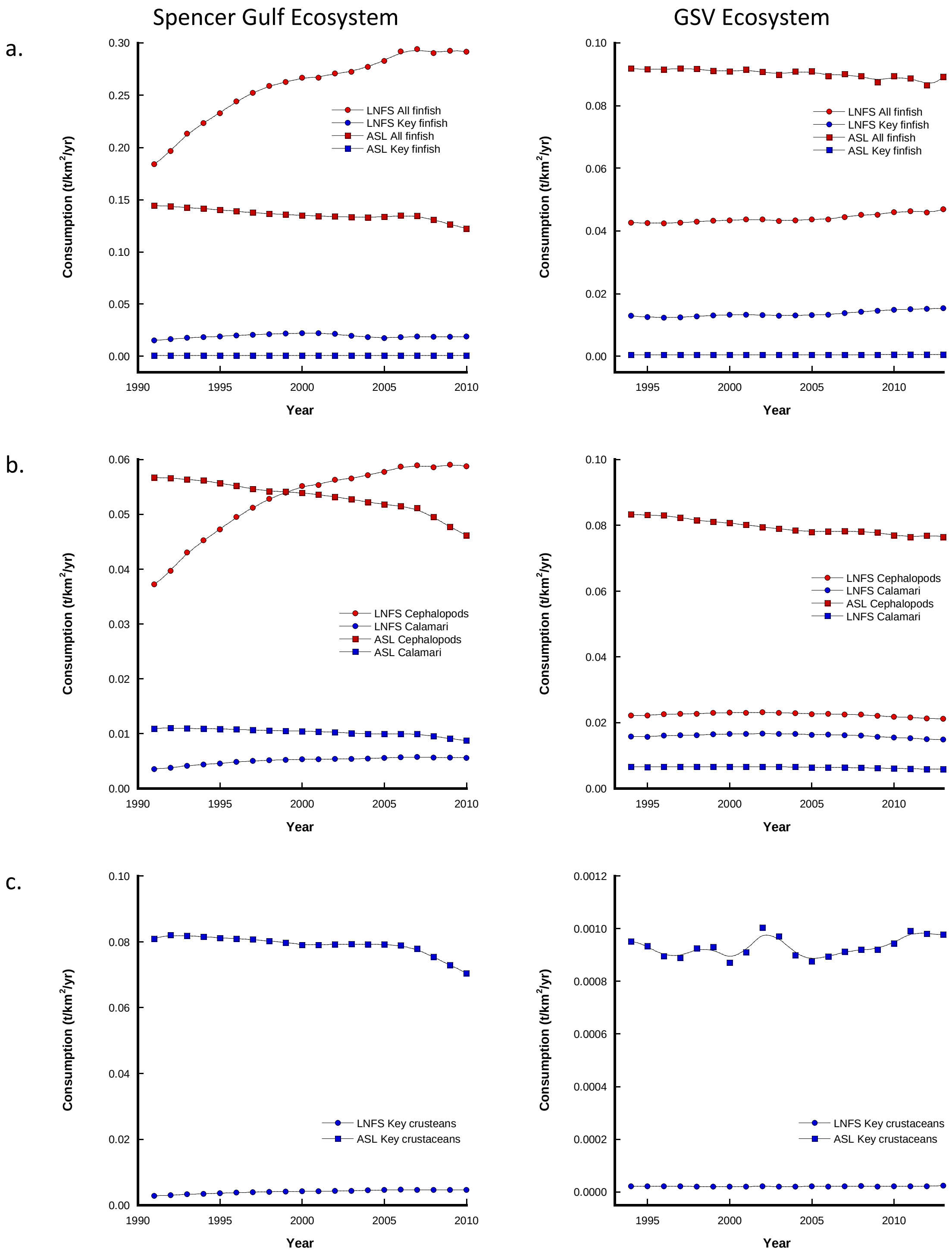


Figure 7.8. Temporal change in estimated annual consumption by Long-nosed Fur Seals (LNFS) and Australian Sea Lions (ASL) of (a) all finfish and commercially targeted key finfish species (Snapper, King George Whiting, Garfish, Sardine); (b) all cephalopods and commercially targeted Southern Calamari; and (c) commercially targeted key crustacean species (Western King Prawns, Blue Crabs, Southern Rock Lobster) in the Spencer Gulf (1990 to 2010) and Gulf St Vincent (GSV) ecosystems (1993 and 2013).

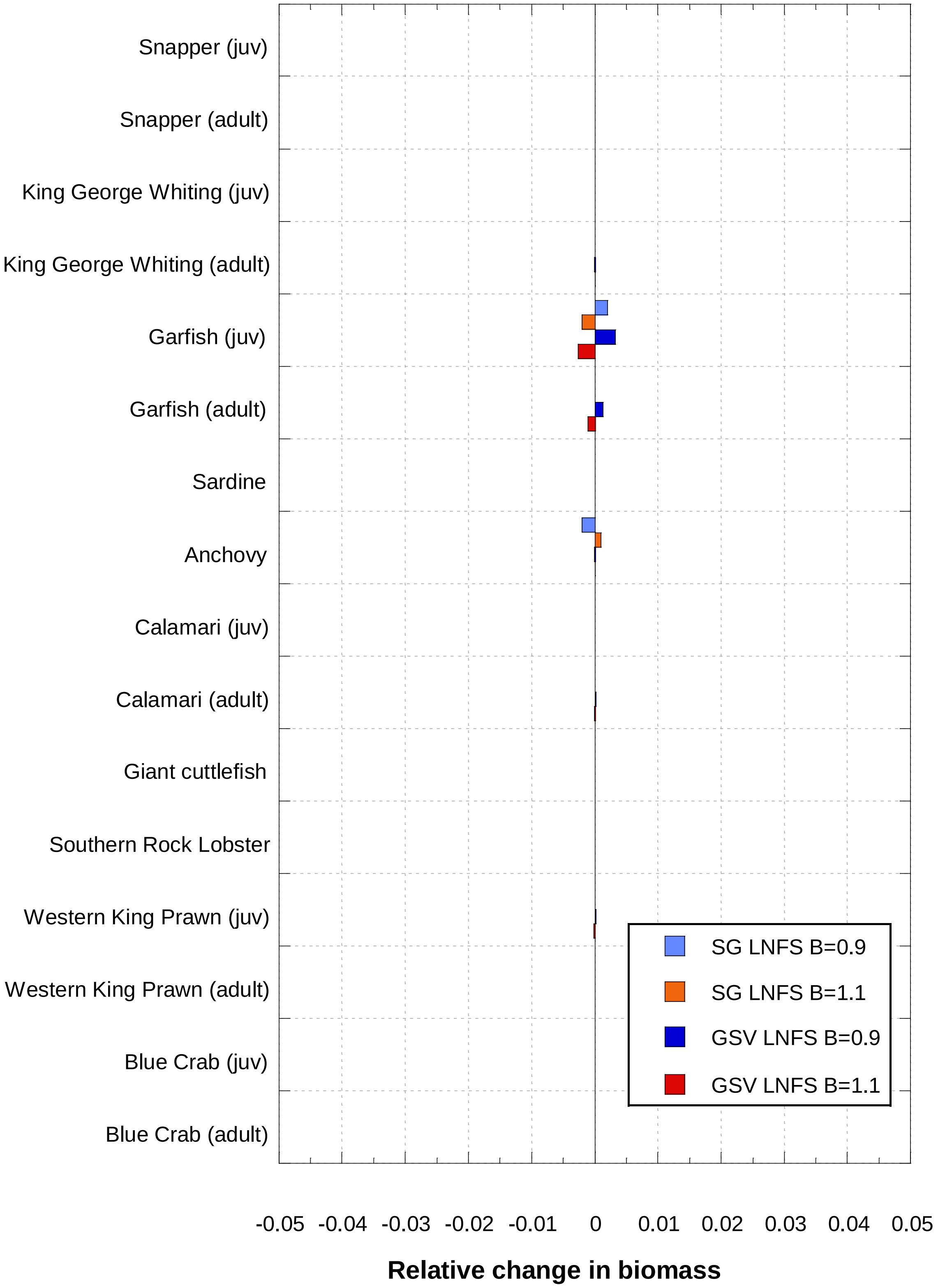


Figure 7.9. Sensitivity analyses estimating the relative change in the biomass of selected functional groups to either a 10% decrease (B=0.9) or a 10% increase (B=1.1) in Long-nosed Fur Seal (LNFS) biomass in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change under each scenario is plotted relative to the base model Spencer Gulf (2010) and GSV (2013) output run over a 50-year period.

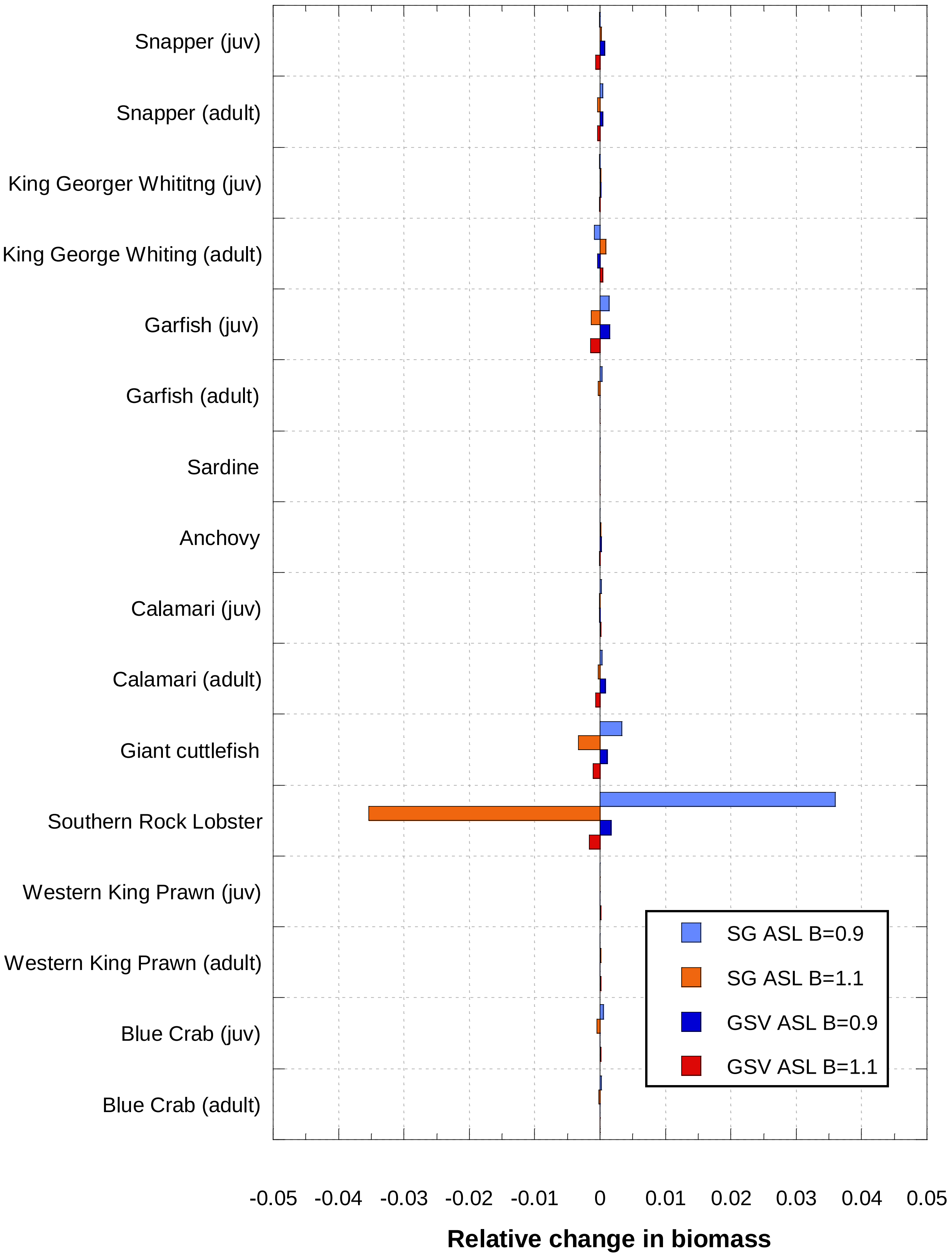


Figure 7.10. Sensitivity analyses estimating the relative change in the biomass of selected functional groups to either a 10% decrease (B=0.9) or a 10% increase (B=1.1) in Australian Sea Lion (ASL) biomass inthe Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change under each scenario is plotted relative to the base model SG (2010) and GSV (2013) output run over a 50-year period.

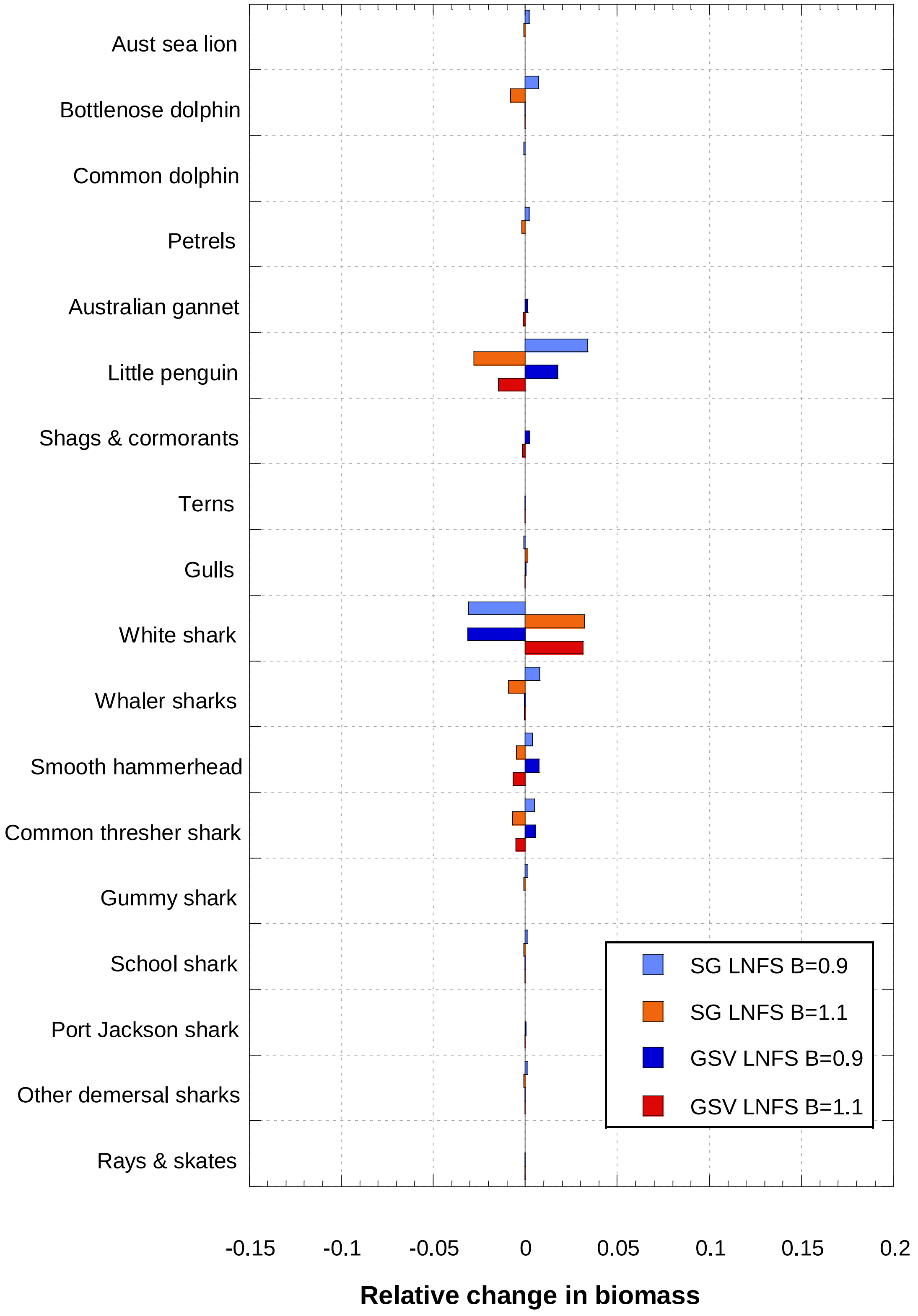


Figure 7.11. Sensitivity analyses estimating the relative change in the biomass of selected functional groups to either a 10% decrease (B=0.9) or a 10% increase (B=1.1) in Long-nosed Fur Seal (LNFS) biomass in theSpencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change under each scenario is plotted relative to the base model SG (2010) and GSV (2013) output run over a 50-year period.

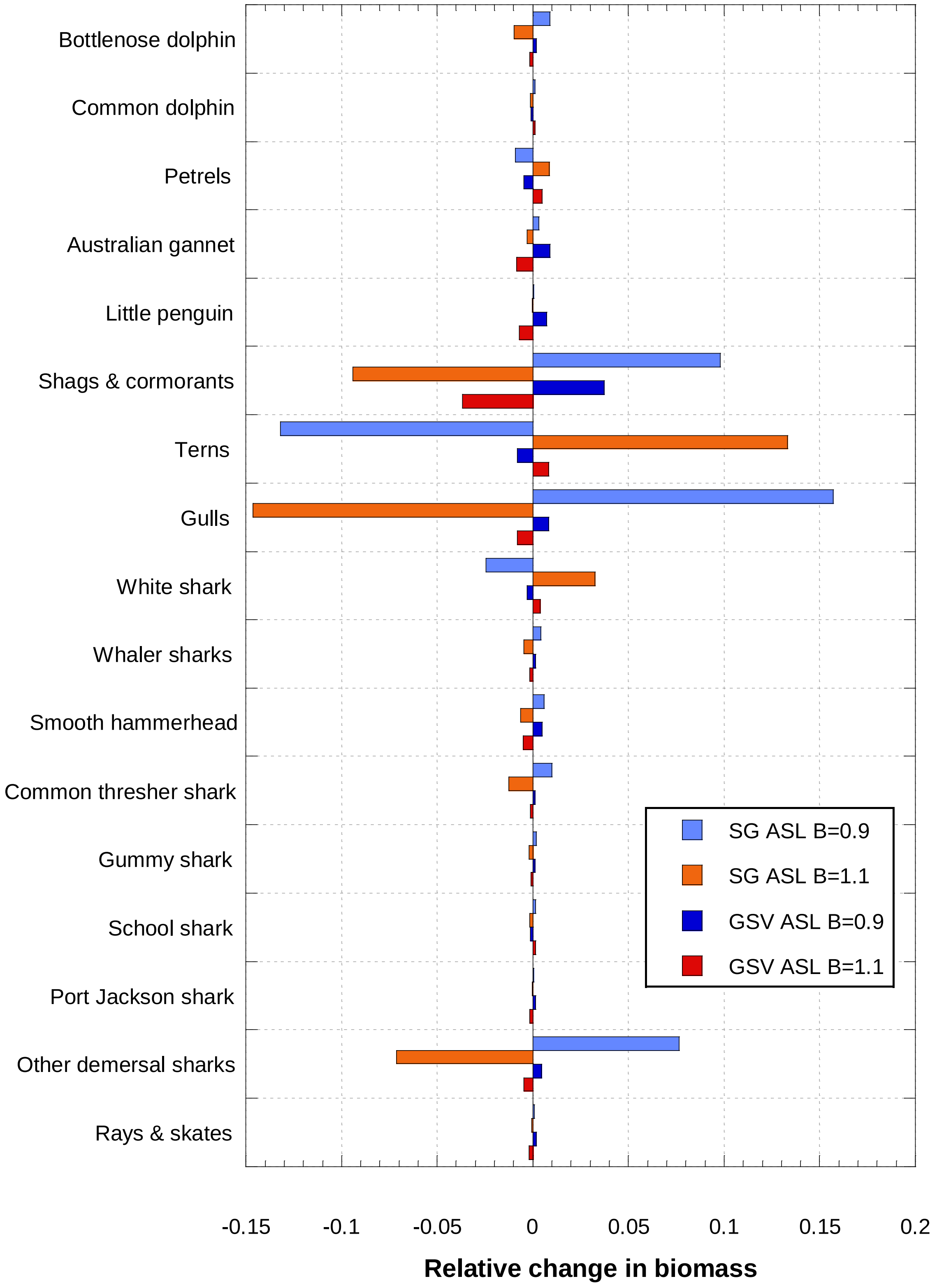


Figure 7.12. Sensitivity analyses estimating the relative change in the biomass of selected functional groups to either a 10% decrease (B=0.9) or a 10% increase (B=1.1) in Australian Sea Lion (ASL) biomass in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change under each scenario is plotted relative to the base model SG (2010) and GSV (2013) output run over a 50-year period.

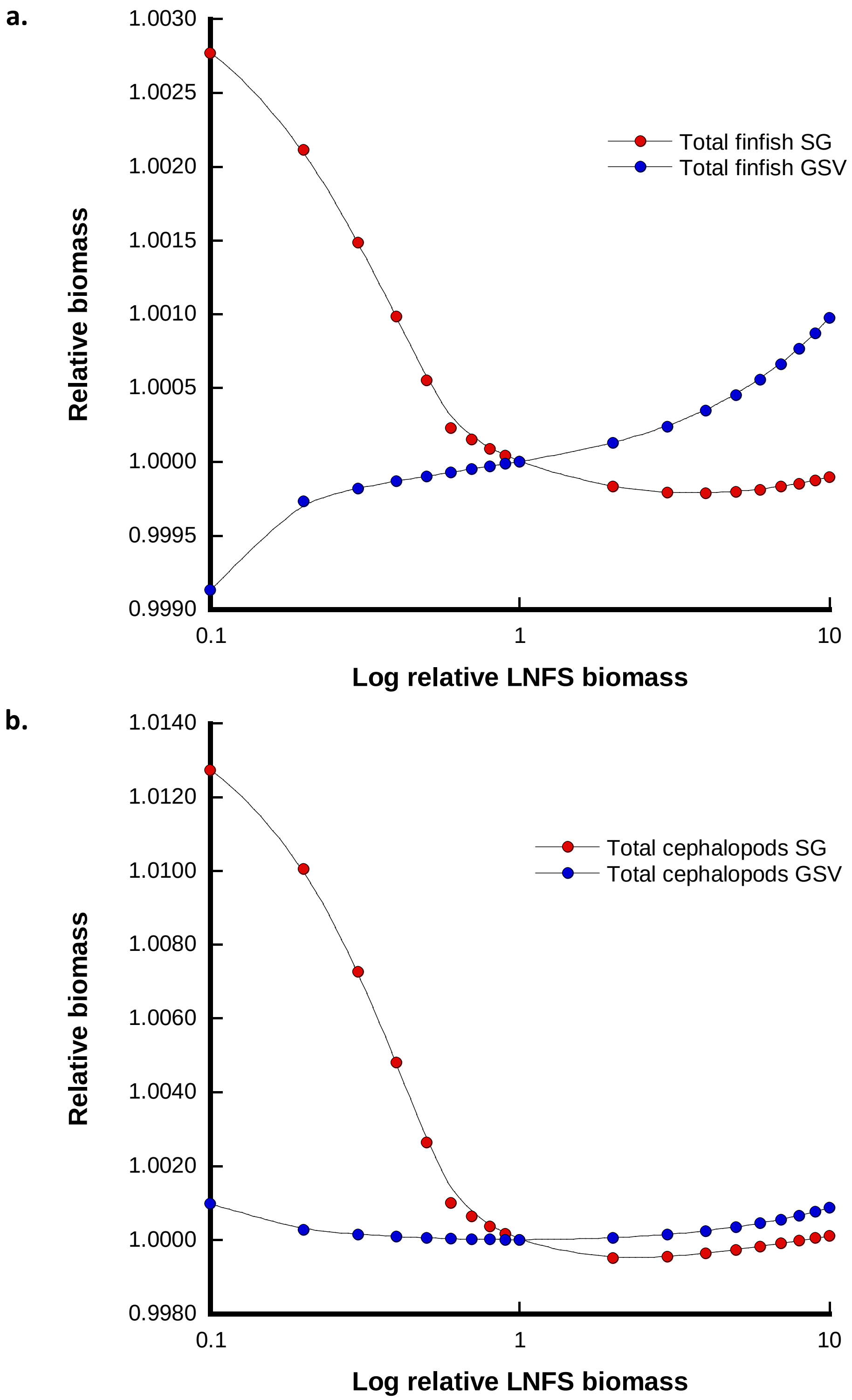


Figure 7.13. Relative biomass change of (a) all finfish, and (b) all cephalopods to different scenarios of Long-nosed Fur seal (LNFS) biomass in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass relates to the base model biomasses for the SG (2010) and GSV (2013) ecosystem models.

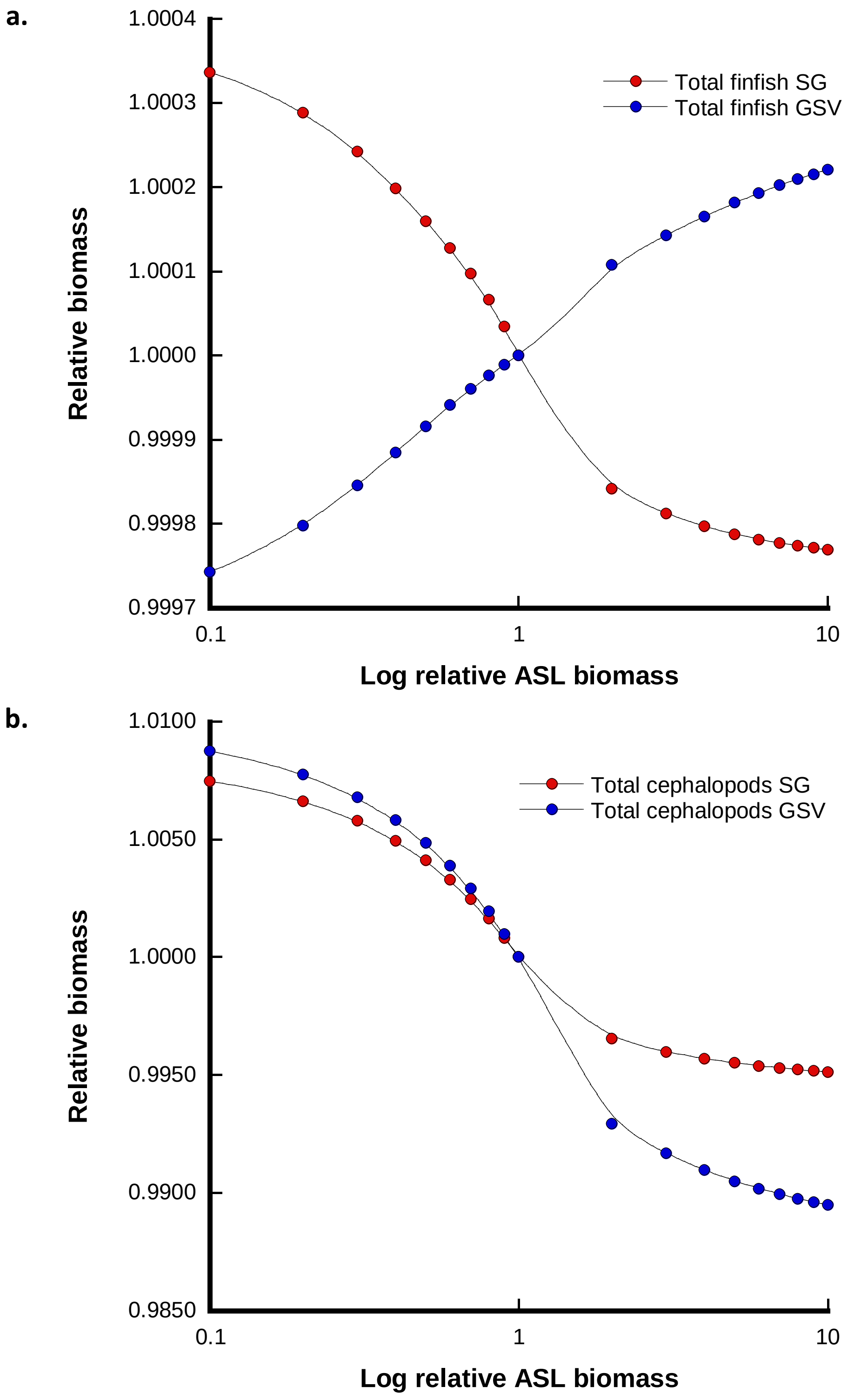


Figure 7.14. Relative biomass change of (a) all finfish, and (b) all cephalopods to different scenarios of Australian Sea Lion (ASL) biomass in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass relates to the base model biomasses for the SG (2010) and GSV (2013) ecosystem models.

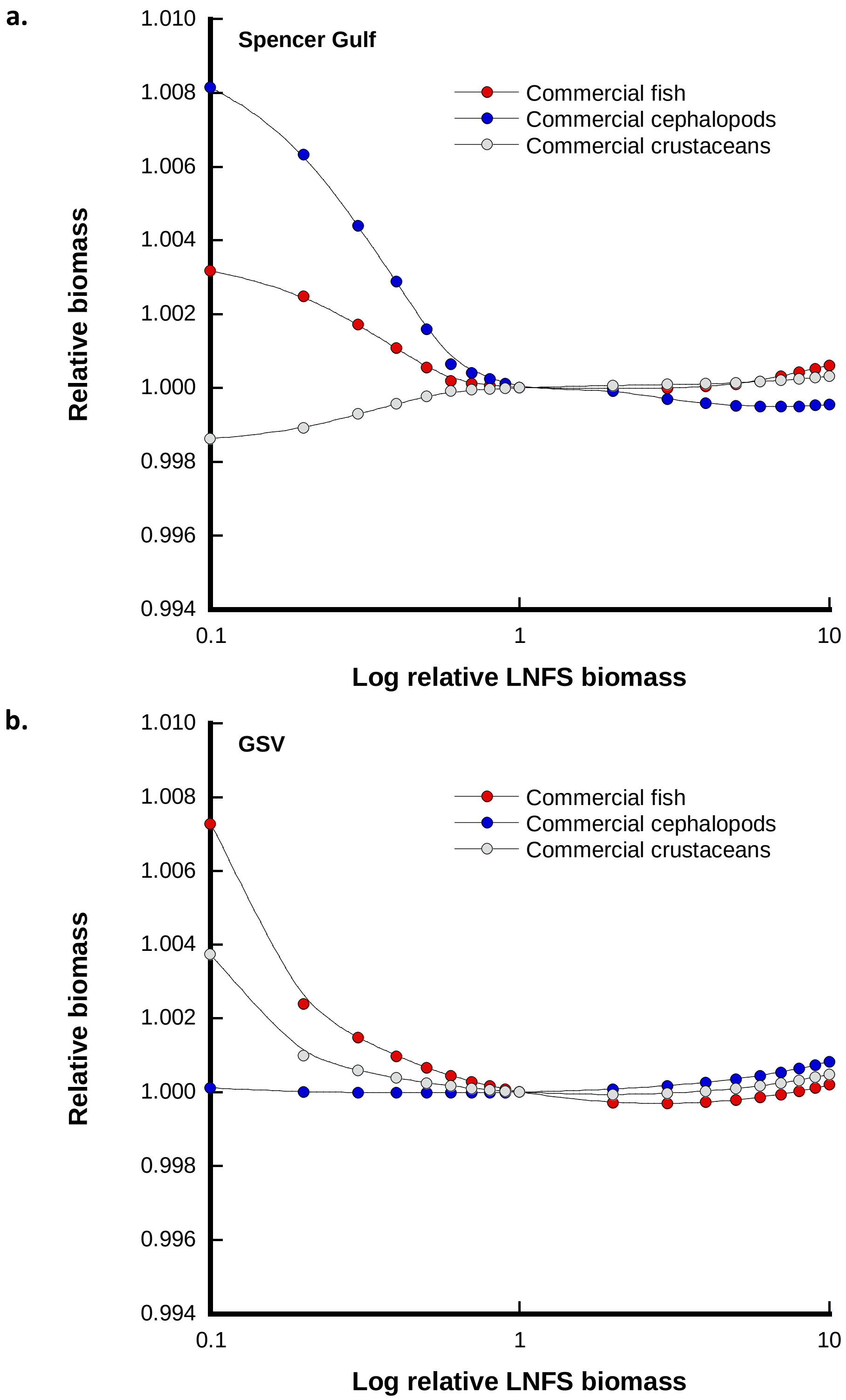


Figure 7.15. Relative biomass change of key commercially targeted fish (Snapper, King George Whiting, Garfish and Sardine), cephalopods (Southern Calamari) and crustaceans (Southern Rock Lobster, Western King Prawns, Blue Crabs) to different scenarios of Long-nosed Fur Seal (LNFS) biomass in the Spencer Gulf (a) and Gulf St Vincent (GSV) (b) ecosystem models. Relative biomass relates to the base model biomasses for the Spencer Gulf (2010) and GSV (2013) ecosystem models.

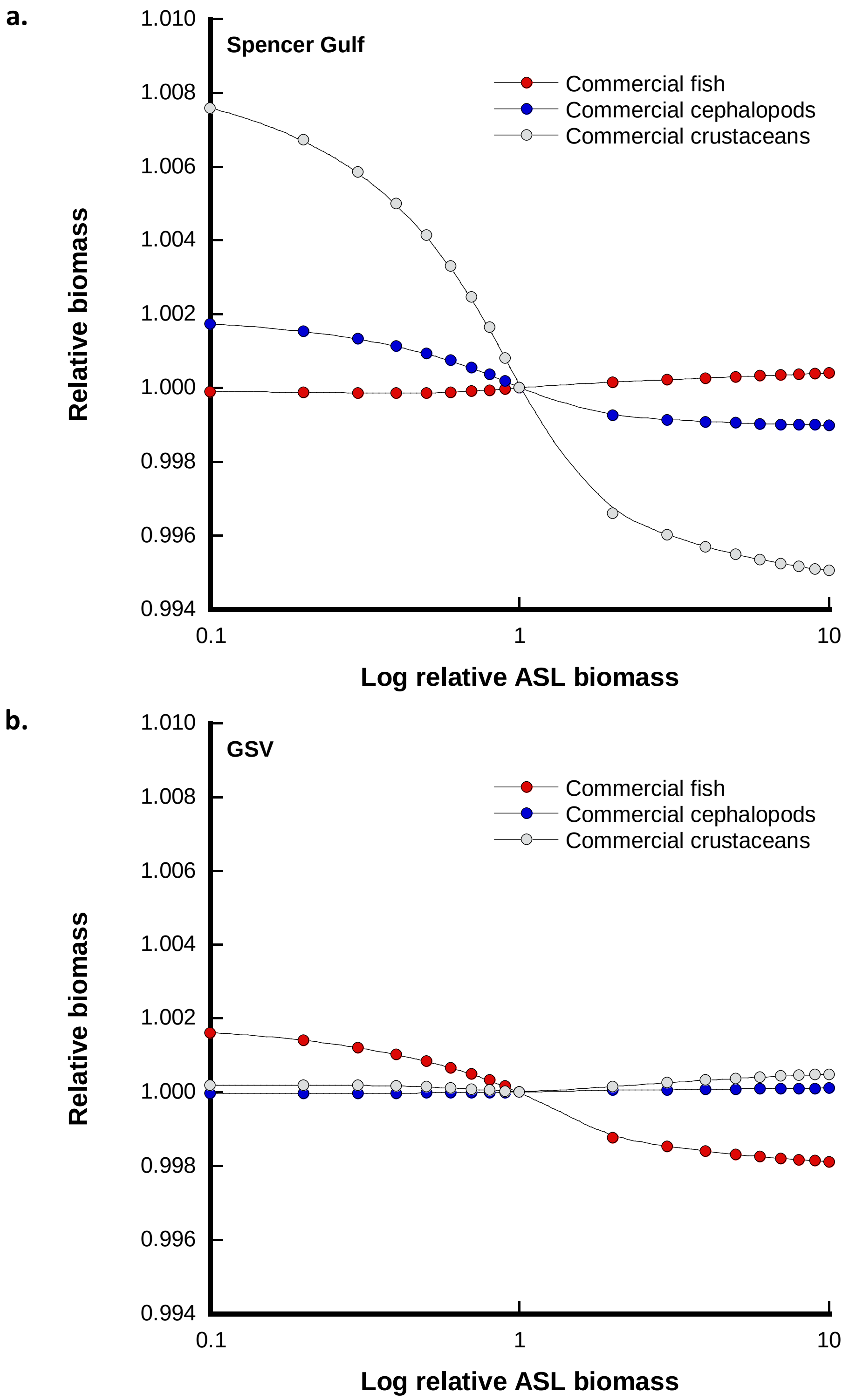


Figure 7.16. Relative biomass change of key commercially targeted fish (Snapper, King George Whiting, Garfish and Sardine), cephalopods (Southern Calamari) and crustaceans (Southern Rock Lobster, Western King Prawns, Blue Crabs) to different scenarios of Australian Sea Lion (ASL) biomass in the Spencer Gulf (a) and Gulf St Vincent (GSV) (b) ecosystem models. Relative biomass relates to the base model biomasses for the Spencer Gulf (2010) and GSV (2013) ecosystem models.

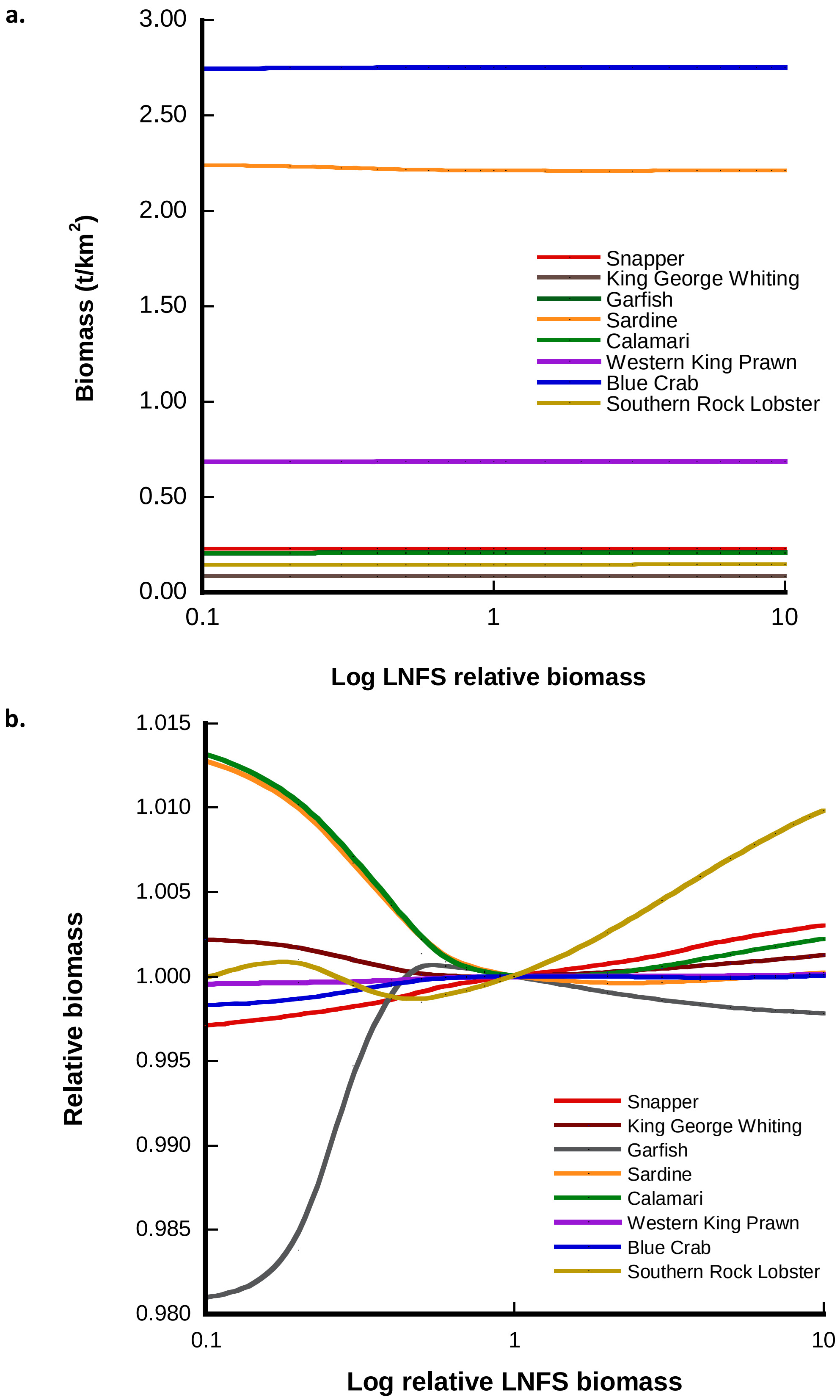


Figure 7.17. Absolute (a) and relative (b) biomass changes of key commercially fished species under different scenarios of Long-nosed Fur Seal (LNFS) biomass in the Spencer Gulf ecosystem model. Relative biomass change relates to the base model biomasses for the Spencer Gulf ecosystem model in 2010.

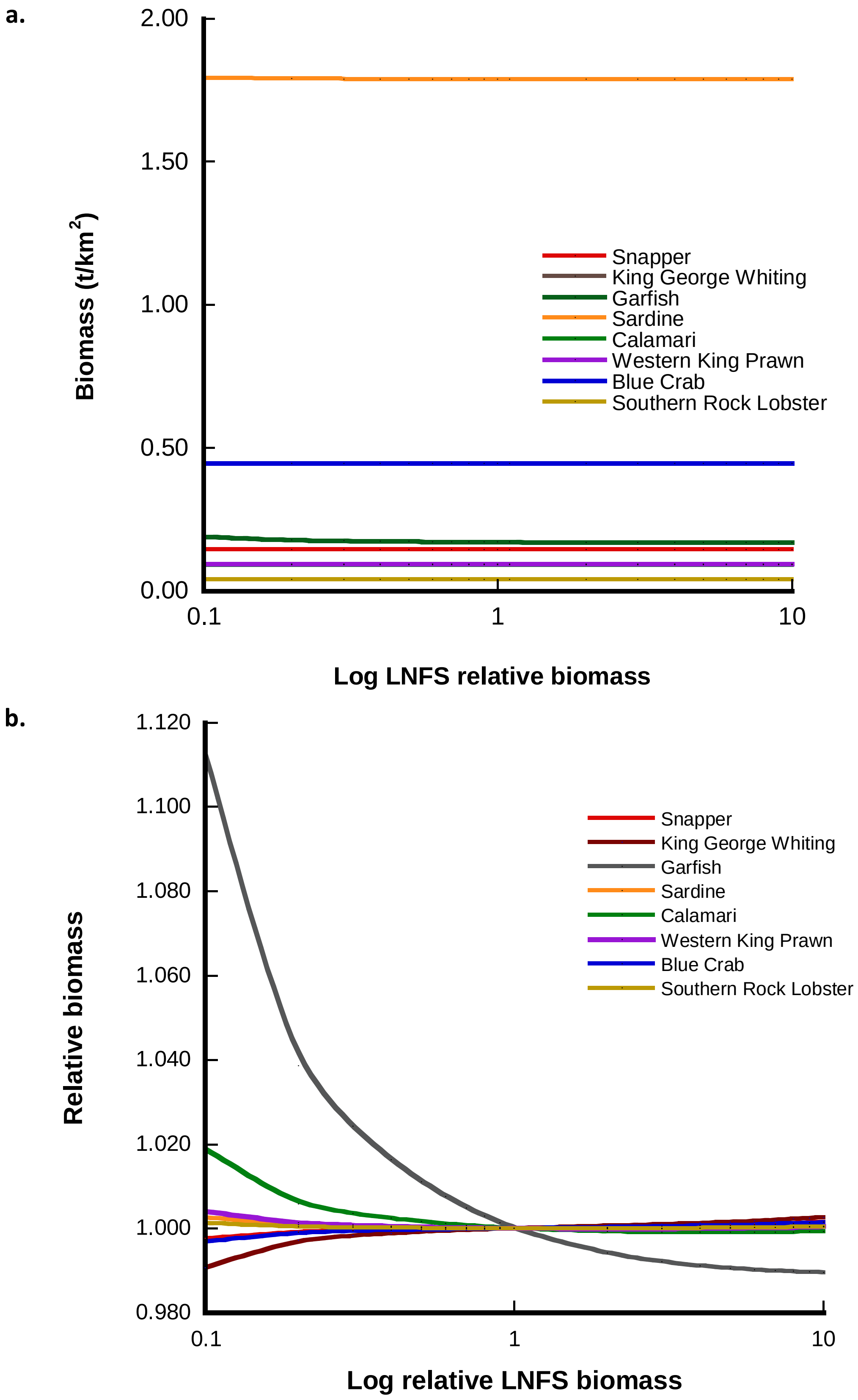


Figure 7.18. Absolute (a) and relative (b) biomass changes of key commercially fished species under different scenarios of Long-nosed Fur Seal (LNFS) biomass in the Gulf St Vincent ecosystem model. Relative biomass change relates to the base model biomasses for the Gulf St Vincent ecosystem model in 2013.

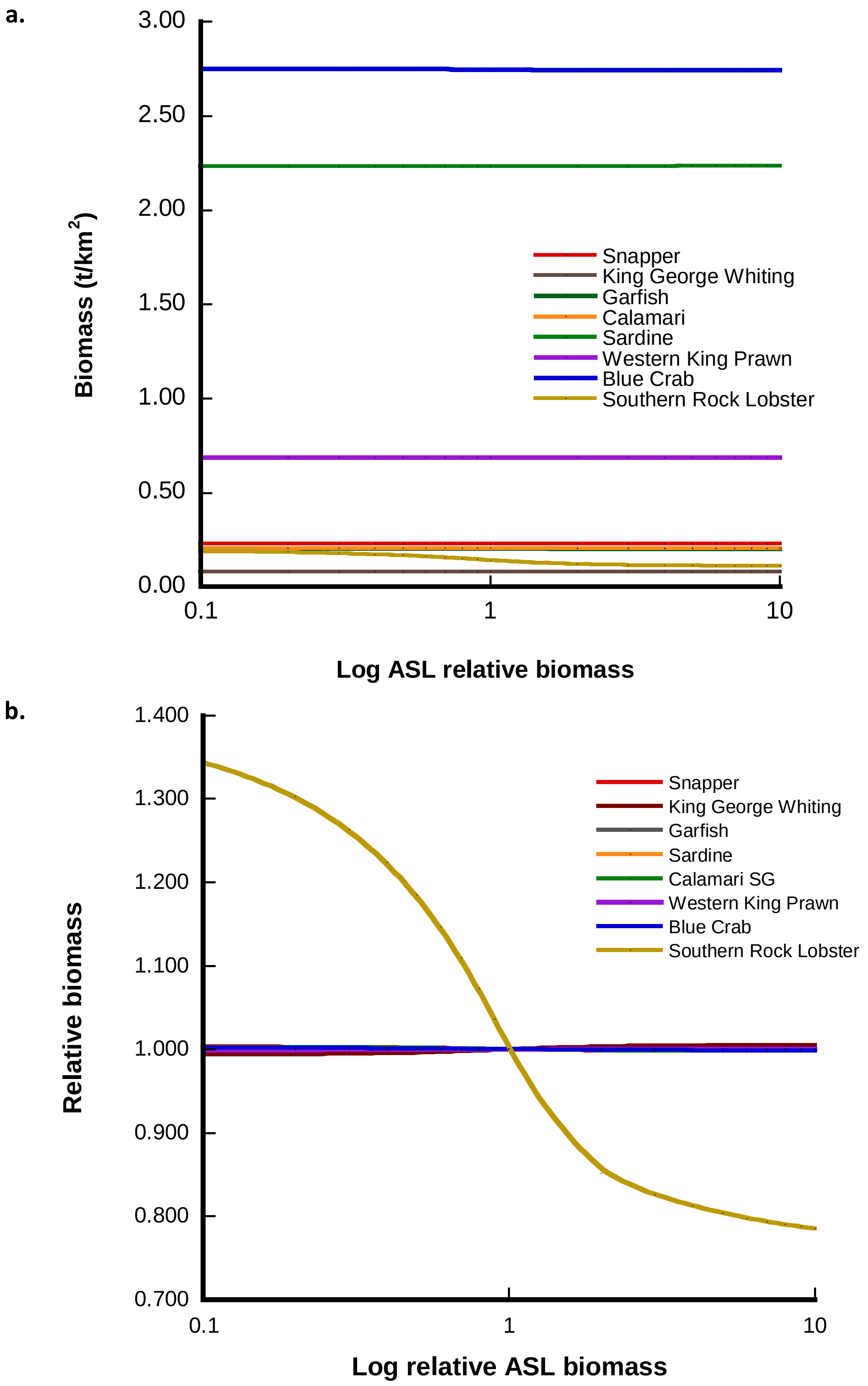


Figure 7.19. Absolute (a) and relative (b) biomass changes of key commercially fished species under different scenarios of Australian Sea Lion (ASL) biomass in the Spencer Gulf ecosystem model. Relative biomass change relates to the base model biomasses for the Spencer Gulf ecosystem model in 2010.

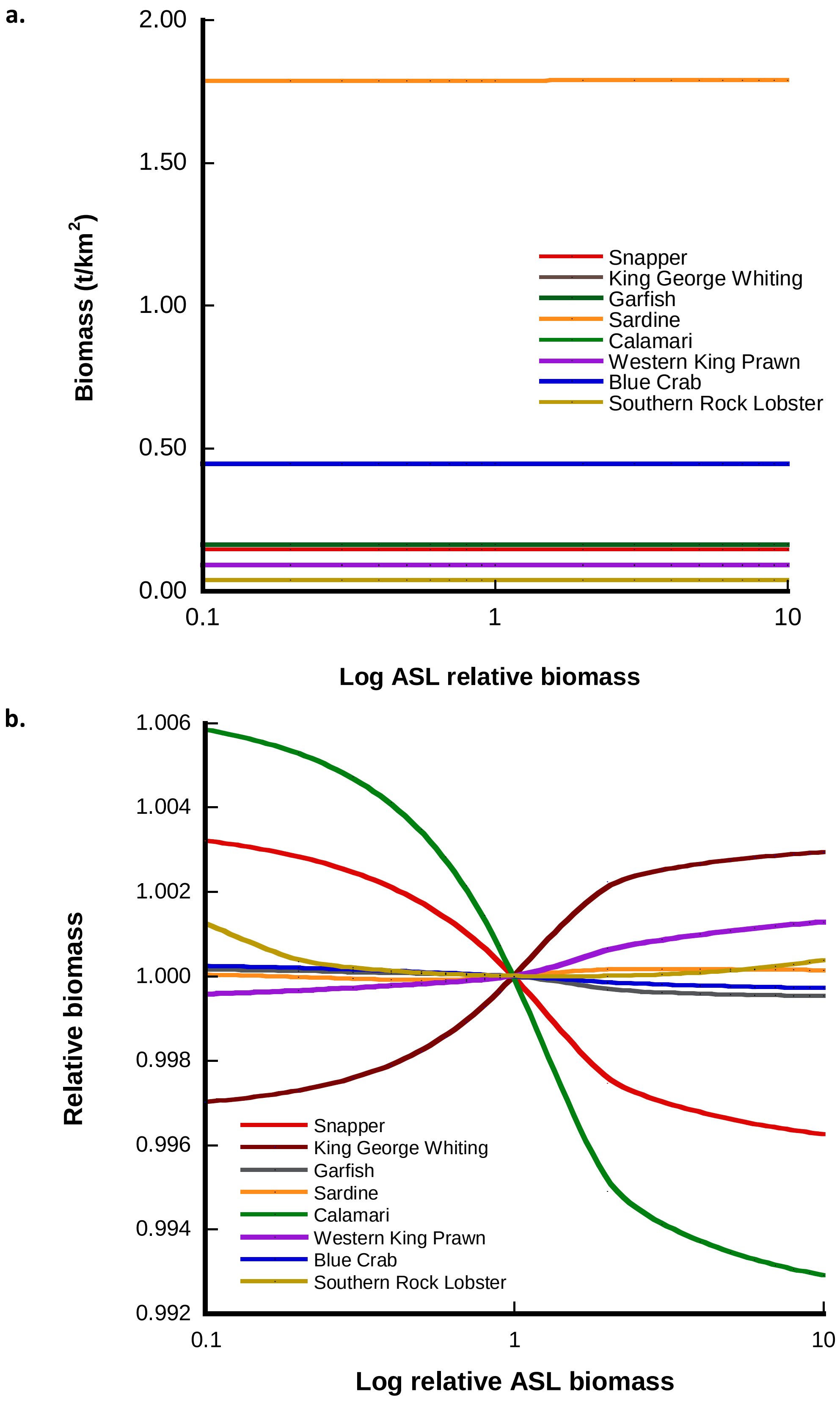


Figure 7.20. Absolute (a) and relative (b) biomass changes of key commercially fished species under difference scenarios of Australian Sea Lion (ASL) biomass in the Gulf St Vincent ecosystem model. Relative biomass change relates to the base model biomasses for the Gulf St Vincent ecosystem model in 2013.

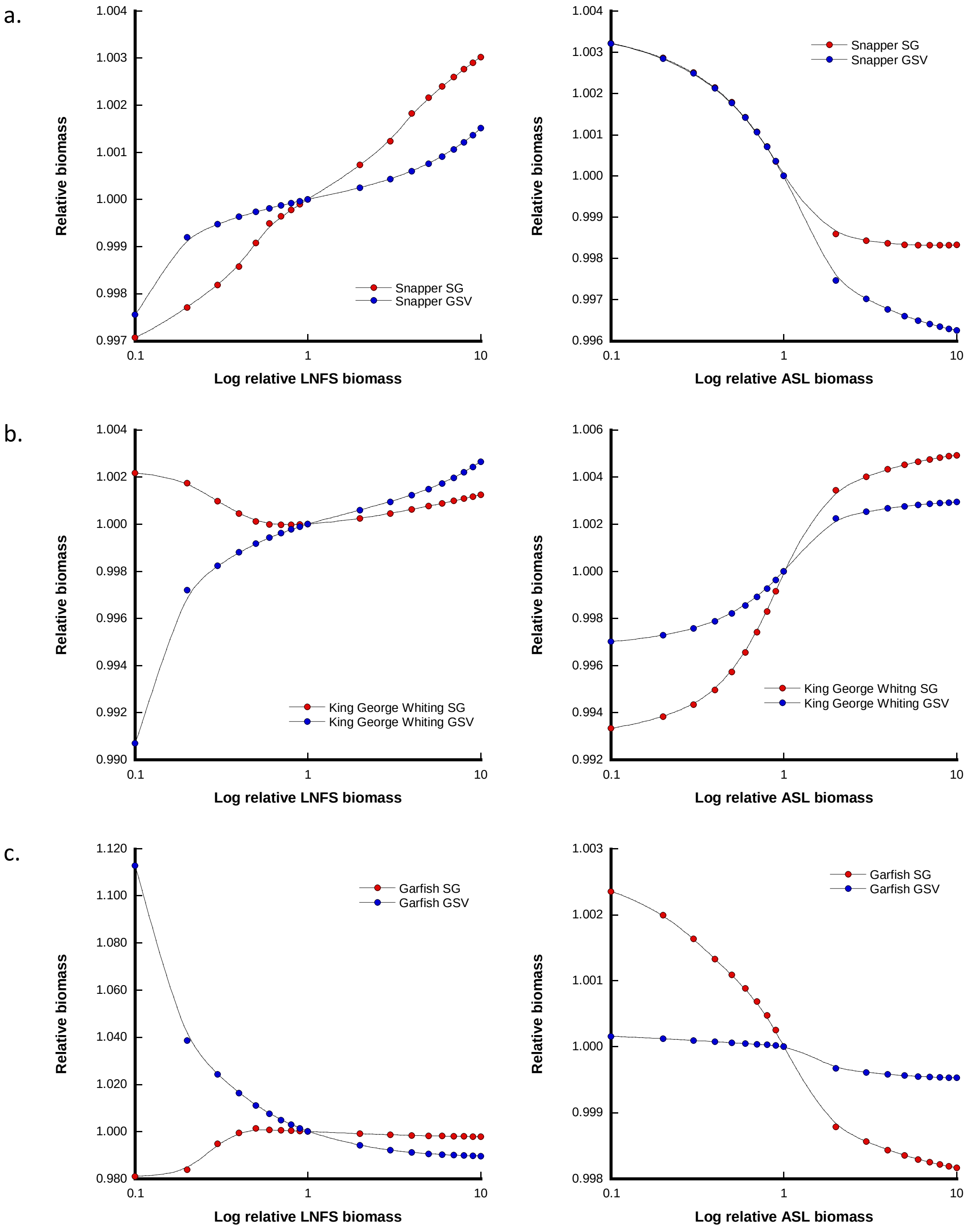


Figure 7.21. Relative biomass changes of (a) Snapper, (b) King George Whiting, (c) Garfish, (d) Sardine and (e) Southern Calamari under difference scenarios of Long-nosed Fur Seal (LNFS, left hand panels) and Australian Sea Lion (ASL) biomass (right hand panels) in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change relates to the base model biomasses for the SG (2010) and GSV (2013) ecosystem models.

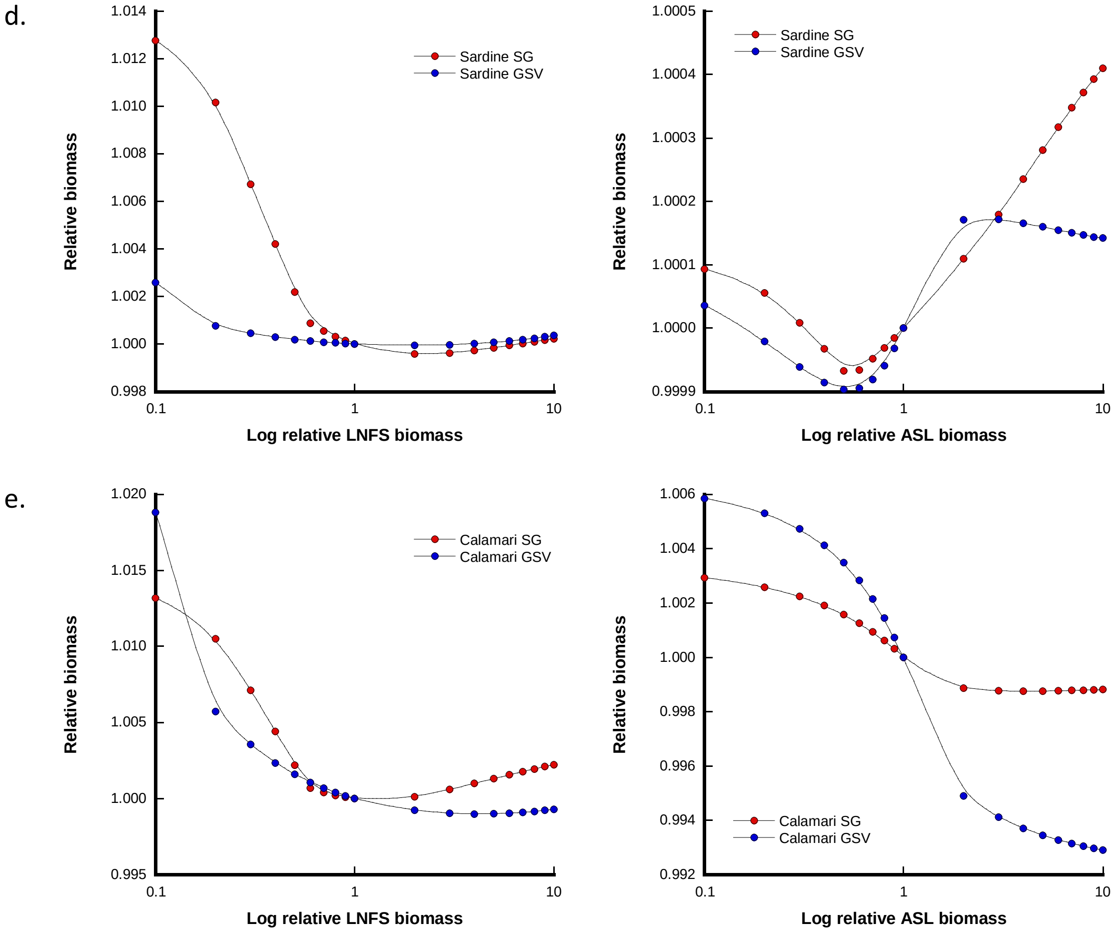


Figure 7.21. cont.

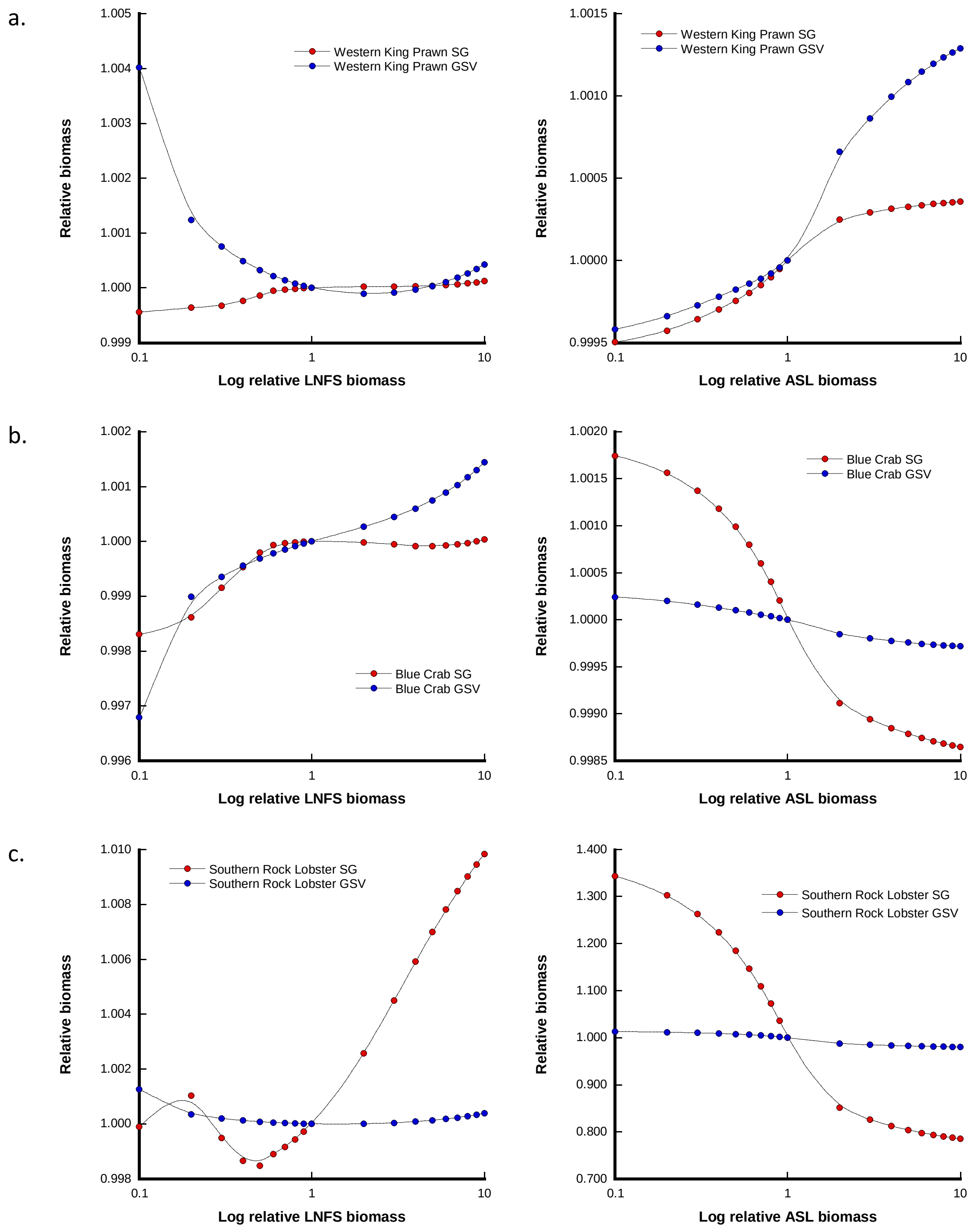


Figure 7.22. Relative biomass changes of (a) Western King Prawn, (b) Blue Crab and (c) Southern Rock Lobster under different scenarios of Long-nosed Fur Seal (LNFS, left hand panels) and Australian Sea Lion (ASL) biomass (right hand panels) in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change relates to the base model biomasses for the SG (2010) and GSV (2013) ecosystem models.

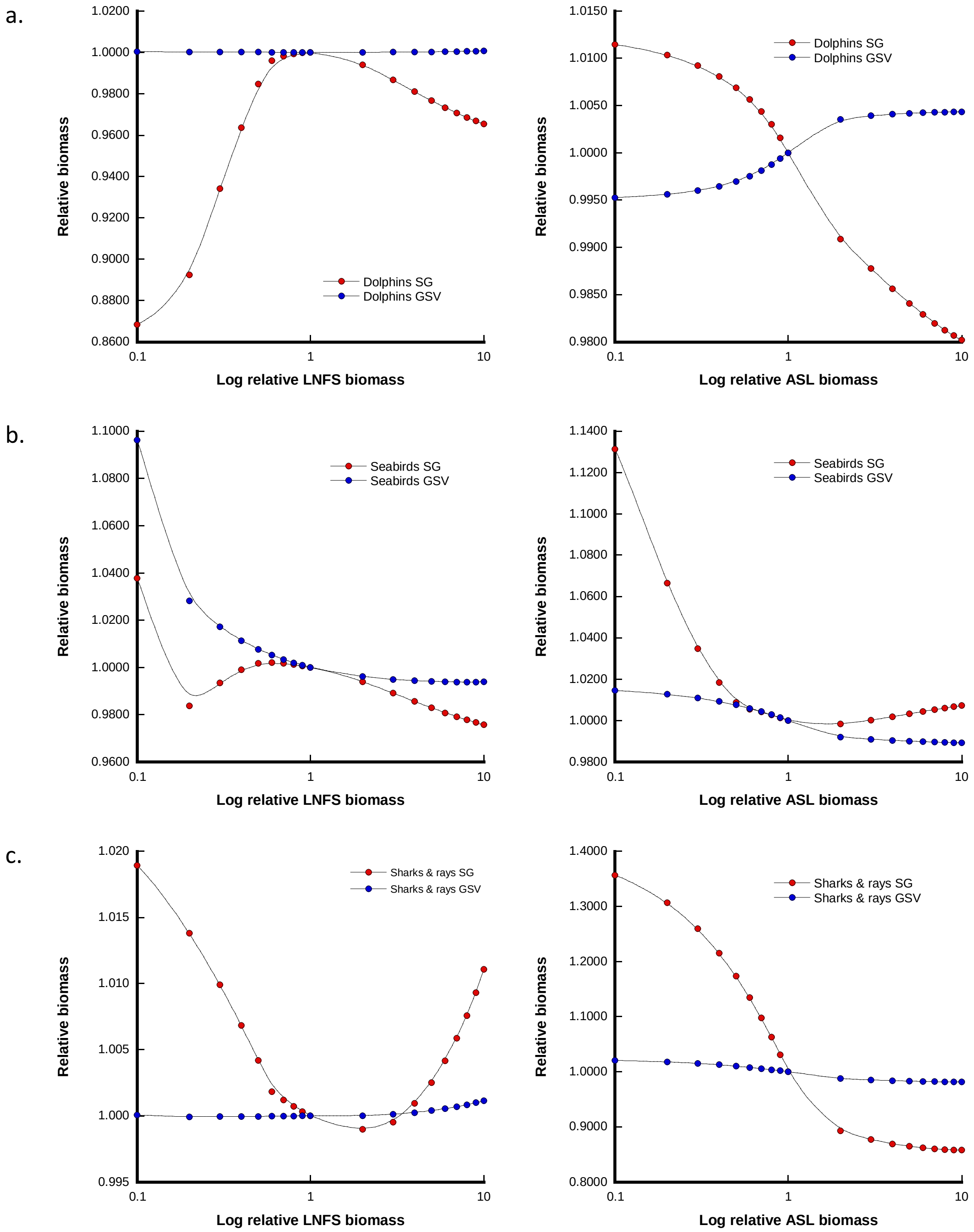


Figure 7.23. Relative biomass changes of (a) dolphins, (b) seabirds and (c) sharks and rays groups under different scenarios of Long-nosed Fur Seal (LNFS, left hand panels) and Australian Sea Lion (ASL) biomass (right hand panels) in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change relates to the base model biomasses for the SG (2010) and GSV (2013) ecosystem models.

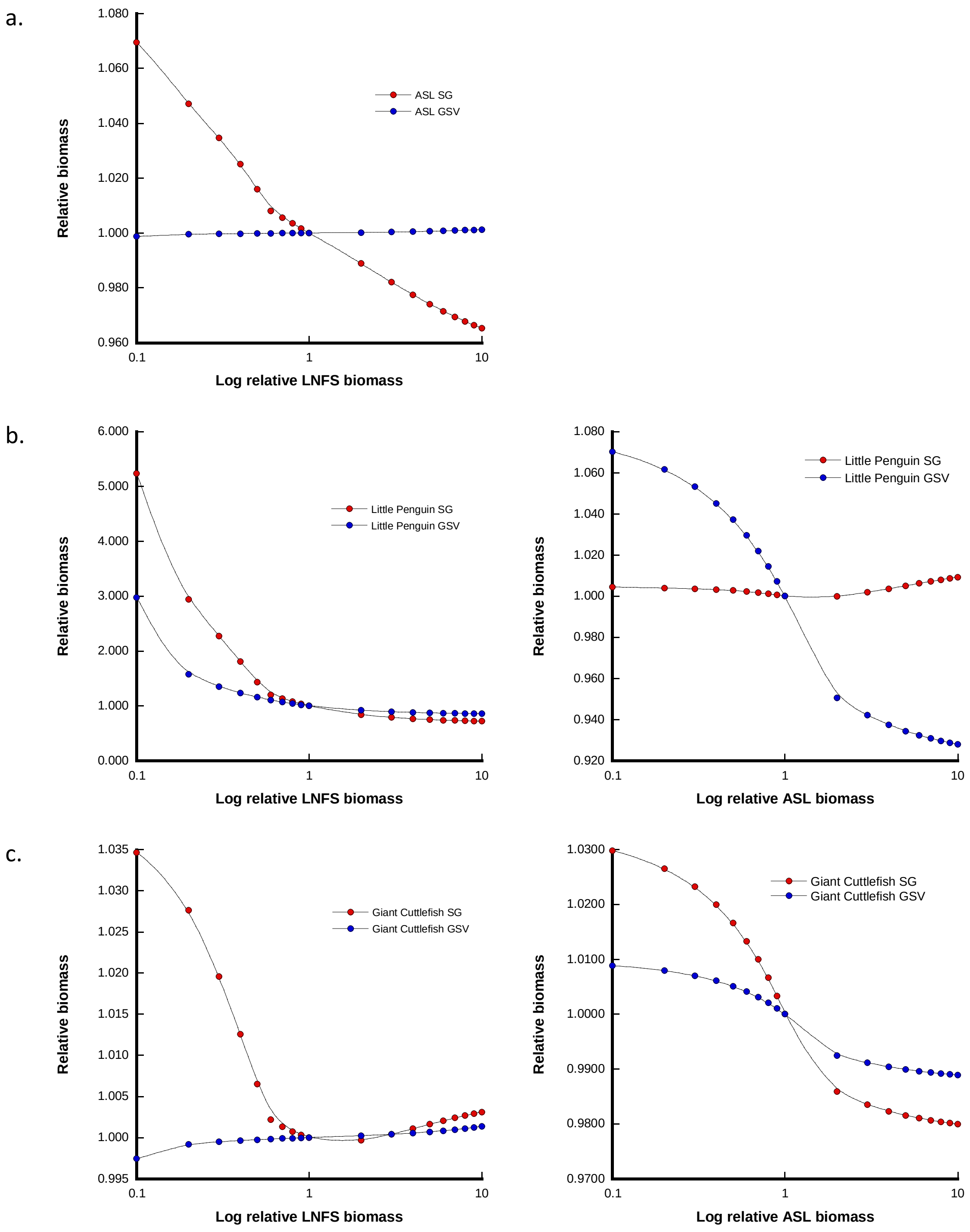


Figure 7.24. Relative biomass changes of (a) Australian Sea Lions (ASL), (b) Little Penguins and (c) Giant Cuttlefish under different scenarios of Long-nosed Fur Seal (LNFS, left hand panels) and Australian Sea Lion (ASL) biomass (right hand panels) in the Spencer Gulf (SG) and Gulf St Vincent (GSV) ecosystem models. Relative biomass change relates to the base model biomasses for the SG (2010) and GSV (2013) ecosystem models.

7.4 Discussion

This study provides the most comprehensives synthesis of the diet of South Australian pinnipeds. By combining all available diet data based on faecal hard parts, prey DNA and crittercam data, this study has significantly improved our understanding of pinniped diets, especially with respect to the relative importance of commercially fished species. It has identified that ASL and LNFS preyed on a large number of taxa (181 and 143, respectively), compared to AFS (34. This is likely to reflect, in part, the limited number of samples and data available for AFS in SA. Fish were found to be the most numerous prey, accounting for more that 68% of prey taxa, followed by cephalopods (12-16%). However, commercially fished taxa only made up between 4-6% of the total number of taxa consumed across all three pinnipeds.

In terms of estimated prey biomass consumed, ASL were estimated to consume fish and cephalopods in similar proportions (50% and 45%, respectively), while more fish and fewer cephalopods were estimated to be consumed by LNFS (81% and 15%, respectively) and AFS (95% and 1%, respectively). Commercially targeted fish species were estimated to contribute to just 5.0%, 4.3% and 1.6% to the total dietary biomass of LNFS, ASL and AFS, respectively. For LNFS, only three key commercial taxa were significant contributors to the overall diet, Garfish (1.8%), Southern Calamari (1.7%) and Sardine (1.3%). For ASL, the only commercial taxa that accounted for significant prey biomass was Southern Calamari (3.6%). For AFS, Garfish and Blue Crab were the only commercially fished species detected, but both were very minor contributors to estimated dietary biomass (just 0.8% in both cases).

Regional variation in diet could be assessed for LNFS, and indicated that Garfish, Sardine and Southern Calamari were prey in all regions, except the Coorong. King George Whiting were detected in all regions except the West Coast and Coorong, and Snapper was only detected in SG and GSV. Yellow-eye Mullet and Mulloway were detected in the diet of LNFS in the Coorong, while Western King Prawn were only detected in GSV, and Blue Crabs were only detected in SG and the south coast of Kangaroo Island. In terms of estimated dietary biomass, commercial taxa were a very minor contributor to the diets of LNFS on the West Coast (0.6%), south coast of Kangaroo Island (0.7%) and the Coorong (0.1%); they were more prevalent in SG (6.0%) and were a major part of the diet in GSV (52.2%). Subadult (SAM) and adult males were the main age-classes that consumed commercially fished taxa in SG (5.9% and 5.0%, respectively), where the key commercial taxa was Sardine; and in GSV (42.9% and 42.0%, respectively), where the key commercial taxa consumed was Calamari (24.4% by SAMs, 23.7% by adult males) and Garfish (16.8% by SAMs, 16.7% by adult males).

In summary, the key findings from the dietary analyses were:

- commercially fished taxa account for a small component of pinniped diet, both in terms of number of prey taxa and estimated biomass, and were estimated to make up just 5%, 4%, and 2% of the total prey biomass of LNFS, ASL and AFS;
- commercially fished taxa constituted a low prey biomass in the diet of LNFS across most regions in SA, the highest being in SG (6%) and GSV (52%);
- in LNFS, most consumption of commercially fished taxa was by subadult and adult males, and the key commercially fished taxa consumed were Sardine (3% of prey biomass) in SG, and Calamari (24%) and Garfish (17%) in GSV.

A key challenge in this study, as with all studies on marine predator diets, was accounting for all the potential pitfalls and biases of the various dietary estimation and reconstruction methods, in order to estimate ‘true diet’ (Chiaradia *et al.* 2014). Our study used both hard-parts and prey DNA methods, both of which are subject to bias. These biases have been extensively reviewed (e.g. Bowen and Iverson 2013, Casper *et al.* 2007, Chiaradia *et al.* 2014, Pompanon *et al.* 2012, Tollit *et al.* 2007, Tollit *et al.* 2006, Tollit *et al.* 1997, Tollit *et al.* 2009, Tollit *et al.* 2003). To minimise some of these biases, we applied a commonly used compound index that enabled the incorporation of all metrics of prey occurrence by number, frequency and biomass, namely, the index of relative importance (IRI, Pinkas *et al.* 1971). Although using complimentary approaches has been shown to improve estimates of actual diet in top marine predators (Bowen and Iverson

2013, Chiaradia *et al.* 2014), the key bias of spatial representativeness is a more difficult one to overcome. We know that for species such as fur seals, that dietary information based on scats collected onshore are likely to be biased towards coastal species preyed upon just prior to hauling-out, and are likely to under-represent prey species consumed when feeding in offshore/oceanic areas, where animals often spend weeks or months foraging during individual foraging trips.

Although such biases are important to acknowledge when trying to gain a better understanding of the overall 'true diet' in fur seals, their impacts on the ecosystem models developed as part of this study are likely to be less significant. This is because these models are coastal (SG and GSV ecosystems) and the potential coastal bias in diet is less of an issue because the models were mediated to take into account the proportion of diet obtained in coastal waters, and that derived from elsewhere (import) for each of the different LNFS age and sex groups. Our limited understanding of the import diet (offshore) is not relevant to coastal models, and we have behavioural and ecological data for each age and sex group to estimate the proportion of time each of them spends in coastal waters.

The food web models developed here examined the significance and ecological impact of predation on coastal prey by pinnipeds in general, but they also gave context to that consumption by examining its significance relative to consumption by other marine predators. As the trophodynamic models developed in EwE were mass-balanced, the overall consumption of a particular prey taxa by any group relative to other groups could be readily assessed. Based on these analyses the key finding were that:

- most finfish (96% and 94%) and cephalopods (93% and 91%) consumed in the SG and GSV ecosystems, were consumed by other finfish and cephalopods;
- seals (LNFS and ASL) consumed an estimated 1.2% and 0.8% of the total finfish, and 2.1% and 2.7% of the total cephalopods consumed in the SG and GSV ecosystems, respectively;
- seals were estimated to consume just 0.4% and 0.6% of the total ecosystem consumption of key commercial finfish species (Snapper, King George Whiting, Garfish and Sardine) in the SG and GSV ecosystems, respectively, with most of this consumption by LNFS; and
- although fur seal populations have recovered substantially over recent decades, the increased consumption of key commercially fished species has been relative minor, increasing from 0.23 to 0.38% of total consumption between 1991 and 2010 in SG, and from 0.46 to 0.55% of total consumption between 1994 and 2013 in GSV.
- Including fisheries catch as part of the total consumption did not significantly change the above results.

These finding are in marked contrast to the perceived level of impact that seals have on marine ecosystems in general, especially their consumption of commercially targeted species (see Chapter 2). Results from this study indicate that the vast majority of key commercially targeted finfish are consumed by other fish and squid, with that consumed by LNFS making up less than 1% of total ecosystem consumption. In comparison, fisheries were estimated to account for 15% and 1.5% of the total catch and consumption of key finfish taxa in the SG and GSV ecosystems.

The potential impacts of seals on SA marine ecosystems and commercially targeted species was also assessed by undertaking sensitivity analyses of various taxa groups in the SG and GSV ecosystem models to a 10% increase or decrease in LNFS or ASL biomass. These analyses indicated that the majority of taxa groups, including those commercially targeted, were relatively insensitive to either increases or decreases in seal biomass, with the majority of taxa (~80% in the SG model and 90% in the GSV model) responding by <0.1% to a 10% increase or decrease in LNFS biomass.

A more detailed assessment of how the production of taxa response to changing biomass of seals came from scenario analyses, in which changes in LNFS and ASL biomass were simulated to vary from 0.1 to 10 times current biomass levels. Initial analyses examined the response of broad taxa groups, namely total finfish and cephalopods to changes in LNFS and ASL biomass. Additional scenarios examined the response of the total pooled biomass of key commercially fished finfish (Snapper, King George Whiting, Garfish and Sardine), cephalopods (Southern Calamari) and crustaceans (Western King Prawns, Blue Crabs, Southern Rock

Lobster). The key observations from the scenario outputs were that the magnitude of change in relative biomass of key groups to major changes in seal biomass (from 0.1 to 10 fold current levels) were very small (<±1%); the response relationships were non-linear; the direction (+ve or –ve) and magnitude of change varied under low, current and high seal biomass scenarios with the greatest magnitude of responses at low seal biomass; and there were some differences in the response relationships between the SG and GSV models.

In terms of the potential impacts of increasing LNFS populations on commercial fish production (finfish, cephalopods and crustaceans), outputs from both the SG and GSV models indicated in general a very weak negative relationships under low LNFS, with a <1% decline in commercial fish production as LNFS biomass increased from 0.1 to current biomass levels, with the response relationships attenuating as seal biomass approached current levels. However, under increasing LNFS biomass the production of all commercially targeted groups either remained stable, or increased with further increases in LNFS biomass.

The next level of sensitivity analyses assessed the response of individual commercially targeted species to changes in LNFS and ASL biomass. The key findings of these analyses are similar to those above, namely:

- an almost imperceptible responses in terms of absolute biomass by most commercially fished species to very significant changes in seal biomass (from 0.1 to 10 fold current levels). For most species, the magnitude and nature of the response relationships were only apparent when biomass changes were expressed as relative changes in biomass;
- the magnitude of change in relative biomass of commercially fished species to major changes in seal biomass (from 0.1 to 10 fold current levels) was generally very small (for most groups < ±1.5%).
- exceptions were Garfish (increasing by almost 12% under a 0.1 LNFS biomass scenario in GSV) and Southern Rock Lobster (increasing by almost 35% under a 0.1 ASL biomass scenario in SG);
- commercially fished species were directly or indirectly negatively, positively or neutrally impacted by changes in LNFS and ASL biomass, but for most species the magnitude of impact was very small (i.e. <1% change when seal biomass ranges from 0.1 to 10 fold current biomass);
- the response relationships were often non-linear and their direction (+ve or –ve) and degree of influence (slope of the response relationship) often changed under low, current and high seal biomass scenarios;
- many response relationships differed between LNFS and ASL,
- within prey species, the response relationships often differed between the two Gulf models; and
- as with the broad taxa grouping analyses, the magnitude and range of the response relationships were typically greatest at low seal biomasses, and lowest at high seal biomasses.

The response of apex predator groups (dolphins, seabirds, and sharks and rays) to changes in seal biomass was also estimated through scenario analyses. As with other response scenarios, the responses by apex predator groups to changes in seal biomass were generally small, most were non-linear and the direction of response often changed under low and high seal biomass scenarios. Response scenarios of individual species were also examined for ASL, Little Penguins and Giant Cuttlefish. The most significant of these was the strong negative response of Little Penguins to increased LNFS biomass. The response relationship was the strongest of any of the scenarios undertaken in this study. The magnitude of decline in Little Penguin biomass as LNFS biomass increased from 0.1 to current biomass levels, was ~80% and ~60% in the SG and GSV ecosystem models, respectively. Importantly, the extent of these declines was not seen to increase further (i.e they stabilised) under increasing LNFS biomass scenarios. These results suggest a stabilisation of Little Penguin populations at a lower biomass following the recovery of LNFS populations. Declines in numbers of Little Penguins have been reported for several colonies within SA (Bool *et al.* 2007, Colombelli-Négrel and Kleindorfer 2014, Wiebkin 2011), and have coincided with increases in fur seal numbers. There has been much speculation that recovering LNFS populations have contributed to the decline in some Little Penguin populations in SA. Although the presence of Little Penguins in the diet of LNFS has been confirmed in multiple dietary studies, whether this predation pressure has been significant enough to cause a decline in Little Penguin populations has been the source of some debate. The ecological models developed as part of this study provides some of the first clear evidence that recovering population of LNFS may have caused the declines in some Little Penguin populations.

Results from the ecological modelling have been important in providing a better understanding of the impacts of seals on South Australian coastal ecosystems, and have enabled their consumption of commercially targeted species to be examined in the context of consumption by other predators. The models have clearly identified that the most significant consumers of finfish and cephalopods were other finfish and cephalopods. Seals only consumed around 1% of all finfish and 2-3% of all cephalopods, and only accounted for around 0.5% of the total consumption of commercially targeted finfish. Furthermore, scenarios that examined the impacts of increasing LNFS biomass, demonstrated that the total seafood production (finfish, cephalopods and crustaceans) remained either unchanged, or increased slightly as fur seal biomass increased. The notion that recovering fur seal populations will have catastrophic impacts on both seafood production and the broader marine ecosystem is not supported by the results from this study.

Not only has this study been able to provide a clearer perspective on the impact of consumption by seals, the sensitivity and scenario analyses have provided a better understanding of the role of seals in coastal ecosystems. They have shown how changes in the biomass and consumption of seals impact taxa in different ways. Linear or step-wise relationships were uncommon. An example of such a relationship was the stepwise increase in Snapper biomass as LNFS biomass increased (i.e., as seal biomass increased, so did Snapper biomass). But for most commercially targeted species, the relationships were highly non-linear, and the direction and magnitude of the response could be quite different under low, current and higher seal biomass. Such complex relationships suggest that direct impacts of changing seal biomass on the biomass of a commercially targeted species may be less than the indirect impacts on other predators or on competitors of a commercially targeted species. These relationships suggest that seals are important in mediating predator-prey interactions that affect the biomass of many taxa, including those targeted by commercial fishers. It also provides a very different perspective on the role of seals in coastal Australian food webs and their impacts on commercial fisheries. The scenario analyses provide a means to visualise the dynamic changes that may occur across taxa, and how trophic interactions may reconfigure when the biomass of seals in ecosystems is increased or reduced.

One of the intriguing outcomes from the scenario analyses was the consistent pattern in which the magnitude of response (either positive of negative) tended to decrease under high seal biomass scenarios, while the greatest responses were generally observed under low seal biomass scenarios. Morissette *et al*. (2012) used seven EwE models developed for ecosystems in different parts of the world to examine the trophic impacts of marine mammals on commercially important species. They noted a similar paradoxical trend in these studies, which suggested that as marine mammals consume more, they caused less reduction in the overall biomass of impacted species. The role of marine mammals in mediating predator-prey interactions and inducing beneficial predation is likely to explain part of this paradoxical response (Morissette *et al.* 2012). When Morissette *et al*. (2012) ran scenarios in which all seals were hypothetically removed from their respective ecosystems, they observed an overall decrease in commercial fish biomass from most of the studied systems.

Goldsworthy *et al*. (2013) modelled the potential ecosystem impacts of declines and recoveries of key predators in the eastern Great Australian Bight ecosystem, most notably the major historic reductions and subsequent recovery of LNFS and Southern Bluefin Tuna. That study also found, perhaps paradoxically, that as these apex predator populations recovered, the predator-prey relationships changed, reducing the biomass of short-lived predators (especially Arrow Squid), and enabling greater biomass of small pelagic fish to be directed into the higher trophic levels.

Understanding the trophic role of marine mammals and evaluating their competition with fisheries using ecosystem models such as EwE can enhance our ability to understand these complex interactions that would otherwise be very difficult to study. The incorporation of multi-stanza groups that reflect different life history stages (stanzas) for species with complex trophic ontogenies, has been recognised as the most appropriate approach to understanding complex predator-prey interactions, such as those between marine mammals and fisheries (Carl Walters, *in litt*). Multi-stanza groups were developed for most of the key commercially caught species, but for only one seal species, the LNFS. For LNFS, females and males were modelled as separate trophic groups, within which four and five stanzas were developed, respectively. Multi-stanza models were particularly relevant for LNFS, given the marked intersexual differences in growth strategies, adult body size and diets (McKenzie *et al.* 2007a, Page *et al.* 2005a). Integrating multi-stanza models for LNFS would not have been possible without detailed dietary data for juveniles, subadults and adult fur seals. However, a key uncertainty for all these stanzas, was the proportion of diet obtained from coastal relative to offshore waters. In this study available information was used to estimate these figures, but for the juvenile and subadult males that use coastal waters, great certainty remains in what portion of the population comes into coastal waters to feed in winter months. Further research in this areas is needed to further improve our understanding of the impacts of LNFS on coastal ecosystems. For ASL, sex and age-class differences in diet are poorly understood, and this is limiting the development for multi-stanza models for this species. Given the conservation concerns for ASL at present, such research should be prioritised.

To improve our understanding of some of these dynamic trophic changes in more detail, future models should incorporate the EwE spatial module, Ecospace. This module links taxa distributions to specific habitats and is particularly important in better representing the extent to which species overlap and interact in space and time. For example, for species that rarely share the same habitats and rarely interact, some of the impacts identified in current models may have been overestimated. This is important in further understanding the impact of seals on marine ecosystems, as spatial modelling of the distribution of consumption effort of both LNFS and ASL clearly identified that their foraging effort is not homogeneous over coastal waters, and there was a tendency for there to be a spatial mismatch between areas of intensive seal foraging and commercial catch (see Chapter 6). This is especially apparent in SG and GSV, where the upper gulfs are regions of low consumption by seals (see Chapter 6). It is therefore likely that the impacts of seals on these ecosystems is much less in the upper gulfs relative to the lower gulf regions. Previous studies in several species have identified that the extent of competition is strongly affected by the degree of spatial and temporal overlap between seal foraging and commercial fishing areas (Butterworth *et al.* 1988, Goldsworthy *et al.* 2003, Weise and Harvey 2008).

In recent decades, interest in the interactions between marine mammals and fisheries has been growing. Although most studies have focused on the potential impacts of commercial fishing on marine mammal populations, some have investigated the extent to which marine mammals compete with and impact fisheries (DeMaster *et al.* 2001, Gales *et al.* 2003, Goldsworthy *et al.* 2003, Kaschner *et al.* 2001, Morissette *et al.* 2012, Smith 1995, Yodzis 1998, Yodzis 2001). The nature of these interactions is generally very complex, and is complicated further by many challenges, including: when, where and how marine mammals and fisheries interact; limited data on predation rates and their relationship to available biomass; limited quantitative data on diet, their biases and variability in space and time; and the paucity of detailed fisheries data including biomass, landings and discards (Morissette *et al.* 2012).

Appendix 7.1. Estimated dietary biomasscontributions in the diets of ASL, AFS and LNFS

Prey species and estimated percentage contribution to the diets of Australian Sea Lions (ASL), Australian Fur Seals (AFS) and Long-nosed Fur Seals (LNFS). LNFS diet is broken down by ages class (Juvenile JUV, subadult males SAM, adult male AM and adult females AF), by region (West coast, south coast of Kangaroo Island SC KI, Spencer Gulf SG, Gulf St Vincent GSV, and The Coorong), and by age class ecosystem model (Spencer Gulf SG, and Gulf St Vincent GSV). The model group names and numbers are provided. Prey groups that do not occur in either of the SG or GSV ecosystem model domains are noted (***).

					ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
Common name	**Genus sp.**	**SG EwE No.**	**GSV EwE No.**	**Model Group Name**	All regions	All regions	JUV	SAM	AM	AF	All regions	West Coast	SC KI	SG	GSV	Coorong	SG	SG	SG	SG	GSV	GSV	GSV	GSV
																	JUV	SAM	AM	AF	JUV	SAM	AM	AF
Albatross		13	13	Petrel					0.000		0.000		0.001						0.000				0.000	
Flesh-footed shearwater	*Ardenna carneipes*	13	13	Petrel					0.004		0.000		0.000						0.001				0.001	
Short-tailed shearwater	*Puffinus tenuirostris*	13	13	Petrel				0.134	0.034	0.001	0.039	0.016	0.049	0.106	0.015		0.021	0.112	0.091	0.012	0.003	0.039	0.019	0.003
Other birds		13	13	Petrel					0.003	0.001	0.001		0.002						0.001	0.001			0.001	0.001
Elegant (Rock) parrot	*Neophema* spp.	***	***	Other birds	0.008																			
Australian gannet	Morus serrator	14	14	Australian gannet					0.078		0.000		0.000						0.016				0.016	
Little penguin	Eudyptula minor	15	15	Little penguin	0.014		0.057	14.46	2.306	0.107	3.378	0.484	4.420	3.093	5.126	0.378	0.664	5.366	2.936	0.405	1.071	6.992	4.562	0.609
Black-faced Cormorant	*Phalacrocorax fuscescens*	16	16	Shags & cormorants	0.075						0.066				0.346						0.069	0.277	0.277	0.035
Silver gull	*Larus novaehollandiae*	18	18	Gulls	0.075	0.790																		
Great White Shark	*Carcharodon carcharias*	19	19	White shark							0.029			0.085			0.017	0.068	0.068	0.009				
Gummy shark	*Mustelus antarcticus*	23	23	Gummy shark	0.008																			
Port Jackson Shark	*Heterodontus portusjacksoni*	25	25	Port Jackson Shark	0.033						0.007				0.038						0.008	0.031	0.031	0.004
Collar Carpetshark	*Parascyllium collare*	26	26	Other demersal sharks	0.033																			
Southern saw shark	*Pristiophorus nudipinnis*	26	26	Other demersal sharks	0.033						0.007			0.021			0.004	0.017	0.017	0.002				
Grey Spotted Catshark	*Asymbolus analis*	26	26	Other demersal sharks	0.243																			
Dwarf Catshark	*Asymbolus parvus*	26	26	Other demersal sharks		0.790																		
Australian angelshark	*Squatina australis*	26	26	Other demersal sharks	0.075																			
Spikey Dogfish	*Squalus megalops*	26	26	Other demersal sharks		0.790																		
Shark - other	Elasmobranchii	26	26	Other demersal sharks																				
Eagle ray	*Myliobatis* sp.	27	27	Rays & skates	0.133																			
Thornback skate	*Dipturus lempreri*	27	27	Rays & skates	0.075						0.066			0.086		32.49	0.017	0.068	0.068	0.009				
Melbourne skate	*Dipturus whitleyi*	27	27	Rays & skates	0.008																			
Unclassified coffin ray species	*Torpedo marmorata*	27	27	Rays & skates	0.008																			
Stingaree	*Trygonoptera testacea*	27	27	Rays & skates	0.010																			
Southern fidler ray	*Trygonorrhina guanerius*	27	27	Rays & skates	0.033																			
Banded Stingaree	*Urolophus cruciatus*	27	27	Rays & skates	0.075																			
Unclassified Stingaree species	*Urolophus sp._OTU307*	27	27	Rays & skates	0.033																			
Unclassified stingaree species	*Urolophus sp._OTU384*	27	27	Rays & skates	0.033																			
Coastal stingaree	*Urolophus orarius*	27	27	Rays & skates	0.075																			
Sparsely-spotted Stingaree	*Urolophus paucimaculatus*	27	27	Rays & skates	0.406						0.007			0.021			0.004	0.017	0.017	0.002				
Southern bluefin tuna	*Thunnus maccoyii*	28	28	Southern bluefin tuna							0.117			0.342				0.273	0.273					
Yellowtail Kingfish	*Seriola lalandi*	29	29	Yellowtail Kingfish	0.671						0.728			2.136				1.709	1.709					
Snapper	*Chrysophrys auratus*	30/31	30/31	Snapper	0.008						0.117			0.021	0.346		0.004	0.017	0.017	0.002	0.069	0.277	0.277	0.035
Longfin pike	*Dinolestes lewini*	32	32	Snook	0.207		0.002			0.003	0.006	4.883	0.006	0.021			0.006	0.017	0.017	0.005	0.002			0.003
Snook	*Sphyraena novaehollandiae*	32	32	Snook							0.029				0.154						0.031	0.123	0.123	0.015
Slender Escolar	*Paradiplospinus gracilis*	33	33	Barracouta							0.007		0.006											
Barracouta	*Thyrsites atun*	33	33	Barracouta	0.671		0.199	0.099	1.344	0.381	1.745	0.409	1.007	0.814	0.346		0.817	0.671	0.920	0.672	0.228	0.297	0.546	0.378
Skipjack trevally	*Pseudocaranx wrighti*	34	34	Skipjack trevally	0.828						0.728			1.047	0.346		0.209	0.837	0.837	0.105	0.069	0.277	0.277	0.035
Silver Trevally	*Pseudocaranx dentex*	34	34	Skipjack trevally							0.066		0.006	0.085			0.017	0.068	0.068	0.009				
Trevally	*Pseudocaranx sp.*	34	34	Skipjack trevally	0.008			0.016			0.001			0.002	0.123		0.000	0.005	0.001	0.000	0.025	0.102	0.099	0.012
Tasselled Angler	*Rhycherus filamentosus*	35	35	Medium piscivore fish	0.133																			
Sergeant Baker	*Latropiscis purpurissatus*	35	35	Medium piscivore fish	0.207	0.790					0.029		0.006	0.021			0.004	0.017	0.017	0.002				
Conger Eel	*Gnathophis bathytopos*	35	35	Medium piscivore fish	0.075																			
Unclassified Conger Eel species	*Gnathophis sp._OTU50*	35	35	Medium piscivore fish	1.002						0.007				0.038						0.008	0.031	0.031	0.004
Unclassified Conger Eel species	*Gnathophis sp._OTU635*	35	35	Medium piscivore fish	0.008																			
Bearded rock cod	*Lotella rhacina*	35	35	Medium piscivore fish	0.207																			

Appendix 7.1. cont.

Common name	Genus sp.	SG EwE No.	GSV EwE No.	Model Group Name	ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
					All regions	All regions	JUV	SAM	AM	AF	All regions	West Coast	SC KI	SG	GSV	Coorong	SG	SG	SG	SG	GSV	GSV	GSV	GSV
																	JUV	SAM	AM	AF	JUV	SAM	AM	AF
Red rock cod	*Pseudophycis bachus*	35	35	Medium piscivore fish	0.014	0.361		0.000	0.423	0.007	0.050		0.138	0.012	0.008		0.002	0.010	0.094	0.008	0.002	0.006	0.091	0.007
Bearded cod	*Pseudophycis barbata*	35	35	Medium piscivore fish	0.008						0.007		0.006											
Unclassified cod species		35	35	Medium piscivore fish	0.207						0.029			0.021	0.038		0.004	0.017	0.017	0.002	0.008	0.031	0.031	0.004
Mulloway	*Argyrosomus japonicus*	35	35	Medium piscivore fish				0.041			0.000					0.019		0.008				0.008		
Tiger flathead	*Platycephalus richardsoni*	35	35	Medium piscivore fish	0.828																			
Southern Sand Flathead	*Platycephalus bassensis*	35	35	Medium piscivore fish	2.120						0.007			0.021			0.004	0.017	0.017	0.002				
Longspine Flathead	*Platycephalus longispinis*	35	35	Medium piscivore fish	0.033																			
Rock Flathead	*Thysanophrys cirronasa*	35	35	Medium piscivore fish	0.133																			
Flathead spp.	*Platycephalus spp.*	35	35	Medium piscivore fish	0.014	0.197			0.093	0.001	0.023		0.048	0.001			0.000	0.001	0.019	0.001			0.019	0.000
Sweep	*Scorpis aequipinnis*	35	35	Medium piscivore fish	0.033						0.000	0.001												
Blue warehou	*Seriolella punctata*	35	35	Medium piscivore fish					0.006	0.005	0.050		0.025	0.003	0.346		0.001	0.002	0.004	0.005	0.069	0.277	0.278	0.039
Red Gurnard	*Chelidonichthys kumu*	35	35	Medium piscivore fish							0.007				0.038						0.008	0.031	0.031	0.004
Common stargazer	*Kathetostoma laeve*	35	35	Medium piscivore fish	0.033																			
Stargazers	*Kathetostoma sp.*	35	35	Medium piscivore fish	0.075	0.048	0.009		0.015	0.002	0.009	0.001	0.011	0.003			0.008	0.003	0.006	0.002	0.007		0.003	0.001
Yank Flathead	*Platycephalus speculator*	35	35	Medium piscivore fish	0.008																			
Ocean perch	Helicolenus sp,	**	**	Deep demersal fish	0.406																			
Common Stinkfish	*Synchiropus calauropomus*	***	***	Deep demersal fish							0.007		0.006											
Silver dory	*Cyttus australis*	***	***	Deep demersal fish	0.008				0.002		0.000		0.001						0.000				0.000	
Bigscale rubyfish	Plagiogeneion macrolepis	***	***	Deep demersal fish	0.008	3.159					0.066			0.085	0.038		0.017	0.068	0.068	0.009	0.008	0.031	0.031	0.004
Gemfish	*Rexea solandri*	***	***	Deep demersal fish		0.790	1.586	0.060	1.612	0.437	0.467	0.070	1.448	0.180			1.305	0.156	0.466	0.411	1.269	0.012	0.322	0.393
Blackring Waryfish	*Scopelosaurus meadi*	***	***	Deep demersal fish							0.007				0.038						0.008	0.031	0.031	0.004
Unclassified Waryfish species	*Scopelosaurus sp.*	***	***	Deep demersal fish							0.007				0.038						0.008	0.031	0.031	0.004
Pink ling	*Genypterus blacodes*	***	***	Deep demersal fish	0.207																			
Unclassified Dragonfish species	*Stomias sp?*	***	***	Deep demersal fish	0.298	0.790					0.262			0.342	0.154		0.068	0.273	0.273	0.034	0.031	0.123	0.123	0.015
Smalleye Squaretail	*Tetragonurus cuvieri*	***	***	Deep demersal fish							0.007		0.006											
Western Roughy	*Optivus agrammus*	***	***	Deep demersal fish	0.075						0.029		0.006	0.021			0.004	0.017	0.017	0.002				
Harpuku	*Polyprion oxygeneios*	***	***	Deep demersal fish	0.033																			
Jackass morwong	*Nemadactylus macropterus*	36	36	Medium echinoderm fish	0.075	0.790																		
Short Boarfish	*Parazanclistius hutchinsi*	36	36	Medium echinoderm fish				0.011			0.002		0.006		0.081			0.002			0.016	0.067	0.065	0.008
Longsnout boarfish	*Pentaceropsis recurvirostris*	36	36	Medium echinoderm fish	0.008																			
Australian salmon	*Arripis truttacea*	37	37	Australian salmon	0.075		0.002	0.004		0.000	0.010		0.001	0.085	0.103		0.018	0.069	0.068	0.009	0.022	0.083	0.082	0.010
Australian Herring	*Arripis georgianus*	38	38	Australian Herring	0.018			0.031	0.019	0.013	0.127	0.472	0.001	0.097	0.197		0.019	0.084	0.082	0.022	0.039	0.164	0.161	0.032
King George whiting	*Sillaginodes puncata*	39/40	39/40	King George whiting	0.008			0.007	0.001	0.001	0.003		0.002	0.004	0.021		0.001	0.005	0.004	0.001	0.004	0.018	0.017	0.003
Southern sea garfish	*Hyporhamphus melanochir*	41/42	41/42	Southern sea garfish	0.207	0.790	0.717	1.142	0.420	0.479	1.767	0.018	0.337	0.989	20.73		0.771	1.019	0.875	0.530	4.720	16.82	16.67	2.504
Yellow-eye mullet	*Aldrichetta forsteri*	43	43	Red Mullet			0.003	0.001			0.002		0.000		0.056	0.056	0.003	0.000			0.014	0.045	0.045	0.006
Goatfish	*Upeneichthys sp.*	43	43	Red Mullet	0.033																			
Red Mullet	*Upeneichthys vlamingii*	43	43	Red Mullet	13.92	0.005		0.002	0.013	0.001	0.038		0.008	0.342	0.148		0.068	0.274	0.276	0.035	0.030	0.119	0.121	0.015
Silverbelly	*Parequula melbournensis*	44	44	Silverbelly	3.313	0.015	0.064		0.113	0.103	0.078		0.073	0.050	0.154		0.061	0.040	0.062	0.098	0.082	0.123	0.146	0.108
Western Silverbelly	*Parequula elongata*	44	44	Silverbelly	0.008																			
Yelloweye nannygai	*Centroberyx australia*	45	45	Medium crustacean fish	0.133						0.001		0.003											
Bight redfish	*Centroberyx gerrardi*	45	45	Medium crustacean fish		0.790					0.029			0.085			0.017	0.068	0.068	0.009				
Swallowtail	*Centroberyx lineatus*	45	45	Medium crustacean fish	0.104	0.158			2.037	0.163	0.528		0.068	0.380			0.076	0.304	0.712	0.185			0.407	0.147
Nannygai/swallowtail	*Centroberyx sp.*	45	45	Medium crustacean fish			0.001	0.019	0.001	0.000	0.013		0.021				0.001	0.004	0.000	0.000	0.001	0.004	0.000	0.000
Coves' Horned Anglerfish	*Cryptopsaras couesii*	45	45	Medium crustacean fish		0.790																		
Southern tongue sole	*Cynoglossus broadhursti*	45	45	Medium crustacean fish	0.298						0.007			0.021			0.004	0.017	0.017	0.002				
Gulf gurnard perch	*Neosebastes bougainvillii*	45	45	Medium crustacean fish	0.008																			

Appendix 7.1. cont.

					ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
Common name	**Genus sp.**	**SG EwE No.**	**GSV EwE No.**	**Model Group Name**	All regions	All regions	JUV	SAM	AM	AF	All regions	West Coast	SC KI	SG	GSV	Coorong	SG	SG	SG	SG	GSV	GSV	GSV	GSV
																	JUV	SAM	AM	AF	JUV	SAM	AM	AF
Gurnard perch (big-head)	*Neosebastes pandas*	45	45	Medium crustacean fish	0.033																			
Rock Ling	*Genypterus tigerinus*	45	45	Medium crustacean fish	0.027																			
Greenback Flounder,	*Rhombosolea tapirina*	45	45	Medium crustacean fish							0.007			0.021			0.004	0.017	0.017	0.002				
Estuary catfish	*Cnidoglanis macrocephalus*	45	45	Medium crustacean fish	0.014																			
Butterfly Perch	*Caesioperca lepidoptera*	45	45	Medium crustacean fish	0.530																			
Perch	*Serranidae*	45	45	Medium crustacean fish	0.014																			
Common stinkfish	*Foetorepus calauropomus*	46	46	Medium moluscan fish	0.033																			
Spotted stinkfish	*Repomucenus calcaratus*	46	46	Medium moluscan fish	0.133																			
Silver spot	*Chironemus maculosus*	46	46	Medium moluscan fish	0.033																			
Red velvetfish	*Gnathanacanthus goetzeei*	46	46	Medium moluscan fish	0.010																			
Zebra fish	*Girella zebra*	46	46	Medium moluscan fish	0.008																			
Snakeskin wrasse	Eupetrichthys angustipes	46	46	Medium moluscan fish	0.033																			
Senator (Braun's)Wrasse	*Pictilabrus laticlavius*	46	46	Medium moluscan fish	0.008						0.007			0.021			0.004	0.017	0.017	0.002				
Wrasse sp.	*Pseudolabrus* sp.	46	46	Medium moluscan fish	0.075																			
Western foxfish	Bodianus frenchii	46	46	Medium moluscan fish	0.018																			
Blue throat wrasse	*Notolabrus tetricus*	46	46	Medium moluscan fish	0.828																			
Senator wrasse	Pictilabrus laticlavius	46	46	Medium moluscan fish	0.207																			
Rosy Wrasse	*Pseudolabrus rubicundus*	46	46	Medium moluscan fish							0.007			0.021			0.004	0.017	0.017	0.002				
Unclassified Perch species	(Perciformes)	46	46	Medium moluscan fish	0.008																			
Unclassified Perch species	(Labriformes)	46	46	Medium moluscan fish	0.133						0.007			0.021			0.004	0.017	0.017	0.002				
Southern Cardinalfish	*Vincentia conspersa*	47	47	Small Crustacean fish	0.207				0.034	0.000	0.003	0.051	0.000	0.007	0.038		0.001	0.006	0.013	0.001	0.008	0.031	0.037	0.004
Western Smooth Boxfish	*Anoplocapros amygdaloides*	49	49	Small ploychaete fish	0.008						0.029			0.021	0.038		0.004	0.017	0.017	0.002	0.008	0.031	0.031	0.004
Deepwater hardyhead	*Atherinason hepestoides*	47	47	Small Crustacean fish			0.001	0.001	0.001	0.002	0.002		0.005	0.009			0.002	0.007	0.007	0.003	0.001	0.000	0.000	0.002
Unclassified Hardyhead species	Atherinason sp.	47	47	Small Crustacean fish				0.006			0.017			0.004	0.850		0.001	0.005	0.003	0.000	0.170	0.682	0.680	0.085
Pikehead Hardyhead	*Kestratherina esox*	47	47	Small Crustacean fish							0.029			0.021	0.038		0.004	0.017	0.017	0.002	0.008	0.031	0.031	0.004
Mueller's flounder	*Arnoglossus muelleri*	47	47	Small Crustacean fish	0.008																			
Dusky morwong	*Dactylophora nigricans*	47	47	Small Crustacean fish	0.010																			
Tasseled kelpfish	*Chironemus georgianus*	49	49	Small ploychaete fish	0.033																			
Southern crested weedfish	*Cristiceps australis*	47	47	Small Crustacean fish	0.033																			
Rosy weedfish	*Heteroclinus roseus*	47	47	Small Crustacean fish	0.008																			
Australian burrfish	Allomycterus pilatus	47	47	Small Crustacean fish	0.075	0.790					0.007			0.021			0.004	0.017	0.017	0.002				
Old wife	*Enoplosus armatus*	47	47	Small Crustacean fish	0.008																			
Sculptured Goby	*Callogobius mucosus*	47	47	Small Crustacean fish	0.133																			
Spinytail Leatherjacket	*Acanthaluteres brownii*	49	49	Small ploychaete fish	0.239						0.513			5.029			1.006	5.522	4.399	0.821				
Bridled leatherjacket	*Acanthaluteres spilomelanurus*	49	49	Small ploychaete fish	1.483						1.041			5.093			1.019	5.593	4.455	0.831				
Toothbrush leatherjacket	*Acanthaluteres vittiger*	49	49	Small ploychaete fish	4.529						5.142	8.522		13.57	2.999		2.714	14.90	11.87	2.214	0.600	3.962	2.791	0.631
Mosaic Leatherjacket	*Eubalichthys mosaicus*	47	47	Small Crustacean fish	0.582						0.513			5.029			1.006	5.52	4.399	0.821				
Fourspine Leatherjacket	*Eubalichthys quadrispinis*	47	47	Small Crustacean fish	0.015																			
Ocean jacket	*Nelusetta ayraudi*	49	49	Small ploychaete fish	0.046	14.50					2.711		4.015	10.21			2.042	11.21	8.929	1.666				
Degan's leatherjacket	*Thamnaconus degeni*	48	48	Degens/Rough leatherjacket	5.766						8.508	55.39		10.04	25.00		2.008	11.02	8.780	1.638	4.999	33.02	23.26	5.261
Southern Pygmy Leatherjacket	*Brachaluteres jacksonianus*	47	47	Small Crustacean fish	0.158																			
Gunn's Leatherjacket	*Eubalichthys gunnii*	47	47	Small Crustacean fish	0.158						0.513			2.525			0.505	2.773	2.209	0.412				
Brownstriped leatherjacket	*Meuschenia australis*	47	47	Small Crustacean fish	0.015																			
Sixspine leatherjacket	*Meuschenia freycineti*	47	47	Small Crustacean fish	0.094																			
Leatherjacket	*Meuschenia hippcrepsis*	47	47	Small Crustacean fish	0.015																			
Velvet Leatherjacket	*Meuschenia scaber*	47	47	Small Crustacean fish	1.270	14.50					0.513	4.261			1.461						0.292	1.930	1.360	0.308

Appendix 7.1. cont.

Common name	**Genus sp.**	**SG EwE No.**	**GSV EwE No.**	**Model Group Name**	ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
					All regions	All regions	JUV	SAM	AM	AF	All regions	West Coast	SC KI	SG	GSV	Coorong	SG	SG	SG	SG	GSV	GSV	GSV	GSV
																	JUV	SAM	AM	AF	JUV	SAM	AM	AF
Rough Leatherjacket	*Scolinichthys granulatus*	48	48	Degens/Rough leatherjacket	1.483																			
Leatherjacket spp.		49	49	Small ploychaete fish			0.002	76.74	19.24	3.616							0.001							
Little gurnard perch	*Maxillicosta scabriceps*	47	47	Small Crustacean fish	0.207																			
Rainbow cale	*Heteroscarus acroptilus*	47	47	Small Crustacean fish	0.075																			
Little weed whiting	*Neoodax balteatus*	49	49	Small ploychaete fish	0.008						0.007			0.021			0.004	0.017	0.017	0.002				
Herring cale	*Olisthops cyanomelas*	49	49	Small ploychaete fish	0.075																			
Longray Weed Whiting	*Siphonognathus radiatus*	49	49	Small ploychaete fish	0.008						0.007				0.038						0.008	0.031	0.031	0.004
Shortfin Worm Eel	*Scolecenchelys australis*	47	47	Small Crustacean fish							1.231			1.367	0.962		0.273	1.094	1.094	0.137	0.192	0.770	0.770	0.096
Shorthead Worm Eel	*Scolecenchelys breviceps*	47	47	Small Crustacean fish	1.002																			
Smalltooth Flounder	*Pseudorhombus jenynsii*	47	47	Small Crustacean fish	0.033																			
Slender bullseye	*Parapriacanthus elongatus*	47	47	Small Crustacean fish	0.055			0.166	0.022	0.021	0.537		0.075	1.423	1.016		0.285	1.171	1.143	0.161	0.203	0.846	0.817	0.120
Common Bullseye	*Pempheris multiradiata*	47	47	Small Crustacean fish	0.014	0.004	0.002	0.182		0.037	0.035		0.018	0.093	0.034		0.020	0.111	0.074	0.043	0.008	0.063	0.027	0.037
Barred grubfish	*Parapercis allporti*	47	47	Small Crustacean fish	0.008																			
Wavy grubfish	*Parapercis haackei*	47	47	Small Crustacean fish	0.008																			
Soldier fish	*Gymnapistes marmoratus*	47	47	Small Crustacean fish	0.530						0.007			0.021			0.004	0.017	0.017	0.002				
Southern Rockcod	*Scorpaena papillosa*	47	47	Small Crustacean fish	0.008																			
Unclassified Gurnard Perch	(Scorpaenidae)	47	47	Small Crustacean fish	0.075																			
Western school whiting	*Sillago bassensis*	49	49	Small ploychaete fish	0.133		0.042	0.011	0.025	0.019	0.024	0.001	0.026	0.018	0.067		0.038	0.016	0.019	0.019	0.047	0.055	0.058	0.024
Eastern School Whiting	*Sillago flindersi*	49	49	Small ploychaete fish	0.014	0.016	0.002	0.118	0.009	0.002	0.009		0.006	0.055			0.013	0.067	0.045	0.007	0.002	0.024	0.002	0.002
Duskybanded sole	*Zebrias penescalaris*	47	47	Small Crustacean fish	0.033																			
Flounder		47	47	Small Crustacean fish	0.008																			
Western striped trumpeter	*Pelates octolineatus*	49	49	Small ploychaete fish	0.298						0.007			0.021			0.004	0.017	0.017	0.002				
Starry Toadfish	*Arothron firmamentum*	47	47	Small Crustacean fish	0.008																			
Ringed toadfish	*Omegophora armilla*	47	47	Small Crustacean fish	0.406																			
Puffer Fish		47	47	Small Crustacean fish	0.010																			
Southern shortfin gurnard	*Lepidotrigla cf. spinosa*	47	47	Small Crustacean fish	0.033																			
Supreme gurnard	*Lepidotrigla grandis*	47	47	Small Crustacean fish	0.033																			
Spiny gurnard	*Lepidotrigla papilio*	47	47	Small Crustacean fish	1.623																			
Unclassified Scorpionfish species	Scorpaeniformes	47	47	Small Crustacean fish	0.075																			
Spotted Pipefish	*Stigmatopora argus*	50	50	Syngnathids	0.008																			
Blue Mackerel	*Scomber australasicus*	51	51	Blue mackerel					0.001	0.004	0.011		0.005	0.184			0.037	0.147	0.148	0.022			0.000	0.004
Jack Mackerel	*Trachurus declivis*	52	52	Jack/yellow-tail mackerel	0.033	2.340	0.064	0.378	1.899	0.788	1.444	2.505	0.617	3.093	0.038		0.670	2.550	2.854	1.019	0.059	0.106	0.411	0.713
Yellowtail Scad	*Trachurus novaezelandiae*	52	52	Jack/yellow-tail mackerel	0.014	7.108					3.852	4.883	0.089	5.468	0.154		1.094	4.375	4.375	0.547	0.031	0.123	0.123	0.015
King Gar/Saury	*Scomberesox saurus*	52	52	Jack/yellow-tail mackerel						0.005	0.011		0.002	0.019			0.004	0.016	0.016	0.006				0.004
Jack Mackerel/Redbait		52	52	Jack/yellow-tail mackerel			0.021	0.036	0.002	0.015							0.017	0.007	0.000	0.013	0.017	0.007	0.000	0.013
Redbait	*Emmelichthys nitidus*	**	**	Redbait	0.075	46.24	0.739	0.048	49.37	81.05	38.67	2.184	67.13	9.573	0.032		2.506	7.67	17.53	73.90	0.597	0.035	9.899	72.95
Maray	*Etrumeus teres*	53	53	Sardine	0.008						0.262			0.085	0.616		0.017	0.068	0.068	0.009	0.123	0.493	0.493	0.062
Dotted Gizzard Shad	*Konosirus punctatus*	53	53	Sardine							0.182			0.534			0.107	0.427	0.427	0.053				
Sardine	*Sardinops sagax*	53	53	Sardine	0.033		0.012	0.566	0.378	1.101	0.872	0.405	0.176	3.013	0.863		0.612	2.524	2.486	1.292	0.182	0.803	0.766	1.077
Anchovy	*Engraulis australis*	54	54	Anchovy	0.033		1.577	0.043	0.439	0.397	0.723	0.206	0.288	0.917	0.580		1.445	0.742	0.822	0.449	1.378	0.472	0.552	0.415
Sandy Sprat	*Hyperlophus vittatus*	55	55	Sprats						0.000	0.000			0.003	0.346		0.001	0.002	0.002	0.001	0.069	0.277	0.277	0.035
Unclassified Sprat species	*Spratelloides* sp.	55	55	Sprats							0.007				0.038						0.008	0.031	0.031	0.004
Blue cubehead	*Cubiceps caeruleus*	***	***	Offshore small pelagics				0.001			0.001		0.001	0.021	0.038		0.004	0.017	0.017	0.002	0.008	0.031	0.031	0.004
Microstomatid	*Nansenia macrolepis*	***	***	Mesopelagics					0.020	0.038	0.012	0.006	0.016	0.060			0.012	0.048	0.052	0.040			0.004	0.034
Myctophid (Diaphus sp.)	*Diaphus sp.*	***	***	Mesopelagics						0.000	0.000		0.000							0.000				0.000
Myctophid (Electrona sp.)	*Electrona sp.*	***	***	Mesopelagics				0.004		0.100	0.025	0.001	0.037	0.021			0.004	0.018	0.017	0.092		0.001		0.090

Appendix 7.1. cont.

Common name	**Genus sp.**	**SG EwE No.**	**GSV EwE No.**	**Model Group Name**	ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
					All regions	All regions	JUV	SAM	AM	AF	All regions	West Coast	SC KI	SG	GSV	Coorong	SG	SG	SG	SG	GSV	GSV	GSV	GSV
																	JUV	SAM	AM	AF	JUV	SAM	AM	AF
Myctophid (Gymnoscopelus sp.)	*Gymnoscopelus sp*	***	***	Mesopelagics			0.647		0.278	0.228	0.245		0.467	0.058	0.006		0.529	0.047	0.102	0.211	0.519	0.005	0.060	0.205
Hector's Lanternfish	*Lampanyctodes hectoris*	***	***	Mesopelagics							0.007		0.006											
Bright Lanternfish	*Myctophum phengodes*	***	***	Mesopelagics							0.029		0.006		0.038						0.008	0.031	0.031	0.004
Barnard's Lanternfish	*Symbolophorus barnardi*	***	***	Mesopelagics		0.049	92.78	0.071	4.308	5.468	5.651	0.253	12.53	0.096	0.148		74.24	0.091	0.938	4.931	74.25	0.133	0.980	4.936
Murray-Darling Golden Perch	*Macquaria ambigua*	***	***	Freshwater/Esuarine species							0.007				0.038						0.008	0.031	0.031	0.004
Congolli	*Pseudaphritis urvillii*	***	***	Freshwater/Esuarine species							0.066			0.021	0.154		0.004	0.017	0.017	0.002	0.031	0.123	0.123	0.015
Tamar Goby	*Afurcagobius tamarensis*	***	***	Freshwater/Esuarine species							0.017					13.57								
Goby Species		***	***	Freshwater/Esuarine species							0.002					1.669								
Bony Herring	*Nematolosa erebi*	***	***	Freshwater/Esuarine species							0.018				0.038	16.37					0.008	0.031	0.031	0.004
Common Carp	*Cyprinus carpio*	***	***	Freshwater/Esuarine species							0.048				0.038	35.45					0.008	0.031	0.031	0.004
Unidentified fish	*Actinopterygii_OTU455*	***	***	Unclassified Fish species	0.008																			
Unidentified fish	*Actinopterygii_OTU476*	***	***	Unclassified Fish species	0.133																			
Calamary squid	*Sepioteuthis australis*	59/60	57/58	Southern calamary	3.564		0.067	3.329	0.131	0.073	1.511	0.181	0.184	1.202	13.55		0.294	1.627	0.988	0.186	2.763	11.50	10.86	1.421
Luminous Bay Squid	*Uroteuthis noctiluca*	59/60	57/58	Southern calamary				0.642			0.157		0.006	0.021	16.00		0.004	0.145	0.017	0.002	3.201	12.93	12.80	1.600
Giant cuttlefish	*Sepia apama*	61	59	Giant cuttlefish	7.078	0.033		0.213	0.023		1.048	4.883	0.079	0.003	1.217		0.001	0.045	0.007	0.000	0.243	1.017	0.979	0.122
Unclassified Cuttlefish species	*Sepiida_OTU310*	61	59	Giant cuttlefish							0.029		0.006	0.021			0.004	0.017	0.017	0.002				
Unclassified Cuttlefish species	*Sepiida_OTU56*	61	59	Giant cuttlefish	1.558		0.001	0.000	0.001	0.002	0.003	4.883			0.038		0.001	0.000	0.000	0.002	0.008	0.031	0.031	0.006
Unclassified Cephalopod species	*Sepiolina petasa*	62	60	Other squids	0.008																			
Jewel squid	*Histioteuthis sp.*	62	60	Other squids		0.021	0.001		0.006	0.009	0.005	0.002	0.007	0.003			0.001	0.002	0.004	0.009	0.001		0.001	0.008
Oceanic Squid	*Lycoteuthis lorigera*	62	60	Other squids							0.007				0.038						0.008	0.031	0.031	0.004
Unclassified Squid species		62	60	Other squids							0.117		0.050		0.038						0.008	0.031	0.031	0.004
Gould's squid	*Nototodarus gouldi*	62	60	Other squids	1.076	0.047	1.295	0.302	10.31	3.433	9.203	0.025	5.766	5.864	0.079		2.209	4.751	6.753	3.676	1.052	0.124	2.126	3.098
Arrow (Unclassified Flying) Squid	*Nototodarus sp.*	62	60	Other squids	3.210			0.617	0.156	0.876	0.740	0.119	0.464	2.148	0.037		0.430	1.842	1.750	1.003	0.007	0.153	0.061	0.792
Filippova's/Southern Ocean arrow squid	*Todarodes filippovae*	62	60	Other squids			0.109	0.029	4.717	0.905							0.087	0.006	0.943	0.815	0.087	0.006	0.943	0.815
Onychoteuthis sp.	*Onychoteuthis sp.*	62	60	Other squids				0.002		0.049								0.000		0.044		0.000		0.044
Southern dumpling squid	*Euprymna tasmanica*	62	60	Other squids	1.828	0.790					0.466		0.006		1.885						0.377	1.508	1.508	0.189
Striped Pyjama Squid	*Sepioloidea lineolata*	62	60	Other squids	0.298																			
Unclassified Cephalopod species	Cephalopoda_OTU181	62	60	Other squids	0.008																			
Unclassified Cephalopod species	Cephalopoda_OTU266	62	60	Other squids	0.008																			
Southern keeled octopus	*Octopus berrima*	63	61	Octopus	0.055					0.000	0.000		0.000							0.000				0.000
Common Sydney octopus	*Octopus cf. tetricus*	63	61	Octopus	0.133																			
Souther sand octopus	*Octopus kaurna*	63	61	Octopus	1.863						0.182				0.962						0.192	0.770	0.770	0.096
Maori octopus	*Octopus maorum*	63	61	Octopus	0.084				0.049	0.000	0.007		0.016						0.010	0.000			0.010	0.000
Pale octopus	*Octopus pallidus*	63	61	Octopus				0.007			0.000			0.002			0.000	0.003	0.002	0.000		0.001		
Southern argonaut	*Argonauta nodosa*	63	61	Octopus					0.006	0.000	0.002		0.002	0.021			0.004	0.017	0.018	0.002			0.001	0.000
Velvet Octopus	*Grimpella thaumastocheir*	63	61	Octopus	0.075																			
Unclassified Octopus species	*Octopodidae_OTU11*	63	61	Octopus	9.019						0.728	4.883		0.534	0.616		0.107	0.427	0.427	0.053	0.123	0.493	0.493	0.062
Unclassified Octopus species	*Octopodidae_OTU21*	63	61	Octopus	1.400						0.357		0.022	0.192	0.154		0.038	0.154	0.154	0.019	0.031	0.123	0.123	0.015
Unclassified Octopus species	*Octopodidae_OTU366*	63	61	Octopus							0.029		0.022											
Unclassified Octopus species	*Octopodidae_OTU152*	63	61	Octopus	0.207						0.007			0.021			0.004	0.017	0.017	0.002				
Unclassified Octopus species	*Octopodidae_OTU186*	63	61	Octopus							0.029			0.021	0.038		0.004	0.017	0.017	0.002	0.008	0.031	0.031	0.004
Unclassified Octopus species	*Octopodidae_OTU212*	63	61	Octopus	0.075																			
Unclassified Octopus species	*Callistoctopus sp._OTU51*	63	61	Octopus	1.400						0.007				0.038						0.008	0.031	0.031	0.004
Unclassified Octopus species	*Callistoctopus sp._OTU109*	63	61	Octopus	0.075																			
Unclassified Octopus		63	61	Octopus	11.65	0.149		0.468	0.024	0.004	0.058		0.009	0.469	0.024		0.094	0.469	0.380	0.050	0.005	0.112	0.024	0.006
Southern rock lobster	*Jasus edwardsii*	64	62	Southern rock lobster	0.302																			
Western king prawn	*Melicertus latisulcatus*	65/66	63/64	Western king prawn	0.133						0.007				0.038						0.008	0.031	0.031	0.004
Unclassified swimming crab species		67/68	65/66	Blue swimmer crab	0.075	0.790					0.117		0.022	0.085			0.017	0.068	0.068	0.009				
Sand Crab	*Ovalipes australiensis*	69	67	Sand Crabs	0.039																			
Unclassified Sand Crab species	*Ovalipes sp.*	69	67	Sand Crabs	0.828						0.357		0.050	0.342			0.068	0.273	0.273	0.034				
Red Swimmer crab	*Nectocarcinus integrifrons*	70	68	Other large crabs/bugs	0.671						0.262			0.534	0.038		0.107	0.427	0.427	0.053	0.008	0.031	0.031	0.004

Appendix 7.1. cont.

					ASL	AFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS	LNFS
Common name	**Genus sp.**	**SG EwE No.**	**GSV EwE No.**	**Model Group Name**	All regions	All regions	JUV	SAM	AM	AF	All regions	West Coast	SC KI	SG	GSV	Coorong	SG	SG	SG	SG	GSV	GSV	GSV	GSV
																	JUV	SAM	AM	AF	JUV	SAM	AM	AF
Unid rock crab crab		70	68	Other large crabs/bugs		0.790					0.007		0.006											
Eastern king prawn	*Melicertus plebejus*	71	69	SAO crustaceans	1.002						0.066				0.346						0.069	0.277	0.277	0.035
Southern velvet shrimp	*Metapenaeopsis palmensis*	71	69	SAO crustaceans					0.026	0.049	0.018		0.048						0.005	0.044			0.005	0.044
Burrowing shore crab	*Leptograpsodes octodentatus*	71	69	SAO crustaceans																				
Stone crab		71	69	SAO crustaceans	0.018																			
Unclassified Decapod species	Decapoda_OTU69	71	69	SAO crustaceans							0.007		0.006											
Unclassified Decapod species	Decapoda_OTU133	71	69	SAO crustaceans	0.008						0.029		0.006		0.038						0.008	0.031	0.031	0.004
Unclassified Decapod species	Decapoda_OTU300	71	69	SAO crustaceans	0.008																			
Unclassified Decapod species	Decapoda_OTU312	71	69	SAO crustaceans	0.298																			
Unclassified Decapod species	Decapoda_OTU491	71	69	SAO crustaceans	0.008																			
Unclassified Decapod species	Decapoda_OTU497	71	69	SAO crustaceans	0.008						0.007				0.038						0.008	0.031	0.031	0.004
Unclassified Decapod species	Decapoda_OTU604	71	69	SAO crustaceans							0.007			0.021			0.004	0.017	0.017	0.002				
Unclassified Gastropod species		72	70	Herbivorous macrobenthos	0.008																			
Unclassified Bivalve species (Bivalvia)		73	71	Sand zoobenthos feeders	0.008																			

8. General discussion

South Australia is an important region for seal biodiversity. It contains breeding populations of all three seal species that breed in coastal Australian waters and more than 80% of the Nation's LNFS and ASL populations, as well as a small proportion of the AFS population. The sealing era in the early 1800s almost resulted in the extirpation of seals from coastal Australian waters, and for almost 150 years that followed, seal populations remained at very low levels. It was during this period that most of Australia's contemporary fishing and aquaculture industries developed. However, the last three decades have seen a major recovery of fur seal populations and concomitant with this recovery, direct interactions between seals and some fisheries and finfish aquaculture operations have increased, as have the perceptions about their impacts on fish stocks and the broader marine environment. As large bodied, conspicuous marine predators, seals are viewed by many marine stakeholders as direct competitors that could have negative economic impacts on their livelihoods. Whether real or perceived, the impacts of seals have become a very complex socio-ecological and economic issue.

This project set out to significantly improve our understanding of the nature and extent of seal interactions with South Australian marine industries (aquaculture, commercial and recreational fisheries, and ecotourism), by using a range of diverse methodologies and approaches. These included social perception surveys of marine stakeholders to assess the perceived impacts of seals on their livelihood, and on the broader marine ecosystem, and to provide an estimate of the economic impact of seals on the finfish aquaculture industry (see Chapter 2 and Appendix 2.1). Two main dietary studies were undertaken to improve our understanding of the diet of seals in South Australian waters. The first, utilised new molecular metabarcoding tools applied to prey DNA extracted from seal faecal samples (scats) (Chapter 3). The second utilised traditional faecal hard-part analyses to examine the diet of LNFS across different coastal regions in South Australia, and for a subset of samples, compared the application of hard part and DNA metabarcoding methods (Chapter 4).

A satellite telemetry study of male LNFS was undertaken to evaluate their foraging patterns and determine the extent to which the distribution of individual foraging effort was associated with important finfish aquaculture locations, and regions important to commercial and recreational fishing (Chapter 5). The key regions included Port Lincoln (southern SG), Kangaroo Island and The Coorong. These spatial data were integrated with existing satellite tracking data and demographic consumption models to estimate the spatial distribution of foraging and consumption effort of LNFS and ASL off SA. The extent of overlap with the spatial distribution of catch in the major SA fisheries was also evaluated (Chapter 6).

Data from the two dietary studies (Chapters 3 and 4) were integrated with historical data sets to provide an estimate of the overall diet of LNFS, AFS and ASL, as well as to estimate age-class and regional differences in the diet of LNFS (Chapter 7). These dietary syntheses were integrated into ecological models developed for SG and GSV, two coastal regions critical to the State's commercial and recreational fisheries (Chapter 7). These models incorporated multiple stanzas (age-classes) for key commercially targeted species and LNFS, and were used to evaluate the importance of consumption by seals relative to other marine predators. Scenarios were run in each of these models to assess the potential impacts of changing biomasses of seals on the biomasses of key commercially fished species and other taxa.

Seal impacts on finfish aquaculture

The social perception surveys have provided new insights into the nature, extent and economic impacts of interaction between seals and the finfish aquaculture industry in SA. All questionnaire respondents indicated they had interactions with seals, most (79%) indicated these interactions were with both LNFS and ASL. Aquaculture operators judged both seal species to impact their operations; LNFS were considered to be proportionately more disruptive, while ASL were also seen to damage equipment, including sub-surface nets, and to harass farm workers.

Interactions between seals and finfish aquaculture operations are very common, with half of the respondents reporting daily interactions. Although interactions occur throughout the year, many respondents indicated that seals were most economically damaging just before the harvest, usually June and July. Respondents judged that seal interactions posed a moderate (29%), major (47%) or extreme (20%) risk to their business, with most respondents believing that seal interactions had increased or significantly increased over the last five years.

The range of economic impacts were diverse, with no one impact dominating. The most acute impacts included loss and damage of fish stock, and their subsequent sale. Many operators (47%) judged that the impact on their operations was between 1 and 5% a year, with a third of operators estimating the overall cost of seal interactions at $100,000 per year. Some judged stock loss to range between 5 and 20% a year, representing a significant financial liability. The impact of seal interactions on the quality of the fish, whether by scarring (appearance) or meat quality (due to stress or the fish being scared off their feed) was one of the most significant issues for aquaculture operators, with most (86%) noting a negative impact exceeding $1,000 per year. Damage to nets, other infrastructure and loss of feed was estimated to cost more than $1,000 a year and as much as $50,000 to $100,000 a year. Many respondents indicated that the cost of replacing nets was prohibitive, and that seal-proofing cages was a big issue.

Three key observations can be made about changes in the nature and impact of seal interactions with finfish aquaculture between 2005 (Goldsworthy *et al.* 2009a) and 2015 (this study). First, in 2005 the impacts from ASL were considered more significant while in this study the impacts from LNFS were. Second, the economic significance of seal interactions with aquaculture has increased over the last decade. Third, whereas damage to equipment was considered to be relatively rare in 2005 (Goldsworthy *et al.* 2009a, p. 31), in this survey most (86%) respondents estimated that the cost of gear replacement exceeded $1,000 per annum. Recent surveys also suggest that there is some level of acceptance that managing seal interactions is part of the ongoing business costs that need to be factored into ongoing planning and management.

Aquaculture operators reported using a range of measures to mitigate and manage seal interactions, including: anti-predator fences above water (69% of respondents), anti-predator fences below water (45%), net stiffening and cage tensioning (50%), electric fences (17%) and steel mesh nets (30%). Previous practices no longer used included acoustic deterrent devices and shooting (79% and 18% of respondents, respectively). Three important changes in the way industry mitigates and manages seal interactions over the last decade have been identified by this study. First, a reduction in the use of high fences on the pontoons from 100% to 69% (Goldsworthy *et al.* 2009a). Second, regular removal of tuna carcasses was considered less important in reducing interactions with seals now then it was in 2005. Third, whereas net maintenance was considered important in reducing entry points used by seals by all respondents in 2005, it was not mentioned by any respondent in this study. In general terms, results from the 2005 study indicated that mitigation measures, particularly the use of seal fences (above water), worked to manage the impact of seal interactions. This contrasts with the findings of this survey, where most operators felt that seal interactions remained an issue notwithstanding their efforts at mitigation. The 2014-2015 survey also showed that a wider range of mitigation measures had been used, ranging from seal fences (above water and below water) to acoustic devices.

Satellite telemetry data obtained by this study on the movement behaviour of nine subadult and adult male LNFS fitted with GPS tags at Donington Reef, off Port Lincoln, has provided fine-scale movement data on individual fur seals, in particular their close association with Southern Bluefin Tuna (SBT) aquaculture pens. All but one of these seals foraged in tight association within active SBT leases over many weeks or months that the tags were transmitting. A total of 14 aquaculture lease areas were visited by seals, with each seal visiting between five and nine different lease areas. Seals typically made short nightly foraging trips to nearby tuna leases within a 20km radius of haul-out sites, most animals using Donington Reef, but some also utilising nearby Rabbit and Sibsey Islands as haul-out (resting) sites. The majority of GPS locations within lease sites were transmitted at night. Fur seals show a strong preference for foraging at night in general (Page *et al.* 2005b), so it is unclear whether the preference for night foraging in association with pens is an extension of their normal nocturnal foraging, or a response to avoiding humans working at pens during daylight hours. The core foraging areas of the individuals that associated with aquaculture leases were all within 20 km of Donington Reef. Interestingly, within ten days of the last tuna pens being harvested (August), the three seals whose GPS tags were still transmitting at the time, all left SG to undertake extended shelf or oceanic foraging trips lasting weeks or months to distant foraging locations over 800 km away from Donington Reef. The contrast between this foraging strategy and that adopted by seals when foraging in association with tuna pens (nightly foraging trip of less than 20km) is profound. It raises many questions about the cost-benefits of the different foraging strategies, and highlights the plasticity and flexibility of the foraging behaviour of LNFS males. Clearly while tuna pens are stocked, they provide a reliable and readily accessible source of food to many fur seals, a short commute from multiple haul-out sites.

Dietary studies of faecal prey DNA recovered from scats collected from LNFS and ASL at Donington Reef in July 2016 provide important insights into what seals are feeding on when foraging in and around aquaculture pens. For LNFS, two key aquaculture species, Yellowtail Kingfish (YTK) and SBT were detected in 50% and 19% of scats, respectively, but these species made up <2% of the total prey DNA sequence reads. The other commonly detected prey species were Yellowtail (52% of scats) and Jack Mackerel (45%), and Skipjack Trevally (20%) and Sardine (20%), with the prey sequence reads dominated by Yellowtail Mackerel and smaller levels of skipjack trevally. Of course, it is not possible to determine from the dietary studies if the key aquaculture species (SBT and YTK) were taken live, injured or dead. However, surveys of farm managers conducted in 2005 indicated that they believed that juvenile LNFS were too small to attack live SBT, and were most likely taking advantage of the baitfish fed to SBT, or were targeting smaller scavenger fish present in or around pens (Goldsworthy *et al.* 2009b). Although the Sardine detected in fur seal scats may have been derived from SBT feed, LNFS are also regularly observed feeding on sardines in association with SA Sardine Fishery, are large portion of which operates in southern SG. However, none of movement behaviours of the GPS tagged seals suggested they were foraging in association with this fishery. Although the dietary data provide support that LNFS are attracted to aquaculture pens in part to directly feed on live, sick or dead SBT or YTK, or on baitfish feed, the prevalence of mackerel and trevally in the diet also suggest that they may be attracted to aquaculture pens to forage on other species attracted to aquaculture operations. Aquaculture pens are fish aggregating devices (FADs), providing structure in the pelagic environment and access to additional nutrients in the form of waste feed (Callier *et al.* 2018, Dempster *et al.* 2010, Fernandez-Jover *et al.* 2008). Fernandes et al. (2007b) identified leatherjackets (especially Degens Leatherjackets) as the main fish species scavenging off baitfish feed around SBT pens off Port Lincoln, but also Jack mackerel. Irrespective of whether fur seals are depredating farmed fish or feeding off wild fish aggregations around cages, aquaculture pens clearly provide a predictable concentrated source of prey that is highly attractive to them.

Dietary analysis of ASL scats obtained from Donington Reef, detected YTK in 46% of scats, but no SBT was detected. ASL diet was dominated by multiple species of leatherjackets (e.g. Degens 64%, Bridled 48%, Toothbrush 32%), Red Mullet (64%), Silverbelly 54% and Skipjack Trevally (48%), with prey sequence reads dominated by Skipjack Trevally and leatherjackets. Although some of these prey species may have been taken in association with aquaculture pens, we do not have support from tracking data to indicate the extent to which ASL that haul-out at Donington Reef, forage in association with aquaculture pens. Extensive satellite telemetry studies were undertaken of ASL in southern SG between 2003 and 2005 (Goldsworthy *et al.* 2009b), however the tags used were Platform Transmitting Terminal (PTT) tags that provide poorer location quality, and it was not possible to determine specific association with aquaculture pens, as could be determined from GPS tags.

Seal impacts on commercial and recreational fishers and other marine stakeholders

The social perception surveys have provided an important contemporary perspective on perceived impacts of seals on marine stakeholders and the broader ecosystem. Based on the responses from various marine stakeholders there is a strong perception that interactions with seals are having an economic impact, but this impact is diffuse, hard to quantify and is positive in some cases. Whereas aquaculture operators judged both seal species (ASL and LNFS) to be having an impact on their operations, for most other marine stakeholders their primary concerns were with LNFS. The fishing sector in the Lakes and Coorong region is experiencing acute and immediate stress and economic impact relative to other stakeholders, with some respondents estimating losses of up to 50% or more in their profit and catch in the last five years due to seal interactions with LNFS. One respondent stated that 'I believe that seals are 'totally destroying' the Coorong and that if something is not done immediately the area's environment and economy will collapse.' In contrast, marine tourism sector stakeholders viewed interactions with seals to have a very positive economic impact, in some cases saving businesses in difficult economic times (e.g., for shark cage dive operators when sharks are absent from licensed areas).

There is a strong perception and belief held by many marine stakeholders that the economic impact of seals is major and potentially catastrophic. This has created social and emotional uncertainty; some people are suffering and are hurt by the issue. Some appear to be fearing bankruptcy, unemployment, divorce or suicide for themselves, family and friends. Much of the discourse around seal interactions is relayed in very emotive terms, making accurate estimation of the economic impact difficult to assess.

Many respondents believed that the broader ecosystem impacts of seals were also potentially catastrophic. Many held a clear belief that seals are responsible for stress and predation of other species, for ruining habitat and creating ecological imbalance in ways that will have future consequences. Some held the view that seals were wreaking havoc on fish stocks, upsetting the balance of ecosystems, and killing birdlife. Many respondents from Kangaroo Island, as well as Granite Island and Victor Harbor, were concerned about significant declines of Little Penguin populations, which they attribute to seal predation and recovery of their population. Some stakeholders held contrary views, and recognised seals as an important part of marine ecosystems, and that recovery of populations depleted by humans was a positive thing.

Survey results highlighted extensive confusion and about the seals, including which species were involved in interactions. Some respondents were unable to decide whether populations were increasing or decreasing. Very few knew anything about the biology and ecology of the species, but most commonly blamed the LNFS for negative interactions. Management of seal interactions was overwhelmingly seen as a government responsibility, and respondents were unanimous in asserting the need for immediate action on the seal interaction issue. The most favoured management option was culling, although nothing was reported on how that might be done, how many seals should be culled, what was the desirable end-point in terms of abundance, who would be responsible for culling and what the consequences of culling might be.

As with interactions with the finfish aquaculture industry, dietary and tracking studies, along with survey data of haul-out areas have markedly improved our understanding of how seals use coastal waters, and the extent to which they interact with, and impact on the abundance of species targeted by commercial and recreational fishers. The extensive tracking datasets available for ASL in SA show that this species is entirely restricted to the continental shelf waters, year round. So there is potential for extensive spatial overlap of the foraging distribution of all age and sex classes of ASL with the States commercial fisheries. For LNFS, tracking data, foraging distribution models and multi-stanza consumption models were used to estimate the proportion of overall consumption that occurs in coastal waters. Pooling all of these sources of data has improved our understanding of the role and potential impact of LNFS in coastal waters. Results all point very clearly to the fact that for most age classes of female and male LNFS, the vast majority of foraging throughout the year occurs in outer shelf or oceanic waters, well away from coastal waters and fisheries. We know that weaned pups (~10 months old) and juvenile LNFS largely forage in oceanic waters of the Southern Ocean, with the mean maximum distance travelled from the colony by satellite tracked juvenile fur seals being ~1,100 km (B. Page, A. Baylis and S. Goldsworthy unpublished data, Page *et al.* 2006). Female LNFSs commence recruiting into the breeding population at age 4 (McKenzie *et al.* 2007b), breed annually (breeding season between December and mid-January (Goldsworthy and Shaughnessy 1994)), and give birth to a single pup which they nurse for about 10 months prior to weaning (Goldsworthy 2006). Females alternate between shore attendance bouts lasting 1-2 days (when pups are nursed) and foraging trips to sea. During the first 4 months (December to April) of lactation, females typically forage in outer shelf waters (Goldsworthy 2006, Page *et al.* 2006), but then transition to oceanic foraging, ~400 to >1,000 km south of breeding colonies in waters associated with the subtropical front (Baylis *et al.* 2008a, Baylis *et al.* 2012). Females largely avoid foraging in coastal waters, but they may opportunistically consume some coastal species as they commute across coastal waters at the very beginning or end of each foraging trip.

As male LNFS do not care for pups and are not large enough to hold breeding territories until around nine years of age (first male tenure average 9 years, McKenzie *et al.* 2007b), their foraging strategies differ markedly from adult females. Satellite telemetry studies have identified that adult males largely forage in continental slope waters (Page *et al.* 2006). However, there has been great uncertainty about the movement, foraging behaviour and diet of subadult males, the age-class that spends the most time in coastal waters. As this age group has the greatest potential to interact and impact on the seafood sector, it has formed a major focus for this study. We are now aware that the presence of fur seals in coastal SA waters is largely a winter phenomenon (Figure 8.1). Survey data available for Southern SG (Donington Reef), GSV (outer Harbour) and The Coorong are all very consistent in showing the seasonal build up in numbers of LNFS, typically with low numbers between November and March, building up and peaking between June and September (Figure 8.1). At Outer Harbour in GSV, the regular surveys undertaken there between 2004 and 2015 show a consistent annual periodicity in numbers, with the peak usually occurring in August or September (Shaughnessy *et al.* 2018). A fitted model to the annual data predicts an annual peak occurring ~9-11 September (Shaughnessy *et al.* 2018). The one year of data available for Donington Reef indicated a peak in abundance occurring in August (Figure 8.1a), while for the three years of data available for The Coorong, peaks in LNFS numbers have been recorded in June, July and August (Figure 8.1c). Observations at these sites and other important haul-out sites around SA during this winter peak, indicate that almost all the seals are male, and most are either older juveniles (2+ years) or subadult males (4-8 years).

In addition to the nine LNFS fitted with GPS tags in SG, GPS tags were deployed on male fur seals on the north coast of Kangaroo Island (2 Kingscote), and in or adjacent to the Coorong (3 West Island, lower Fluerieu Peninsula; 1 Tauwitcherie Barrage, The Coorong). All these deployments occurred in September/October, after the winter peak in abundance and provide further examples of the highly flexible foraging strategies of male fur seals, with many individuals spending time foraging in the coastal margins or within the estuary and lakes systems of The Coorong and Lower Lakes, before switching to offshore oceanic foraging. One individual male seal GPS tagged at Kingscote (Kangaroo Island) foraged in local coastal waters before hauling out at a breeding colony on the south coast of Kangaroo Island, where it remained for about one month just prior to the commencement of the breeding season. It then left and headed south-east, south of Tasmania into the Southern Ocean, before hauling out on an island south east of King Island in Bass Strait, a foraging trip of more than 1,100 km lasting 47 days. The extent to which any of these seals were directly interacting with fishing activities when foraging in near coastal waters is unclear, as real-time location data of catch and effort is not available for most SA coastal fisheries. This is pertinent for the three tracked seals that entered and spent time in The Coorong and Lower Lakes, where LNFS interactions with the Lakes and Coorong Fishery is a major issue. However as none of the licence holders were required to record the location and time of their net-sets and hauls (when this report was drafted), it is not possible to determine if the movement behaviour of any of these seals was associated with fishing activity or not.

Diet data available for LNFS in The Coorong indicate that seals predominantly preyed on European Carp, Bony Herring and Tamar Goby, with the key commercially targeted species (Yelloweye Mullet and Mulloway) only making a small contribution. These results were consistent with the broader dietary analyses undertaken for all seal species that showed that commercial taxa accounted for a relatively small component of the diet, both in terms of number of prey taxa and estimated biomass. Key commercially targeted prey species were estimated to make up just 5%, 4%, and 2% of the total prey biomass of LNFS, ASL and AFS. For LNFS, only three key commercial taxa were significant contributors to the overall diet, Garfish (1.8%), Southern Calamari (1.7%) and Sardine (1.3%). For ASL, the only commercial taxa that accounted for significant prey biomass was Southern Calamari (3.6%). For AFS, Garfish and Blue Crab were the only commercially fished species detected, but both were very minor contributors to estimated dietary biomass (just 0.8% in both cases). Notwithstanding all the major challenges in estimating ‘true diet’ from the combination of hard-part analyses and prey DNA methods (Chiaradia *et al.* 2014), these results indicate that in general, pinnipeds in SA largely prey on non-commercial species.

There was some important regional variation in the contribution of key commercial taxa identified for LNFS. Commercial taxa were a very minor contributor to the diets of LNFS on the West Coast (0.6%), south coast of Kangaroo Island (0.7%) and The Coorong (0.1%); however they were more important in SG (6.0%) and were a major part of the diet in GSV (52.2%). Most consumption of commercial taxa was by male LNFS, and the key commercially fished taxa consumed were Sardine (3% of prey biomass) in SG, and Calamari (24%) and Garfish (17%) in GSV. However, analyses of the spatial overlap in seal consumption and fishery catch indicated that for both ASL and LNFS, there was a tendency for there to be a spatial mismatch between areas of intensive seal foraging and commercial catch. This is particularly noticeable in the upper gulfs, which are regions of low consumption by seals, but high fishing effort. This, combined with the very low consumption of key commercially fished taxa by seals, means that the actual potential for competition between seals and the main SA fisheries, in general terms, is likely to be very low. However, there is potential for some commercially fished species to move between the northern and southern gulf areas where they may be expeosed to more predation pressure by seals. Other studies have also noted the importance of taking into account the degree of spatial and temporal overlap when estimating the degree of competition between fisheries and seals (Butterworth *et al.* 1988, Goldsworthy *et al.* 2003, Weise and Harvey 2008).

The ecological modelling undertaken as part of this study has been critical in evaluating the impacts of seals on South Australian coastal ecosystems. The Ecopath with Ecosim models developed for SG and GSV enabled the consumption of prey species by seals and other predators to be assessed and their relative consumption to be compared. Results clearly identified that the most significant consumers of finfish and cephalopods were other finfish and cephalopods. Seals consumed only about 1% of all finfish and 2-3% of all cephalopods, and only accounted for around 0.5% of the total consumption of commercially targeted finfish. Most of this consumption was by LNFS. Analyses indicated that changes in relative consumption of key commercially fished taxa by LNFS, as a consequence of the recent marked recovery in their populations has been relative minor, increasing from just 0.23 to 0.38% in SG (between 1991 and 2010), and from 0.46 to 0.55% in GSV (between 1994 and 2013).

A more detailed assessment of the potential impact that seals have on commercial fish production, came from scenario analyses. These analyses assessed the response of individual commercially targeted species to changes in LNFS and ASL biomass, which was simulated to vary from 0.1 to 10 times current levels. These analyses showed an almost imperceptible responses in terms of absolute biomass change by most commercially fished species to very significant changes in seal biomass, with details on the response relationships only becoming apparent when biomass changes were expressed in relative terms. For most of the key commercially targeted taxa, the magnitude of change in relative biomass in response to major changes in seal biomass (0.1 to 10 fold current levels) was very small, < ±1%. Response relationships varied markedly, different species responding negatively, positively or neutrally to increases in LNFS and ASL biomass. Most response relationships were highly non-linear and in many cases changed direction (+ve or –ve) with the slope of the response relationship (degree of influence), often different under low, medium and high seal biomass scenarios. Such complex non-linear relationships suggest that direct impacts of changing seal biomass on the biomass of a commercially targeted species is less important than the indirect impacts seal predation has on other predators or competitors of commercially targeted species. The relationships suggest that seals are important in mediating predator-prey interactions that affect the biomass of many taxa, including those targeted by commercial fishers. It also provides a very different perspective on the role of seals in coastal Australian food webs and their impacts on commercial fisheries. The scenario analyses provide a means to visualise the dynamic changes that may occur across taxa, and how trophic interactions may reconfigure when the biomass of seals in ecosystems is increased or reduced. Interestingly, the magnitude and range of the response relationships were typically greatest under low seal biomass scenarios, and lowest under high seal biomass scenarios. Response relationships typically differed between LNFS and ASL, and there was evidence for regional differences in the response relationships in the two Gulf models.

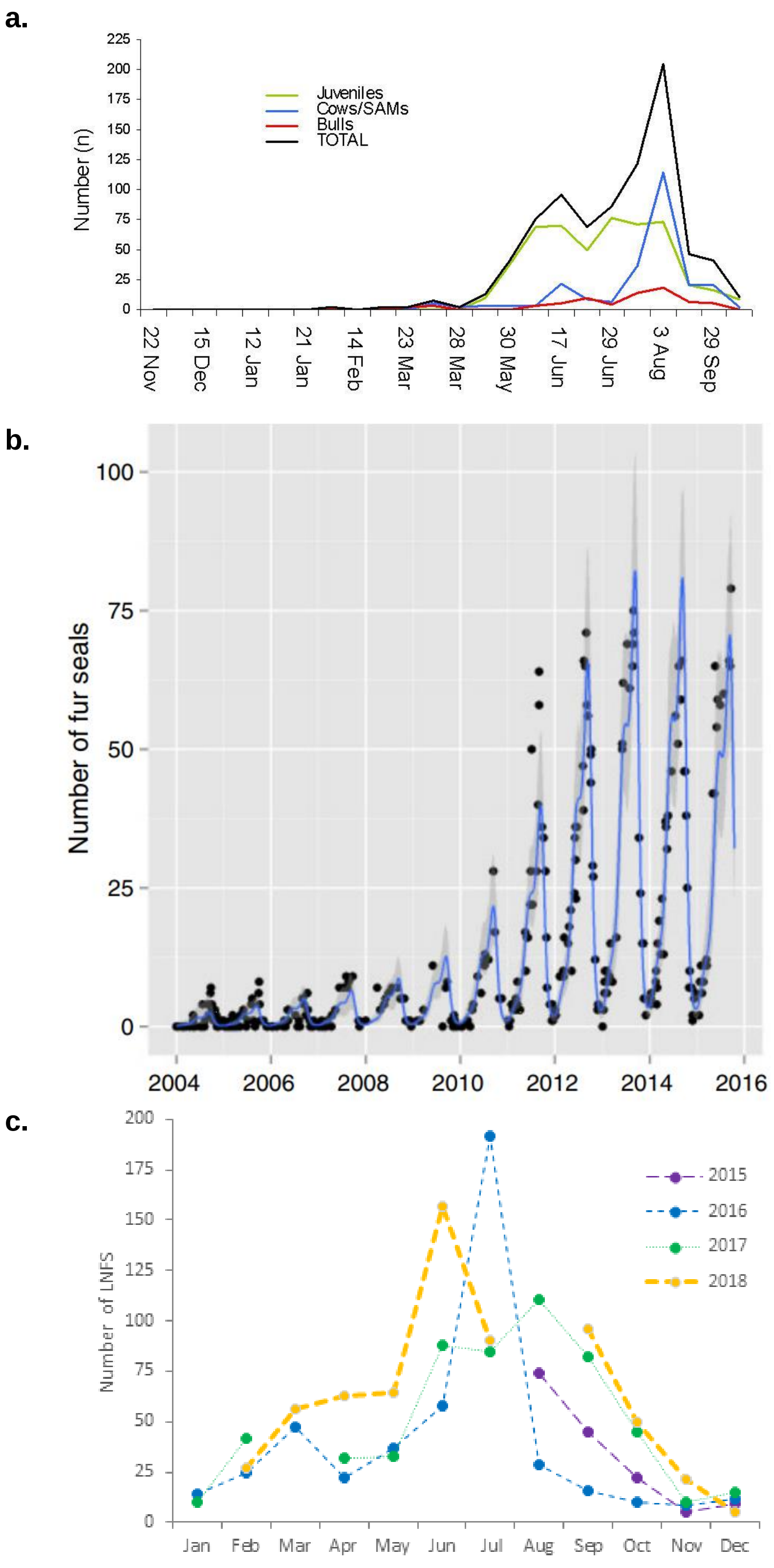


Figure 8.1. Available figures demonstrating the seasonal haul-out behaviour of Long-nosed Fur Seals in a) southern SG (numbers of LNFS at Donington Reef between Nov 2004 and 17 Oct 2005, from Goldsworthy *et al.* 2009b); b) GSV (counts of LNFS on the breakwaters at Outer Harbor between 2004 and 2015, illustrating the annual periodicity in fur seal numbers, from Shaughnessy *et al.* 2018); and c) The upper Coorong (counts between Aug 2015 and Dec 2018, Department for Environment and Water unpublished data).

The greatest impacts detected by seals on commercially targeted species was for Garfish and Southern Rock Lobster. Scenarios indicated a 12% decrease in Garfish biomass in response to LNFS biomass increasing from 0.1 to current biomass levels in the SG model. However, the response relationship in the GSV model was opposite, and indicated a marginal 2% increase in Garfish biomass as LNFS biomass increased from 0.1 to current biomass levels. Both models suggest that further increases in LNFS biomass will have a negligible impact on Garfish biomass (<1%). Given that the fishing effort for Garfish is concentrated in the upper regions of both GSV and SG, where consumption effort by LNFS is very low, it is likely that the extent of interactions between LNFS and Garfish has been over-estimated in the ecosystem models, which were unable to take into account difference in the spatial distribution of taxa. Southern Rock Lobster biomass responded negatively to increasing ASL biomass in both Gulf models, but the relationship was weaker in the GSV model. The negative relationship between Southern Rock Lobster and ASL biomass in the SG ecosystem model was the strongest response relationship detected among all of the interactions between seals and seafood production, with a ~35% increase in Southern Rock Lobster biomass at low ASL biomass levels (0.1 current biomass), and a ~20% decrease in biomass at high ASL biomass (10 times current biomass). However, the relationship was much weaker in the GSV model, where changes in ASL biomass had little impact on the biomass of Southern Rock Lobster, highlighting the importance of considering regional difference in trophic interactions when examining species interactions.

In terms of the potential impacts of increasing LNFS populations on commercial fish production (finfish, cephalopods and crustaceans), outputs from both the SG and GSV models indicate a less than 1% change in biomass as LNFS biomass increased from 0.1 to current biomass levels. Furthermore, under increasing LNFS biomass scenarios (up to 10-fold current levels), the impacts on the biomass of key commercially targeted finfish, cephalopod and crustacean taxa were negligible, with the interactions becoming more positive as the biomass of LNFS increased. It is clear that the impacts of seals on marine ecosystems and commercial fish production are poorly understood by many marine stakeholders, and their perceived impacts have been grossly exaggerated. The notion that recovering fur seal populations will have catastrophic impacts on both seafood production and the broader marine ecosystem is not supported by this study.

Seal impacts on other species of interest

This study also examined potential impacts of seals on species of value to the marine ecotourism industry. The key species and activities of value to these industries include seal watching or swimming tours (ASL and LNFS), Little Penguin tours, White Shark cage diving, swim with Giant Cuttlefish, and general outdoor adventure/ecotourism activities. The social perception surveys of the marine tourism sector, suggest in general that interactions with seals have had a very positive economic impact. Clearly for businesses that incorporate seal watching (e.g. ASL and LNFS on Kangaroo Island, kayaking tours in The Coorong), or seal swimming (e.g. Swim with ASL tours on Eyre Peninsular), abundant and recovering seal populations are seen as a benefit. In the shark cage diving industry where many operators also include seal swimming (with ASL principally at Hopkins Island in SG) on their tours, seal swimming is often critical at times when White Sharks are absent from the licenced cage-diving areas, and have saved some businesses from economic hard times. However, many lLittle Penguin tour operators (e.g at Victor Harbor and Kangaroo Island), and various other marine stakeholders held the strong perception that predation by increasing populations of LNFS was responsible for declines in Little Penguin populations, other stakeholders held concerns for the impact of LNFS on Giant Cuttlefish ecotourism off Whyalla, or felt that the recovery of LNFS was linked to the decline in ASL populations. As with fishery interactions, many of the marine stakeholders concerned about the impacts of LNFS on Little Penguins saw culling of fur seals as the solution. However, a number of the marine ecotourism industry respondents had concerns about the negative image, and economic consequences that could arise if a culling program was introduced.

Ecological models for SG and GSV were used to examine the potential impacts of seals on other key apex predator groups (dolphins, seabirds, and sharks and rays). The response relationships with apex predator group were very similar to those undertake for the key commercially fished species, in that the biomass change responses to changes in seal biomass were generally small, most were non-linear and the direction of response often changed under low and high seal biomass scenarios. A number of individual species response scenarios were modelled, including ASL response to changing LNFS biomass, and the response of Little Penguins and Giant Cuttlefish to changes in biomass of both LNFS and ASL.

ASL biomass responded negatively to increasing LNFS biomass in the SG ecosystem model, with a ~7% decline in biomass as LNFS biomass increased from 0.1 to current biomass levels, and a further ~3% decline as LNF biomass increased to 10 time current biomass. However, no discernible relationship between ASL and LNFS biomass was detected for the GSV model. There is potential for the interactions between LNFS and ASL to be over-estimated in the existing models, as they do not take into account the major difference in the habitats of the species, with fur seals foraging predominantly in the water column and ASL on the benthos, so the extent to which LNFS directly competes with ASL is uncertain.

In the SG ecosystem model, Giant Cuttlefish biomass responded negatively to LNFS at low biomasses (<1.0 current biomass), and positively (but more weakly) at current and higher LNFS biomasses (between 1.0 to 10 fold current biomasses). In the GSV model, the response relation was weakly positive under low and high LNFS biomass. These results indicate that further increases in the populations of LNFS are unlikely to impact negatively on Giant Cuttlefish. Giant Cuttlefish responded negatively to ASL biomass in both Gulf models, although the relationship was stronger in the SG ecosystem (5% decline in Giant Cuttlefish biomass from 0.1 to 10 times current ASL biomass), then it was for GSV (2% decline in). Given the low abundance of ASL and LNFS in upper SG, the model scenarios and the spatial mismatch in the species overlap would suggest the potential for either LNFS and ASL to impact negatively on the Whyalla Giant Cuttlefish population is limited.

Little Penguin biomass showed a strong negative relationship with LNFS biomass in both Gulf models. The relationship was stronger at low LNFS biomasses (especially in the SG ecosystem model), and became much weaker at current and higher biomasses. The response relationship was the strongest of any of the scenarios undertaken in this study, with the projected decline in Little Penguin biomass as LNFS biomass increased from 0.1 to current biomass levels being ~80% in the SG and ~60% in GSV models. Importantly, the extent of these declines was not seen the increase further (i.e they stabilised) under increasing LNFS biomass scenarios. Little Penguin biomass also showed a negatively relationship with ASL biomass in the GSV model but it was much weaker than that for LNFS, there was no discernible relationship between Little Penguin and ASL biomass in the SG model. These results are important as they provide the first quantitative support that recovering LNFS populations may have contributed to declines in Little Penguin populations. However, the extent to which LNFS recovery has impacted on Little Penguin populations in SA still remains uncertain. Firstly, from available dietary studies, it is difficult to quantify the actual contribution of Little Penguins to the diet of seals, as most diet methods can only detect their presence, from either feathers or DNA in seal scats. There are also significant biases that need to be accounted for, for example in this study captive feeding trials on fur seals indicated that a single meal containing penguin feathers would on average be spread across five consecutive scats passed over ~80 hours. Secondly, although this study has been able to provide a better assessment of the prevalence of Little Penguins in the diet of LNFS they are likely to be just one of many other species that predate on Little Penguins for which we currently have little information. A number of shark species are known to predate on seabirds (Cortés 1999, Venter *et al.* 2006), and the dietary data available for many shark species in SA is limited to locations where interaction with Little Penguins are likely to be rare (e.g. upper gulfs, offshore and slope regions). It is therefore possible that the significance of other predators has been underestimated in our models. Without knowing what part of the total mortality of Little Penguins is caused by LNFS, and what other factors (natural or anthropogenic) may be impacting on Little Penguin populations, it’s not possible to assess the extent to which LNFS or any other factors, may be contributing to recent declines observed in some SA Little Penguin populations. However, LNFS and ASL are natural predators of Little Penguins, and the species have coexisted for millennia in southern Australian waters, with the numbers of each species likely fluctuating over time.

Summary

This study set out to improve our understanding of the nature and extent of seal interactions with South Australian marine industries (aquaculture, commercial and recreational fisheries, and ecotourism). Social perception surveys provided an important contemporary perspective of perceived impacts of seals on marine stakeholders and the broader ecosystem. The overwhelming perception from seafood industry stakeholders was that the economic and ecosystem impacts of seals (mainly LNFS) were major and potentially catastrophic, populations of LNFS were perceived to be overabundant and active management of numbers was needed to mitigate their impacts. Importantly, these surveys confirmed that direct interactions with seals were largely restricted to finfish aquaculture (loss and damage to fish stock, loss of feed, damage to nets) and passive gear fisheries, principally the Lakes and Coorong Fishery (depredation of catch and damage to set gillnets). This is consistent with SA commercial fishery log-book data on interactions with threatened, endangered and protected species (TEPS), which indicates very few if any consequential direct interactions occur between seals and any of the State's active gear fisheries, including those using haul-nets and lines (Marine Scalefish Fishery), purse seine nets (South Australian Sardine Fishery), and trawling methods (SG, West Coast and GSV Prawn Trawl Fishery) (Mackay 2017). This pattern where passive gear fisheries are more vulnerable to direct interactions with seals (damage to gear and catch) compared to active gear fisheries, is typical of seal-fishery conflicts elsewhere (Olsen *et al.* 2018). Although the economic impact of seal interactions was assessed for the finfish aquaculture industry in this study, it has yet to be assessed for the Lakes and Coorong Fishery. However, the social perception surveys clearly suggest that this fishery is suffering acute economic, as well as mental health impacts. The economic impacts of seal interactions in this fishery are being assessed in FRDC Project 2018-036 'Seal-fisher-ecosystem interactions in the Lower Lakes and Coorong: understanding causes and impacts to develop longer-term solutions.'

Although this study found support for seal interactions causing economic impacts in the finfish aquaculture industry and in the Lakes and Coorong Fishery, it found no evidence to support claims that seals, and specifically increasing populations of LNFS, were having potentially catastrophic impacts on commercial fish production, or on the integrity and health of the broader marine ecosystem. Instead, the study found that commercially fished species comprise a very small fraction of the diet of both LNFS and ASL, and that their contribution to the total ecosystem-wide consumption of commercially fished species was minor. Scenarios modelling of the potential impacts of increasing seal populations on commercially fished species found no evidence that further increases in seal biomass would result in significant impacts on future fish production. The study found that most key fished species responded indirectly to changes in seal biomass, indicating that the predation effects of seals on other predators or competitors of commercially fished species were more important than their direct predation on these species. In this way, seals are important in mediating predator-prey interactions that affect the biomass of many taxa, including those targeted by commercial fishers.

The perceptions and concerns about the impacts of recovering populations of seals on seafood industries, marine communities and coastal ecosystems of South Australia have clearly intensified in recent years, becoming a very complex socio-ecological and economic issue that bears all the hallmarks of a Wicked Problem (see Appendix 2.1, Rittel and Webber 1973). This issue is not unique to SA. In temperate and higher latitude regions around the world, many pinniped species have shown the same pattern of depletion, recovery and conflict (Roman *et al.* 2015). Most of these conflict issues are rooted in the perception that seal populations are overabundant and that populations are 1) growing unnaturally and explosively, 2) are causing declines in fish stocks and other species, and 3) that culling provides the obvious solution (Olsen *et al.* 2018). The reality, however, is that most seal populations were larger in the past, and many are still depleted from historic sealing or more recent anthropogenic impacts (Kovacs *et al.* 2012). Recovery in the form of exponential growth, which has been observed for the LNFS population in SA over the last 30 years (Shaughnessy *et al.* 2015), is a normal response for depleted populations released from the pressures that led to their decline. Furthermore, seals, like other species, are subject to the effects of density dependence, so populations will stabilise.

Olsen *et al*. (2018) note that conflicts between fisheries and seals present an intriguing reversal of the 'shifting baseline syndrome' coined by Daniel Pauly (Pauly 1995). The syndrome originally described the gradual acceptance of depletion of fish stocks by successive generations of fisheries scientists, with each new generation starting their career with a new, lower baseline. However, with many seal-fishery conflicts, Olsen *et al*. (2018) argue that as seal populations and the ensuing conflicts with seafood industries and coastal communities grow, the acceptance and tolerance of either real or perceived impacts quickly exceeds the accepted 'modern baseline' of low abundance. LNFS populations in SA were almost extirpated by colonial sealers in early 19th century, with the industry almost economically inviable by time the State was officially declared a colony in 1836. The absence of accurate estimates of the size of LNFS populations prior to exploitation by sealers, and the fact the LNFS population remained at historically low levels for the next 150 years or so, meant that marine industries developed at a time when seals were uncommon, and there was no collective public memory of their former abundance to provide context to this modern baseline. As expressed by many respondents in the public perception surveys, the recent recovery of fur seal populations in SA is unwelcome, perceptions about their recovery and impacts are often expressed in very emotive ways, and the species is widely considered to be overabundant and requiring active management. However, there is no indication that LNFS populations in SA are more abundant than they were prior to the sealing era. Populations are not over abundant, rather they are recovering from past exploitation. Roman *et al*. (2015) argue that such situations demand 'lifting baselines', where public attitudes and management of conflicts can be improved where policy makers actively try to lift baselines when the objective is to allow species to recovery to their former population levels.

9. Conclusion

This project set out to improve our understanding of the nature and extent of seal interactions with South Australian marine industries, including aquaculture, commercial and recreational fisheries, and the ecotourism industry.

The social perception surveys provided an important contemporary perspective of the perceived impacts of seals on marine stakeholders and the broader ecosystem. The most significant direct interactions were between seals and the finfish aquaculture industry off Port Lincoln, and with gillnet fishers in the Lakes and Coorong Fishery. Whereas both seal species (ASL and LNFS) were viewed as having an impact on finfish aquaculture operations, for most other marine stakeholders their primary concerns were with LNFS.

Many finfish aquaculture stakeholders judged that the economic impact of seals on their operations, from loss and damage of fish stock and their subsequent sale, damage to nets, other infrastructure and loss of feed, ranged between 1 and 5% a year, with a third of operators estimating the overall cost of seal interactions to be $100,000 per year.

The fishing sector in the Lakes and Coorong region is experiencing acute and immediate stress and economic impact relative to other stakeholders, with some respondents estimating losses of up to 50% or more in their profit and catch in the last five years, due to interactions with LNFS.

Concerns about the impacts from seal interactions were often relayed in very emotive terms, with many stakeholders believing that the economic impact of seals was major and potentially catastrophic. This was especially the case in the Lakes and Coorong region where seal interactions have also had significant social and wellbeing impacts on the fishing community.

In contrast, marine tourism industry respondents viewed interactions with seals as having a very positive economic impact, in some cases saving businesses in difficult economic times (e.g., for shark cage dive operators when sharks are absent from licensed areas).

Many respondents believed the broader ecosystem impacts of seals to be potentially catastrophic. Key concerns were the impacts of an increasing population of LNFS on fish production, creating imbalance in the ecosystem, and the killing of birdlife. Many respondents attributed declines in Little Penguin populations to predation by fur seals and the recovery of their populations.

Many seafood industry respondents believed that populations of LNFS were overabundant and active management of numbers was needed to mitigate their economic and ecological impacts. The most favoured management option was culling.

The study has confirmed that with respect to LNFS, interactions are largely restricted to older juvenile male (+2 years) and subadult male (~4-8 years) age-classes. A portion of this population comes into coastal waters in autumn-winter months. The rest of the population forages offshore. Analyses of the spatial overlap in seal consumption and fishery catch indicated that for both ASL and LNFS, there was a tendency for there to be a spatial mismatch between areas of intensive seal foraging and commercial catch. This is particularly noticeable in the upper gulfs which are regions of low consumption by seals, but high fishing effort.

Tracking studies provided new data on the movement of male LNFS in coastal waters. GPS tags fitted to male LNFS hauled-out at Donington Reef adjacent to SBT aquaculture cages in SG, demonstrated a remarkably tight association between the seals and tuna cages. Seals were tracked over several months, undertaking nightly foraging trips to tuna leases within a 20km radius of Donington Reef. Within ten days of the last tuna cages being harvested (August), all seals whose GPS tags were still transmitting left SG to undertake extended shelf or oceanic foraging trips lasting weeks or months to distant foraging locations over 800 km away. Results demonstrated that while tuna cages are stocked, they provide a reliable and readily accessible source of food to many fur seals, a short commute from nearby haul-out sites.

Diet analysis provided support that LNFS are attracted to aquaculture cages in part to directly feed on either live, sick or dead tuna or Yellowtail Kingfish, or on baitfish feed. However, the predominance of mackerel and trevally in the diet suggested they may also be attracted to aquaculture cages to forage on other species attracted to aquaculture operations.

A number of male LNFS were also fitted with GPS/satellite tags on the north coast of Kangaroo Island and in or on islands adjacent to the Coorong. Movement data from these animals provided further examples of the highly flexible foraging strategies of male fur seals. Several individuals spent time foraging within the estuary and lakes systems of The Coorong and Lower Lakes, before switching to offshore oceanic foraging. The extent to which these seals forage in association with the LCF could not be assessed.

Dietary studies estimated that key commercially fished species made up just 5%, 4%, and 2% of the total prey biomass consumed by LNFS, ASL and AFS in South Australia. Regional differences in the contribution of key commercially fished species were identified in LNFS diet. They were a minor contributor to the diets on the West Coast, south coast of Kangaroo Island and The Coorong; but were more important in SG (6.0%) and were a major part of the diet in GSV (52.2%). Most of this consumption was by male LNFS, and the key commercially fished taxa consumed were Sardine (3% of prey biomass) in SG, and Calamari (24%) and Garfish (17%) in GSV.

Ecosystem models developed for SG and GSV enabled the consumption of prey species by seals and other predators to be assessed, and their relative consumption to be compared. Results identified that the most significant consumers of finfish and cephalopods were other finfish and cephalopods. Seals consumed only about 1% of all finfish and 2-3% of all cephalopods, and only accounted for around 0.5% of the total consumption of commercially targeted finfish, most (0.4%) of which was consumed by LNFS.

Scenario modelling of the potential impacts of increasing seal populations on commercially fished species found no evidence that further increases in seal biomass would result in significant impacts on future fish production. Outputs from both the SG and GSV models indicated a less than 1% change in biomass of key commercially targeted finfish, cephalopod and crustacean taxa in response to LNFS biomass increasing from 0.1 to current biomass levels. Under increasing LNFS biomass scenarios (from current up to 10-fold current biomass levels), the biomass of key commercially fished taxa tended to increase as the biomass of LNFS increased.

The study found that most key fished species responded non-linearly to changes in seal biomass, indicating that the indirect predation effects of seals on other predators or competitors of commercially fished species were more important than their direct predation on these species. In this way, seals are important in mediating predator-prey interactions that affect the biomass of many taxa, including those targeted by commercial fishers.

Scenario of increasing LNFS biomass in both the SG and GSV provided the first quantitative evidence that recovering LNFS populations may have contributed to declines in Little Penguin populations. However, the impact from other predators, such as sharks, may be underestimated in these models.

The perceptions and concerns about the impacts of recovering populations of seals on seafood industries, marine communities and coastal ecosystems of South Australia have clearly intensified in recent years, becoming a very complex socio-ecological economic issue.

With respect to economic impacts, the study has confirmed that direct interactions with seals (e.g. depredation of catch/farmed fish, loss of feed, damage to nets and gear) can cause significant economic impact, but these are largely restricted to two marine sectors: the finfish aquaculture industry in SG, and the gillnet sector of the Lakes and Coorong Fishery. Direct interactions with other SA fisheries are rare or economically insignificant, principally because these represent active gear fisheries that offer seals less opportunity to exploit.

With respect to ecological impacts, the study found no evidence to support claims that seals, and specifically increasing populations of LNFS, are having potentially catastrophic impacts on commercial fish production, or on the integrity and health of the broader marine ecosystem. This mismatch between the perceived and actual impacts of seals on fish production and the broader marine ecosystem represents one of the key findings of this study.

10. Implications

The key findings that the economic impacts of seals in SA are largely restricted to their direct interactions (finfish aquaculture and passive gear fisheries), and that ecological impacts are unlikely to lead to significant changes in commercial fish production or cause imbalance in coastal ecosystems, has important implications for directing policy and management priorities to address seal conflict issues. Specifically, it provides the basis to direct attention and support to sectors where seal interactions have real economic impacts, and should provide some objectivity to address many of the perception issues about the impacts of seals, especially where the control of populations has been argued as a solution to mitigate ecosystem impacts.

Similarly, results of this study should help the seafood industry shift the focus of efforts around seal conflicts towards mitigating the economic impacts of direct interactions, and allay concerns about the potential impacts of recovering populations of LNFS on commercial fish production and the ecosystems which they are a part. For finfish aquaculture, industry surveys have provided an estimate of the economic costs associated with mitigating and managing seal impacts. The industry has been contending with seal interaction issues since its development, and the extent to which it invests in mitigation and management appears largely an economic costs/benefit trade-off.

For the gillnet sector of the Lakes and Coorong Fishery (LCF), social perception surveys have highlighted the acute challenges faced by the fishing community as it grapples with seal conflict issues. As much as this study has contributed significantly to better understanding the nature and extent of economic impacts of direct interactions with seals in the finfish aquaculture sector, and the perceived ecological interactions through ecological models of SG and GSV, a recently supported FRDC project (2018-036, Seal-fisher-ecosystem interactions in the Lower Lakes and Coorong: understanding causes and impacts to develop longer-term solutions) will similarly quantify the nature and extent of the economic and ecological impacts that seal are having on the LCF and broader Lower Lakes and Coorong ecosystem. Such information will be essential in rationalising a way forward and evaluating the costs and benefits of alternative management strategies in what has become a very complex socio-economic, and ecological issue.

The social perception surveys highlighted extensive confusion and general ignorance about seals, and their role and impact on our coastal ecosystems and seafood industries. For members of the broader community, who may have concerns about the potential impacts of seals, this study provides a wealth of new information on the roles of seals in our coastal ecosystems, movement behaviour, diet and ecological interactions. Importantly, the study provides context to the contribution by seals to the overall consumption of marine resources and commercially fished species, compared with that consumed by other parts of the ecosystem. Furthermore, the study has assessed the likely impacts that changes in seal populations will have on key-fished species and the broader marine ecosystem.

11. Recommendations

The perceptions and concerns about the impacts of recovering populations of seals on seafood industries, marine communities and coastal ecosystems of South Australia have clearly intensified in recent years, becoming a complex socio-ecological and economic issue that bears all the hallmarks of a Wicked Problem.

Part of its complexity stems from the general lack of knowledge about seal populations identified during the social perception surveys, but also the absence of collective public memory about the former size of seal populations or the status of pre-exploitation ecosystems prior to European settlement.

The study identified that the economic impacts of seals in SA is largely restricted to their direct interactions with finfish aquaculture and passive gear fisheries. There was no evidence to support that increasing populations of seals would significantly impact commercial fish production or cause imbalance in coastal ecosystems. In as much as these results should help provide more objectivity and prioritise reducing the economic impacts of direct interactions, it is the management of public perceptions about seals and their impacts that is likely to be the most challenging to address. There is a clear need to better educate marine stakeholders and the broader public about the role and impacts of seals in coastal ecosystems, and address perceptions of overabundance. For example, the building of artificial shellfish reefs is now seen as a positive step to restoring lost habitat and functionality in many coastal ecosystems. Enabling the recovery of seal populations to former levels should also be seen for the positive gains it brings to restoring ecosystems to their former state. Although this study demonstrated that recovery of seal populations would not significantly impact the productivity of coastal fisheries, it did not focus on identifying the range of ecosystem services that restored population abundances may bring. Being able to demonstrate that seals are an integral part of a healthy ecosystem, may help improve tolerance around changing abundances and address misconceptions about their impacts.

With respect to finfish aquaculture interactions, there is still uncertainty as to the extent to which seals are attracted to cages to directly feed on live, sick or dead stock, versus the communities of wild fish attracted to their operations. Although such information may help better understand what motivates seals to interact with finfish aquaculture, industry are aware that keeping seals out of their cages presents the best approach to minimising their economic impact. Given the dynamic nature of the environments where finfish aquaculture operations occur, developing systems that reliably exclude the entry of seals is challenging, and in cases cost-prohibitive. Research and development of reliable and affordable systems to exclude seals from finfish aquaculture is certainly an area of interest to industry.

The key fishery in SA that is impacted by seals is the gillnet sector of the Lakes and Coorong Fishery (LCF). It is a small-scale, community-based commercial fishery that is an important source of local seafood, regional employment and income. Interactions between LNFS and gillnet fishers in the LCF have increased in recent years, and the industry perception surveys clearly indicated that the perceived economic impacts are chronic. While the key economic impacts from depredation of catches and damage to fishing gear have yet to be quantified, the issue has intensified in recent years, with concerns from industry that the fishery may soon not be viable if strategies are not developed to manage the number of seals using the Lower Lakes and Coorong, and mitigate their impacts. Furthermore, many fishers, and Aboriginal and other community members are also concerned about the potential impacts that seals are having on waterbirds, fish populations, and on the broader lakes and estuary ecosystem. An assessment of the nature and extent of the economic and ecological impacts of seals in the Lower Lakes and Coorong region is now recognised as a priority for developing practicable and cost-effective long-term policy/management strategies to address and mitigate LNFS impacts in the Lakes and Coorong region. It has recently been supported as an FRDC project (2018-036, Seal-fisher-ecosystem interactions in the Lower Lakes and Coorong: understanding causes and impacts to develop longer-term solutions), which will commence in early 2019.

Although this study was able to significantly advance our understanding of the diets and movement patterns seals and their and ecological relationships with SA seafood industries, there are still areas where gaps in information create some uncertainty in how results can be interpreted, and where further research and development is recommended:

Assessing the economic and ecological impacts of LNFS in the Lower Lakes and Coorong region. As detailed above, this now forms part of a new FRDC project (2018-036).

Accounting for habitat and distributional differences in fishing activity in ecological models. The Ecopath and Ecosim models developed for the SG and GSV ecosystems in this study, did not include any spatial data, and as such were unable to distribute taxa, and examine interactions taking into account differences in habitat use, or the distribution of fishing effort. As a consequence, some of the interactions may have be over-estimated where taxa or fishing activities do not spatially overlap. Future modelling should attempt to incorporate spatial habitat or other distributional differences of taxa to improve simulations of taxa interactions, through the EwE Ecospace module. Such improvements are proposed to be incorporated into a new South Australian gulfs and coastal ecosystem model to be developed as part of FRDC supported project 2018-011 (‘A South Australian gulfs and coastal ecosystem model to optimise multi-species fisheries management in a changing environment’).

Seasonal movement dynamics of LNFS. It is clear from the results presented in this study and elsewhere, that juveniles, adult female and adult male LNFS largely forage offshore in outer shelf and oceanic waters, well away from coastal regions. However, some older juvenile males and subadult males do move into coastal waters during autumn and winter months, and some of these animals interact with finfish aquaculture and passive gear fisheries. Although this study was able to track the movements of some animals with GPS tags, these can only provide data on movement behaviour for 2-3 months at a time. Many uncertainties remain about what portion of the male population comes into coastal waters in autumn and winter, for how long they stay and the extent to which the seasonal build up in numbers varies annually. It is still uncertain why males move into coastal waters at all, is it because of reduced food availability offshore or increases in food availability inshore, or a combination of factors?

Diet. The ecological models developed as part of this project incorporated extensive dietary datasets. For some taxa the data are reasonably comprehensive and contemporary, but for other taxa they are very limited or based what has been found elsewhere around Australia, or in similar ecosystems around the world. Clearly, data providence and comprehensiveness has a significant impacts on the trophic relationships developed, and these underpin the outputs of analyses and scenarios performed. This is especially important for any species or interactions of interest. A key gap identified in this study was further research into the importance of Little Penguins in the diet of sharks and other predators. Such knowledge will improve our understanding of the potential for predation pressure by LNFS and ASL to reduce populations of Little Penguins.

12. Extension and Adoption

Updates on project progress and key results were presented to relevant fishery and industry groups throughout the study. This included a presentation to the SA Fisheries Council in February 2015. Presentations were given to industry, managers and scientists at the annual Australian Southern Bluefin Tuna Industry Association/FRDC Research Workshops in November 2014, 2015 and 2016. Presentations to industry and managers about the project were given to the Lakes and Coorong Consultative Committee in August 2015, and regular updates were given to the Long-nosed Fur Seal Working Group between 2015 and 2018. Presentations on aspects of the project were given at two scientific conferences, the SA NRM Science Conference in April 2018 and the Australian Marine Sciences Association (AMSA) Conference in July 2018.

Final presentations to relevant industry groups and PIRSA Fisheries and Aquaculture are proposed to occur following release of the final report.

13. References

Ainley, D. G., Ballard, G., Karl, B. J. and Dugger, K. M. (2005). Leopard seal predation rates at penguin colonies of different size. Antarctic Science, 17(3): 335-340.

Ainley, D. G., Wilson, P. R., Barton, K. J., Ballard, G., Nur, N. and Karl, B. (1998). Diet and foraging effort of Adélie penguins in relation to pack-ice conditions in the southern Ross Sea. Polar Biology, 20(5): 311-319.

Allen, S. and Huveneers, C. (2005). First Record of an Australian fur seal (*Arctocephalus pusillus doriferus*) feeding on a wobbegong shark (*Orectolobus ornatus*). Proceedings of the Linnean Society of New South Wales, 126: 95-97.

Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. Austral Ecology, 26: 32-46.

Arnould, J. P. Y., Monk, J., Ierodiaconou, D., Hindell, M. A., Semmens, J., Hoskins, A. J., Costa, D. P., Abernathy, K. and Marshall, G. J. (2015). Use of anthropogenic sea floor structures by Australian fur seals: potential positive ecological impacts of marine industrial development? PLoS One, 10(7): e0130581.

Arthur, B., Hindell, M., Bester, M., Trathan, P., Jonsen, I., Staniland, I., Oosthuizen, W. C., Wege, M. and Lea, M.-A. (2015). Return customers: Foraging site fidelity and the effect of environmental variability in wide-ranging Antarctic fur seals. PLoS One, 10(3): e0120888.

Augé, A. A., Chilvers, B. L., Moore, A. B. and Davis, L. S. (2014). Importance of studying foraging site fidelity for spatial conservation measures in a mobile predator. Animal Conservation, 17(1): 61-71.

Auttila, M., Sinisalo, T., Valtonen, M., Niemi, M., Viljanen, M., Kurkilahti, M. and Kunnasranta, M. (2015). Diet composition and seasonal feeding patterns of a freshwater ringed seal (*Pusa hispida saimensis*). Marine Mammal Science, 31(1): 45-65.

Bacher, K., Gordoa, A. and Sagué, O. (2012). Spatial and temporal extension of wild fish aggregations at *Sparus aurata* and *Thunnus thynnus* farms in the north-western Mediterranean. Aquaculture Environment Interactions, 2(3): 239-252.

Baker, C. and Clapham, P. (2002). Marine mammal exploitation: whales and whaling. Encyclopedia of global environmental change, 3: 446-450.

Baylis, A. M. and Nichols, P. D. (2009). Milk fatty acids predict the foraging locations of the New Zealand fur seal: continental shelf versus oceanic waters. Marine Ecology Progress Series, 380: 271-286.

Baylis, A. M. M., Page, B. and Goldsworthy, S. D. (2008a). Colony-specific foraging areas of lactating New Zealand fur seals. Marine Ecology-Progress Series, 361: 279-290.

Baylis, A. M. M., Page, B. and Goldsworthy, S. D. (2008b). Effect of seasonal changes in upwelling activity on the foraging locations of a wide-ranging central-place forager, the New Zealand fur seal. Canadian Journal of Zoology-Revue Canadienne De Zoologie, 86(8): 774-789.

Baylis, A. M. M., Page, B., McKenzie, J. and Goldsworthy, S. D. (2012). Individual foraging site fidelity in lactating New Zealand fur seals: Continental shelf vs. oceanic habitats. Marine Mammal Science, 28(2): 276-294.

Belda, E. J. and Sanchez, A. (2001). Seabird mortality on longline fisheries in the western Mediterranean: factors affecting bycatch and proposed mitigating measures. Biological Conservation, 98(3): 357-363.

Berger, J., Swenson, J. E. and Persson, I.-L. (2001). Recolonizing carnivores and naive prey: conservation lessons from Pleistocene extinctions. Science, 291(5506): 1036-1039.

Berry, O., Bulman, C., Bunce, M., Coghlan, M., Murray, D. C. and Ward, R. D. (2015). Comparison of morphological and DNA metabarcoding analyses of diets in exploited marine fishes. Marine Ecology Progress Series, 540: 167-181.

Blackburn, J. (1950). Studies on age, growth, and life history of the pilchard, *Sardinops neopilchardus* (Steindachner), in southern and western Australia. Marine and Freshwater Research, 1(2): 221-258.

Blackburn, M. and Gartner, P. E. (1954). Populations of barracouta, *Thyrsites atun* (Euphrasen), in Australian waters. Australian Journal of Marine and Freshwater Research, 5(3): 411-468.

Bonner, W. and Hunter, S. (1982). Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. British Antarctic Survey Bulletin, 56: 75-79.

Bool, N. M., Page, B. and Goldsworthy, S. D. (2007). What is causing the decline of little penguins (*Eudyptula minor*) on Granite island, South Australia. Report to the South Australian Department for Environment and Heritage, Wildlife Conservation Fund and the Nature Foundation SA, July 2007. SARDI Publication Number: F2007/000288-1. SARDI Research Report Series No: 217, 55p.

Boren, L. (2010). Diet of New Zealand fur seal. In: DOC Research and development series 319. Department of Conservation, Wellington, New Zealand.

Boveng, P. L., Hiruki, L. M., Schwartz, M. K. and Bengtson, J. L. (1998). Population growth of Antarctic fur seals: limitation by a top predator, the leopard seal? Ecology, 79(8): 2863-2877.

Bowen, W. and Iverson, S. (2013). Methods of estimating marine mammal diets: a review of validation experiments and sources of bias and uncertainty. Marine Mammal Science, 29(4): 719-754.

Bowen, W. D. (1997). Role of marine mammals in aquatic ecosystems. Marine Ecology Progress Series, 158: 267-274.

Bradshaw, C. J. A., Hindell, M. A., Sumner, M. D. and Michael, K. J. (2004). Loyalty pays: potential life history consequences of fidelity to marine foraging regions by southern elephant seals. Animal Behaviour, 68(6): 1349-1360.

Braley, M., Goldsworthy, S. D., Page, B., Steer, M. and Austin, J. J. (2010). Assessing morphological and DNA-based diet analysis techniques in a generalist predator, the arrow squid *Nototodarus gouldi*. Molecular Ecology Resources, 10(3): 466-474.

Bray, J. R. and Curtis, J. T. (1957). An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs, 27: 325-349.

Bryant, E. (2007). 2D location accuracy statistics for Fastloc (R) cores running firmware versions 2.2 and 2.3. Technical Report TR01. Wildtrack Telemetry Systems, Leeds, UK.

Bucklin, A., Steinke, D. and Blanco-Bercial, L. (2011). DNA barcoding of marine metazoa. Annual Review of Marine Science, 3: 471-508.

Burnham, K. P. and Anderson, D. R. (2002). Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York, USA. pp.

Butler, J. L., Granado, M. L., Barnes, J. T., Yaremenko, M. and Macewicz, B. J. (1996). Age composition, growth, and maturation of the Pacific sardine (*Sardinops sagax*) during 1994. Cal COFI. Report 37,152-159.

Butterworth, D. S. (1992). Will more seals result in reduced fishing quotas? South African Journal of Science, 88: 414-416.

Butterworth, D. S., Duffy, D. C., Best, P. B. and Bergh, M. O. (1988). On the scientific basis for reducing the South African fur seal population. South African Journal of Science, 84: 179-188.

Callier, M. D., Byron, C. J., Bengtson, D. A., Cranford, P. J., Cross, S. F., Focken, U., Jansen, H. M., Kamermans, P., Kiessling, A. and Landry, T. (2018). Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Reviews in Aquaculture, 10(4): 924-949.

Camarinha-Silva, A., Jáuregui, R., Chaves-Moreno, D., Oxley, A. P., Schaumburg, F., Becker, K., Wos-Oxley, M. L. and Pieper, D. H. (2014). Comparing the anterior nare bacterial community of two discrete human populations using Illumina amplicon sequencing. Environmental Microbiology, 16(9): 2939-2952.

Carey, P. W. (1992). Fish prey species of the New Zealand fur seal (*Arctocephalus forsteri*, Lesson). New Zealand Journal of Ecology, 16(1): 41-46.

Casper, R. M., Jarman, S. N., Deagle, B. E., Gales, N. J. and Hindell, M. A. (2007). Detecting prey from DNA in predator scats: a comparison with morphological analysis, using *Arctocephalus* seals fed a known diet. Journal of Experimental Marine Biology and Ecology, 347(1): 144-154.

Catalán, I. A., Jiménez, M., Alconchel, J., Prieto, L. and Muñoz, J. L. (2006). Spatial and temporal changes of coastal demersal assemblages in the Gulf of Cadiz (SW Spain) in relation to environmental conditions. Deep Sea Research Part II: Topical Studies in Oceanography, 53(11-13): 1402-1419.

Catul, V., Gauns, M. and Karuppasamy, P. (2011). A review on mesopelagic fishes belonging to family Myctophidae. Reviews in Fish Biology and Fisheries, 21(3): 339-354.

Chaves-Moreno, D., Plumeier, I., Kahl, S., Krismer, B., Peschel, A., Oxley, A. P. A., Jáuregui, R. and Pieper, D. H. (2015). The microbial community structure of the cotton rat nose. Environmental Microbiology Reports, 7: 929-935.

Cherel, Y. and Ridoux, V. (1992). Prey species and nutritive value of food fed during summer to king penguin *Aptenodytes patagonica* chicks at Possession Island, Crozet Archipelago. Ibis, 134(2): 118-127.

Chiaradia, A., Forero, M. G., McInnes, J. C. and Ramírez, F. J. P. o. (2014). Searching for the true diet of marine predators: incorporating Bayesian priors into stable isotope mixing models. 9(3): e92665.

Childerhouse, S., Dix, B. and Gales, N. (2001). Diet of New Zealand sea lions (*Phocarctos hookeri*) at the Auckland Islands. Wildlife Research, 28(3): 291-298.

Chilvers, B. (2008). Foraging site fidelity of lactating New Zealand sea lions. Journal of Zoology, 276(1): 28-36.

Clarke, K. R., Warwick, R. M. R. M. and Laboratory, P. M. (2001). Change in marine communities : an approach to statistical analysis and interpretation. 2nd ed edition. Plymouth, U.K. : PRIMER-E Ltd. pp.

Colombelli-Négrel, D. and Kleindorfer, S. (2014). Penguin monitoring and conservation activities in the Gulf St Vincent. Report to Adelaide and Mount Lofty Ranges NRM Board, South Australia (Flinders University).

Cortés, E. (1997). A critical review of methods of studying fish feeding based on analysis of stomach contents: Application to elasmobranch fishes. Canadian Journal of Fisheries and Aquatic Sciences, 54(3): 726-738.

Cortés, E. (1999). Standardized diet compositions and trophic levels of sharks. ICES Journal of Marine Science, 56(5): 707-717.

Costa, F. O. and Carvalho, G. R. (2010). New insights into molecular evolution: prospects from the Barcode of Life Initiative (BOLI). Theory in Biosciences, 129: 149-157.

Cottrell, P. E., Trites, A. W. and Miller, E. H. (1996). Assessing the use of hard parts in faeces to identify harbour seal prey: results of captive-feeding trials. Canadian Journal of Zoology, 74: 875-880.

Cowx, I. G. (2003). Interactions between fish and birds: Implications for management. Blackwell Science, Oxford. 384 pp.

Cozzi, G., Chynoweth, M., Kusak, J., Çoban, E., Çoban, A., Ozgul, A. and Şekercioğlu, Ç. H. (2016). Anthropogenic food resources foster the coexistence of distinct life history strategies: year-round sedentary and migratory brown bears. Journal of Zoology, 300(2): 142-150.

Cronin, M., Gerritsen, H., Reid, D. and Jessopp, M. (2016). Spatial overlap of grey seals and fisheries in Irish waters, some new insights using telemetry technology and VMS. PLoS One, 11(9): e0160564.

Currie, D. R., Dixon, C. D., Roberts, S. D., Hooper, G. E., Sorokin, S. J. and Ward, T. M. (2009). Fishery-independent by-catch survey to inform risk assessment of the Spencer Gulf Prawn Trawl Fishery. Report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Currie, D. R. and Sorokin, S. J. (2010). A preliminary evaluation of the distribution and trophodynamics of demersal fish from Spencer Gulf. Report to the South Australian Department for the Environment and

Heritage. South Australian Research and Development Institue (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000088-1. SARDI Research Report Series No. 424. 179pp.

Dalsgaard, J., John, M. S., Kattner, G., Müller-Navarra, D. and Hagen, W. (2003). Fatty acid trophic markers in the pelagic marine environment. Advances in Marine Biology, 46: 225-340.

Daneri, G., Carlini, A., Harrington, A., Balboni, L. and Hernandez, C. (2008). Interannual variation in the diet of non-breeding male Antarctic fur seals, *Arctocephalus gazella*, at Isla 25 de Mayo/King George Island. Polar Biology, 31(11): 1365.

David, J., Cury, P., Crawford, R., Randall, R., Underhill, L. and Meÿer, M. (2003). Assessing conservation priorities in the Benguela ecosystem, South Africa: analysing predation by seals on threatened seabirds. Biological Conservation, 114(2): 289-292.

De Iongh, H. H., Wenno, B. and Meelis, E. (1995). Seagrass distribution and seasonal biomass changes in relation to dugong grazing in the Moluccas, East Indonesia. Aquatic Botany, 50(1): 1-19.

De Pierrepont, J., Dubois, B., Desormonts, S., Santos, M. and Robin, J. (2005). Stomach contents of English Channel cetaceans stranded on the coast of Normandy. Journal of the Marine Biological Association of the United Kingdom, 85(6): 1539-1546.

Deagle, B. E., Eveson, J. P. and Jarman, S. N. (2006). Quantification of damage in DNA recovered from highly degrarded samples—a case study on DNA in faeces. Frontiers in Zoology, 3: 11.

Deagle, B. E., Kirkwood, R. and Jarman, S. N. (2009). Analysis of Australian fur seal diet by pyrosequencing prey DNA in faeces. Molecular ecology, 18: 2022-2038.

Deagle, B. E., Thomas, A. C., Shaffer, A. K., Trites, A. W. and Jarman, S. N. (2013). Quantifying sequence proportions in a DNA-based diet study using Ion Torrent amplicon sequencing: which counts count? Molecular Ecology Resources, 13: 620-633.

Deagle, B. E. and Tollit, D. J. (2007). Quantitative analysis of prey DNA in pinniped faeces: potential to estimate diet composition? Conservation Genetics, 8(3): 743-747.

Deagle, B. E., Tollit, D. J., Jarman, S. N., Hindell, M. A., Trites, A. W. and Gales, N. J. (2005). Molecular scatology as a tool to study diet: analysis of prey DNA in scats from captive Steller sea lions. Molecular ecology, 14: 1831-1842.

DeLong, R., Antonelis, G., Oliver, C., Stewart, B., Lowry, M. and Yochem, P. (1991). Effects of the 1982–83 El Nino on several population parameters and diet of California sea lions on the California Channel Islands. In: Trillmich, F. and Ono, K. A. (Eds). Pinnipeds and El Niño. Springer-Verlag, Berlin, pp. 166-172.

DeMaster, D. P., Fowler, C. W., Perry, S. L. and Richlen, M. F. (2001). Predation and competition: the impact of fisheries on marine-mammal populations over the next one hundred years. Journal of Mammalogy, 82(3): 641-651.

Dempster, T., Fernandez-Jover, D., Sanchez-Jerez, P., Tuya, F., Bayle-Sempere, J., Boyra, A. and Haroun, R. J. (2005). Vertical variability of wild fish assemblages around sea-cage fish farms: implications for management. Marine Ecology Progress Series, 304: 15-29.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J. T., Giménez-Casalduero, F. and Valle, C. (2002). Attraction of wild fish to sea-cage fish farms in the south-western Mediterranean Sea: spatial and short-term temporal variability. Marine Ecology Progress Series, 242: 237-252.

Dempster, T., Sanchez-Jerez, P., Uglem, I. and Bjørn, P.-A. (2010). Species-specific patterns of aggregation of wild fish around fish farms. Estuarine, Coastal and Shelf Science, 86(2): 271-275.

DEWNR Working Group (2017). Long-nosed Fur Seals in the Coorong and Lower Lakes DEWNR Long-nosed fur seals in the Coorong and Lower Lakes Working Group, Communiqué October 2017.

Dixon, C. D., Hooper, G. E. and Burch, P. (2012). Spencer Gulf Prawn *Penaeus* (*Melicertus*) *latisulcatus* Fishery 2010/11. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences). Publication No. F2007/000770-5 (SARDI).

Du Toit, M., Bartlett, P., Bester, M. and Roux, J. (2004). Seabird predation by individual seals at Ichaboe Island, Namibia. South African Journal of Wildlife Research, 34(1): 45-54.

Dunshea, G. (2009). DNA-based diet analysis for any predator. PLoS One, 4(4): e5252.

Earl, J. (2018). Fishery statistics and performance indicators for the South Australian Lakes and Coorong Fishery. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI publication No. F2009/000669-9. SARDI Research Report Series No. 978. 19 pp.

Earl, J., Mackay, A., Greig, M., Kennelly, S. K., MacDonald, N. and Goldsworthy, S. D. (in press). Developing alternative strategies for managing seal-fisher interactions in the South Australian Lakes and Coorong Fishery. Final report to the Fisheries Research and Development Corporation, FRDC Project No. 2016/001. Adelaide: South Australian Research and Development Institute (Aquatic Sciences).

Ebner, B. (2006). Murray cod an apex predator in the Murray River, Australia. Ecology of Freshwater Fish, 15(4): 510-520.

Econsearch (2017). The Economic Impact of Aquaculture on the South Australian State and Regional Economies, 2015/16. A report to PIRSA Fisheries and Aquaculture.72pp. http://www.pir.sa.gov.au/__data/assets/pdf_file/0006/309417/AquaImpacts16_FINAL_170926.pdf.

Emami-Khoyi, A., Hartley, D. A., Paterson, A. M., Boren, L. J., Cruickshank, R. H., Ross, J. G., Murphy, E. C. and Else, T. A. (2016). Prey items from New Zealand fur seal (*Arctocephalus forsteri*) faeces using massive parallel sequencing. Conservation Genetics Resources, 8: 343.

Estes, J. A. and Duggins, D. O. (1995). Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm. Ecological Monographs, 65(1): 75-100.

Estes, J. A. and Palmisano, J. F. (1974). Sea otters: their role in structuring nearshore communities. Science, 185(4156): 1058-1060.

Fea, N. and Harcourt, R. (1997). Assessing the use of faecal and regurgitate analysis as a means of determining the diet of New Zealand fur seals. In: Hindell, M. A. and Kemper, C. (Eds). Marine mammal research in the southern hemisphere: status, ecology and medicine. Surrey Beatty and Sons, vol. 1, pp. 143-150.

Fea, N. I., Harcourt, R. G. and Lalas, C. (1999). Seasonal variation in the diet of New Zealand fur seals (*Arctocephalus forsteri*) at Otago Peninsula, New Zealand. Wildlife Research, 26: 147–160.

Fernandes, M., Lauer, P., Cheshire, A. and Angove, M. (2007a). Preliminary model of nitrogen loads from southern bluefin tuna aquaculture. Marine Pollution Bulletin, 54(9): 1321-1332.

Fernandes, M., Lauer, P., Cheshire, A., Svane, I., Putro, S., Mount, G., Angove, M., Sedawie, T., Tanner, J., Fairweather, P., Barnett, J. and Doonan, A. (2007b). Aquafin CRC – Southern Bluefin Tuna Aquaculture Subprogram: Tuna Environment Subproject – Evaluation of Waste Composition and Waste Mitigation. Technical report, Aquafin CRC Project 4.3.2, FRDC Project 2001/103. SARDI Publication No. RD03/0037-9. SARDI Research Report Series No. 207 (Ed. M. Fernandes). Aquafin CRC, Fisheries Research & Development Corporation and South Australian Research & Development Institute (Aquatic Sciences), Adelaide, 289 pp.

Fernandez-Jover, D., Sanchez-Jerez, P., Bayle-Sempere, J. T., Valle, C. and Dempster, T. (2008). Seasonal patterns and diets of wild fish assemblages associated with Mediterranean coastal fish farms. ICES Journal of Marine Science, 65(7): 1153-1160.

Field, I. C., Bradshaw, C. J., Burton, H. R. and Hindell, M. A. (2005). Juvenile southern elephant seals exhibit seasonal differences in energetic requirements and use of lipids and protein stores. Physiological and Biochemical Zoology, 78(4): 491-504.

Fowler, A. J., McGarvey, R., Steer, M. A. and Feenstra, J. E. (2015). The South Australian Marine Scalefish Fishery – Fishery Statistics for 1983/84 to 2014/15. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences). Publication No. F2007/000565-10. SARDI Research Report Series No. 882, 47.

Fragnito, K. (2013). Identifying the foraging behaviour and foraging habitat of the Australian sea lion, *Neophoca cinerea* using National Geographic Crittercam. Honours thesis. University of Adelaide. 63 pp.

Furlani, D., Gales, R. and Pemberton, D. (2007). Otoliths of common Australian temperate fish: a photographic guide. CSIRO publishing, Melbourne. 216 pp.

Furness, R. (1982). Competition between fisheries and seabird communities. Advances in Marine Biology, 20: 225-307.

Furness, R. and Birkhead, T. (1984). Seabird colony distributions suggest competition for food supplies during the breeding season. Nature, 311(5987): 655-656.

Gales, N. and Cheal, A. (1992). Estimating diet composition of the Australian sea lion (*Neophoca cinerea*) from scat analysis: an unreliable technique. Wildlife Research, 19(4): 447-455.

Gales, N., Hindell, M. and Kirkwood, R. (2003). Marine Mammals: Fisheries, Tourism and Management Issues: Fisheries, Tourism and Management Issues. CSIRO Publishing, Melbourne. 460 pp.

Gales, R. and Pemberton, D. (1994). Diet of the Australian fur seal in Tasmania. Australian Journal of Marine and Freshwater Research, 45: 653-664.

Gales, R., Pemberton, D., Lu, C. and Clarke, M. (1993). Cephalopod diet of the Australian fur seal: variation due to location, season and sample type. Marine and Freshwater Research, 44(5): 657-671.

Gehrke, P. C. and Harris, J. H. (2000). Large-scale patterns in species richness and composition of temperate riverine fish communities, south-eastern Australia. Marine and Freshwater Research, 51(2): 165-182.

Geller, J. B., Meyer, C. P., Parker, M. and Hawk, H. (2013). Redesign of PCR primers for mitochondrial Cytochrome c. oxidase subunit I for marine invertebrates and application in all-taxa biotic surveys. Molecular Ecology Resources, 13: 851-861.

Gillanders, B. M., Goldsworthy, S., Prowse, T. A. A., Doubell, M., Middleton, J., Rogers, P., Tanner, J. E., Clisby, N. A., James, C., Luick, J., van Ruth, P., Bradshaw, C. J. A. and Ward, T. M. (2015). Spencer Gulf research initiative: Development of an ecosystem model for fisheries and aquaculture. University of Adelaide and SARDI Aquatic Sciences, Adelaide. CC BY 3. Report to the FRDC Project 2001/205.

Goldsworthy, S. D. (2006). Maternal strategies of the New Zealand fur seal: evidence for interannual variability in provisioning and pup growth strategies. Australian Journal of Zoology, 54: 31-44.

Goldsworthy, S. D., Bailleul, F., Shaughnessy, P. D., Stonnill, M., Lashmar, K. and Mackay, A. I. (2017a). Monitoring of Seal Bay and other pinniped populations on Kangaroo Island: 2016/17. Report to the Department of Environment, Water and Natural Resources. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000322-4. SARDI Research Report Series No.951. 40 pp.

Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J. and Littnan, C. (2003). Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In: Gales, N., Hindell, M. and Kirkwood, R. (Eds). Marine Mammals and Humans: Fisheries, tourism and management. CSIRO Publishing, Melbourne, pp. 69-99.

Goldsworthy, S. D., He, X., Tuck, G. N., Lewis, M. and Williams, R. (2001). Trophic interactions between the Patagonian toothfish, its fishery, and seals and seabirds around Macquarie Island. Marine Ecology Progress Series, 218: 283-302.

Goldsworthy, S. D., Loo, M., Fowler, A., Steer, M. and Noell, C. (2017b). A trophic model for Gulf St Vincent: Balancing exploitation of three fisheries in an EBFM framework. Final report to the Fisheries Research and Development Corporation FRDC Project 2013/031 Final Report, 104 pp.

Goldsworthy, S. D., Mackay, A. I., Bilgmann, K., Möller, L. M., Parra, G. J., Gill, P., Bailleul, F., Shaughnessy, P. D., Reinhold, S.-L. and Rogers, P. J. (2017c). Status, distribution and abundance of iconic species and apex predators in the Great Australian Bight. Chapter 10: Status and trends in abundance of seabirds in the Great Australian Bight. Final Report GABRP Project 4.1. Great Australian Bight Research Program, GABRP Research Report Series Number 15, 227pp.

Goldsworthy, S. D., Mackay, A. I., Shaughnessy, P. D., Bailleul, F. and Holman, D. (2015). Maintaining the monitoring of pup production at key Australian sea lion colonies in South Australia (2014/15). Final Report to the Australian Marine Mammal Centre. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000665-5. SARDI Research Report Series No. 871. 73pp.

Goldsworthy, S. D., McKenzie, J., Shaughnessy, P. D., McIntosh, R. R., Page, B. and Campbell, R. (2009a). An Update of the Report: Understanding the Impediments to the Growth of Australian Sea Lion Populations. Report to the Department of the Environment, Water, Heritage and the Arts. SARDI Publication Number F2008/00847-1, SARDI Research Report series No. 356. 175pp.

Goldsworthy, S. D. and Page, B. (2007). A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries. Biological Conservation, 139: 269-285.

Goldsworthy, S. D., Page, B., Rogers, P. and Ward, T. (2011). Establishing ecosystem-based management for the South Australian Sardine Fishery: developing ecological performance indicators and reference points to assess the need for ecological allocations. FRDC Project 2005/031 Final Report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000863-1. SARDI Research Report Series No. 529. 173 pp.

Goldsworthy, S. D., Page, B., Rogers, P. J., Bulman, C., Wiebkin, A., McLeay, L. J., Einoder, L., Baylis, A. M., Braley, M. and Caines, R. (2013). Trophodynamics of the eastern Great Australian Bight ecosystem: Ecological change associated with the growth of Australia's largest fishery. Ecological Modelling, 255: 38-57.

Goldsworthy, S. D., Page, B., Shaughnessy, P. D., Hamer, D., Peters, K. D., McIntosh, R. R., Baylis, A. M. M. and McKenzie, J. (2009b). Innovative solutions for aquaculture planning and management: addressing seal interactions in the finfish aquaculture industry. FRDC Project 2009/201 Final Report. SARDI Aquatic Sciences Publication Number F2008/000222-1, SARDI Research Report Series Number 288, 290 pp.

Goldsworthy, S. D., Page, B., Shaughnessy, P. D. and Linnane, A. (2010). Mitigating Seal Interactions in the SRLF and the Gillnet Sector SESSF in South Australia. Report to the Fisheries Research and Development Institute. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000613-1. SARDI Research Report Series No. 405. 213pp.

Goldsworthy, S. D. and Shaughnessy, P. D. (1994). Breeding biology and haul-out pattern of the New Zealand fur seal, *Arctocephalus forsteri,* at Cape Gantheaume, South Australia. Wildlife Research, 21: 365-376.

Gonzalez, A. F. and Rodhouse, P. G. (1998). Fishery biology of the seven star flying squid *Martialia hyadesi* at South Georgia during winter. Polar Biology, 19(4): 231-236.

Green, K., Williams, R., Handaside, K. A., Burton, H. R. and Shaughnessy, P. D. (1990). Interspecific and intraspecific differences in the diets of fur seals, *Arctocephalus* species (Pinnipedia: Otariidae), at Macquarie Island. Australian Mammalogy, 13: 193-200.

Guénette, S., Heymans, S. J., Christensen, V. and Trites, A. W. (2006). Ecosystem models show combined effects of fishing, predation, competition, and ocean productivity on Steller sea lions (*Eumetopias jubatus)* in Alaska. Canadian Journal of Fisheries and Aquatic Sciences, 63(11): 2495-2517.

Gulland, J. A. (1987). Seals and fisheries: a case for predator control? Trends in Ecology and Evolution, 2: 102-103.

Hale, V. L., Tan, C. L., Niu, K., Yang, Y., Cui, D., Zhao, H., Knight, R. and Amato, K. R. (2016). Effects of field conditions on fecal microbiota. Journal of Microbiological Methods, 130: 180-188.

Hamer, D., Goldsworthy, S., Costa, D., Fowler, S., Page, B. and Sumner, M. (2013). The endangered Australian sea lion extensively overlaps with and regularly becomes by-catch in demersal shark gill-nets in South Australian shelf waters. Biological Conservation, 157: 386-400.

Hamer, D. J. and Goldsworthy, S. D. (2006). Seal-fishery operational interactions: identifying the environmental and operational aspects of a trawl fishery that contribute to by-catch and mortality of Australian fur seals (*Arctocephalus pusillus doriferus*). Biological Conservation, 130: 517-529.

Harcourt, R. (2001). Advances in New Zealand mammalogy 1990–2000: pinnipeds. Journal of the Royal Society of New Zealand, 31(1): 135-160.

Harcourt, R. G., Bradshaw, C. J. A., Dickson, K. and Davis, L. S. (2002). Foraging ecology of a generalist predator, the female New Zealand fur seal. Marine Ecology Progress Series, 227: 11-24.

Harris, J. H. and Gehrke, P. C. (1997). Fish and Rivers in Stress –The NSW Rivers Survey. NSW Fisheries Office of Conservation & the Cooperative Research Centre for Freshwater Ecology, Cronulla & Canberra.

Hebert, P. D. N., Ratnasingham, S. and deWaard, J. R. (2003). Barcoding animal life: cytochrome c oxidase subunit 1 divergences among closely related species. Proceedings of the Royal Society London B (Suppl.), 270: S96-S99.

Heise, K., Barrett-Lennard, L. G., Saulitis, E., Matkin, C. and Bain, D. (2003). Examining the evidence for killer whale predation on Steller sea lions in British Columbia and Alaska. Aquatic Mammals, 29(3): 325-334.

Hobson, K. A., Schell, D. M., Renouf, D. and Noseworthy, E. (1996). Stable carbon and nitrogen isotopic fractionation between diet and tissues of captive seals: implications for dietary reconstructions involving marine mammals. Canadian Journal of Fisheries and Aquatic Sciences, 53(3): 528-533.

Hofmeyr, G. J. G. and Bester, M. N. (1993). Predation on king penguins by Antarctic fur seals. South African Journal of Antarctic Research, 23: 71-74.

Hooker, S. K., Iverson, S. J., Ostrom, P. and Smith, S. C. (2001). Diet of northern bottlenose whales inferred from fatty-acid and stable-isotope analyses of biopsy samples. Canadian Journal of Zoology, 79(8): 1442-1454.

Hui, T. C., Gryba, R., Gregr, E. J. and Trites, A. W. (2015). Assessment of competition between fisheries and Steller sea lions in Alaska based on estimated prey biomass, fisheries removals and predator foraging behaviour. PLoS One, 10(5): e0123786.

Hume, F., Hindell, M., Pemberton, D. and Gales, R. (2004). Spatial and temporal variation in the diet of a high trophic level predator, the Australian fur seal (*Arctocephalus pusillus doriferus*). Marine Biology, 144(3): 407-415.

Jarman, S. N., Deagle, B. E. and Gales, N. J. (2004). Group-specific polymerase chain reaction for DNA-based analysis of species diversity and identity in dietary samples. Molecular ecology, 13: 1313–1322.

Jeanniard-du-Dot, T., Thomas, A. C., Cherel, Y., Trites, A. W. and Guinet, C. (2017). Combining hard-part and DNA analyses of scats with biologging and stable isotopes can reveal different diet compositions and feeding strategies within a fur seal population. Marine Ecology Progress Series, 584: 1-16.

Johnson, D. S., London, J. M., Lea, M.-A. and Durban, J. W. (2008). Continuous-time correlated random walk model for animal telemetry data. Ecology, 89(5): 1208-1215.

Jonsen, I. D., Flemming, J. M. and Myers, R. A. (2005). Robust state–space modeling of animal movement data. Ecology, 86(11): 2874-2880.

Jonsen, I. D. and with contributions from S. Luque, A. Winship and M.W. Pedersen, (2014). bsam: Bayesian state-space models for animal movement. R package version 0.43-1. http://www.r-project.org.

Joseph, B. D. L. (1981). Pilchard fishery at Jervis Bay: biology, fishery and population dynamics. MSc. University of New South Wales. 152 pp.

Joyce, W., Campana, S., Natanson, L., Kohler, N., Pratt Jr, H. and Jensen, C. (2002). Analysis of stomach contents of the porbeagle shark (*Lamna nasus* Bonnaterre) in the northwest Atlantic. ICES Journal of Marine Science, 59(6): 1263-1269.

Karpouzi, V. S., Watson, R. and Pauly, D. (2007). Modelling and mapping resource overlap between seabirds and fisheries on a global scale: a preliminary assessment. Marine Ecology Progress Series, 343: 87-99.

Kaschner, K., Watson, R., Christensen, V., Trites, A. W. and Pauly, D. (2001). Modeling and mapping trophic overlap between marine mammals and commercial fisheries in the North Atlantic. In: Zeller, D., Watson, R.

and Pauly, D. (Eds). Fisheries impacts on North Atlantic ecosystems: catch, effort national/regional data sets. . Fisheries Centre Research Reports, vol. 9, pp. 35-45.

Kemper, C. M., Pemberton, D., Cawthorn, M., Heinrich, S., Mann, J., Wursig, B., Shaughnessy, P. and Gales, R. (2003). Aquaculture and marine mammals: co-existence or conflict. In: Gales, N., Hindell, M. and Kirkwood, R. (Eds). Marine Mammals: Fisheries, Tourism and Management Issues. CSIRO, Melbourne, Australia. CSIRO, Melbourne, Australia, pp. 209-225.

Kernaléguen, L., Dorville, N., Ierodiaconou, D., Hoskins, A. J., Baylis, A. M. M., Hindell, M. A., Semmens, J., Abernathy, K., Marshall, G. J. and Cherel, Y. (2016). From video recordings to whisker stable isotopes: a critical evaluation of timescale in assessing individual foraging specialisation in Australian fur seals. Oecologia, 180(3): 657-670.

Kirkwood, R., Gales, R., Terauds, A., Arnould, J. P. Y., Pemberton, D., Shaughnessy, P. D., Mitchell, A. T. and Gibbens, J. (2005). Pup production and population trends of the Australian fur seal (*Arctocephalus pusillus doriferus*). Marine Mammal Science, 21(2): 260-282.

Kirkwood, R. and Goldsworthy, S. (2013). Fur Seals and Sea Lions. CSIRO Publishing, Victoria. 151 pp.

Kirkwood, R., Hume, F. and Hindell, M. (2008). Sea temperature variations mediate annual changes in the diet of Australian fur seals in Bass Strait. Marine Ecology Progress Series, 369: 297-309.

Knight, M. and Tsolos, A. (2011). South Australian Wild Fisheries Information and Statistics Report. South Australian Research and Development Institute (Aquatic Sciences). Publication No. F2009/000804-3 (SARDI).

Kohn, M. H. and Wayne, R. K. (1997). Facts from feces revisited. Trends in Ecology and Evolution, 12: 223-227.

Königson, S., Fjälling, A., Berglind, M. and Lunneryd, S.-G. (2013). Male gray seals specialize in raiding salmon traps. Fisheries Research, 148: 117-123.

Kovacs, K. M., Aguilar, A., Aurioles, D., Burkanov, V., Campagna, C., Gales, N., Gelatt, T., Goldsworthy, S. D., Goodman, S. J. and Hofmeyr, G. J. (2012). Global threats to pinnipeds. Marine Mammal Science, 28(2): 414-436.

Krieger, J. and Fuerst, P. A. (2002). Evidence for a slowed rate of molecular evolution in the order Acipenseriformes. Molecular Biology and Evolution, 19: 891-897.

Lake, S., Burton, H. and van den Hoff, J. (2003). Regional, temporal and fine-scale spatial variation in Weddell seal diet at four coastal locations in east Antarctica. Marine Ecology Progress Series, 254: 293-305.

Lea, M.-A., Cherel, Y., Guinet, C. and Nichols, P. D. (2002). Antarctic fur seals foraging in the Polar Frontal Zone: inter-annual shifts in diet as shown from fecal and fatty acid analyses. Marine Ecology Progress Series, 245: 281-297.

Leray, M., Agudelo, N., Mills, S. C. and Meyer, C. (2013a). Effectiveness of annealing blocking primers versus restriction enzymes for characterization of generalist diets: unexpected prey revealed in the gut contents of two coral reef fish species. PLoS One, 8(4): e58076.

Leray, M. and Knowlton, K. (2015). DNA barcoding and metabarcoding of standardized samples reveal patterns of marine benthic diversity. Proceedings of the National Academy of Sciences USA, 112: 2076-2081.

Leray, M., Meyer, C. P. and Mills, S. C. (2015). Metabarcoding dietary analysis of coral dwelling predatory fish demonstrates the minor contribution of coral mutalists to their highly partitioned, generalist diet. PeerJ, 3: e1047.

Leray, M., Yang, J. Y., Meyer, C. P., Mills, S. C., Agudelo, N., Ranwez, V., Boehm, J. T. and Machida, R. J. (2013b). A new versatile primer set targeting a short fragment of the mitochondrial COI region for metabarcoding metazoan diversity: application for characterizing coral reef fish gut contents. Frontiers in Zoology, 10: 34.

Lewis, D., Baruch-Mordo, S., Wilson, K., Breck, S., Mao, J. and Broderick, J. (2015). Foraging ecology of black bears in urban environments: guidance for human-bear conflict mitigation. Ecosphere, 6(8): 1-18.

Ling, J. K. (1999). Exploitation of fur seals and sea lions from Australian, New Zealand and adjacent subantarctic islands during the eighteenth, nineteenth and twentieth centuries. Australian Zoologist, 31: 323-350.

Lobo, J., Costa, P. M., Teixeira, M. A. L., Ferreira, M. S. G., Costa, M. H. and Costa, F. O. (2013). Enhanced primers for amplification of DNA barcodes from a broad range of marine metazoans. BMC Ecology, 13: 34.

Lowther, A., Harcourt, R. G., Hamer, D. and Goldsworthy, S. (2011). Creatures of habit: foraging habitat fidelity of adult female Australian sea lions. Marine Ecology Progress Series, 443: 249-263.

Lu, C. and Ickeringill, R. (2002). Cephalopod beak identification and biomass estimation techniques: tools for dietary studies of southern Australian finfishes. Museum Victoria Science Report 6 (Museum Victoria).

Machida, S. (1983). A brief review of the squid survey by Hoyo Maru No 67 in southeast Australian waters in 1979/80. Memoirs of National Museum Victoria Melbourne, 44: 291–295.

Mackay, A. I. (2017). Operational interactions with Threatened, Endangered or Protected Species in South Australian Managed Fisheries Data Summary: 2007/08 - 2015/16. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000544-7. SARDI Research Report Series No. 945. 74pp.

McInnes, J. C., Alderman, R., Deagle, B. E., Lea, M. A., Raymond, B. and Jarman, S. N. (2017). Optimised scat collection protocols for dietary DNA metabarcoding in vertebrates. Methods in Ecology and Evolution, 8(2): 192-202.

McIntosh, R. R., Kirkman, S. P., Thalmann, S., Sutherland, D. R., Mitchell, A., Arnould, J. P., Salton, M., Slip, D. J., Dann, P. and Kirkwood, R. (2018). Understanding meta-population trends of the Australian fur seal, with insights for adaptive monitoring. PLoS One, 13(9): e0200253.

McKenzie, J. (2006). Population demographics of New Zealand fur seals (*Arctocephalus forsteri*). PhD. La Trobe University. 166 pp.

McKenzie, J., Page, B., Goldsworthy, S. D. and Hindell, M. A. (2007a). Growth strategies of New Zealand fur seals in southern Australia. Journal of Zoology, 272: 377-389.

McKenzie, J., Page, B., Shaughnessy, P. D. and Hindell, M. A. (2007b). Age and reproductive maturity of New Zealand fur seals (*Arctocephalus forsteri*) in southern Australia. Journal of Mammalogy, 88(3): 639-648.

Méheust, E., Alfonsi, E., Le Ménec, P., Hassani, S. and Jung, J.-L. (2015). DNA barcoding for the identification of soft remains of prey in the stomach contents of grey seals (*Halichoerus grypus*) and harbour porpoises (*Phocoena phocoena*). Marine Biology Research, 11(4): 385-395.

Mohn, R. and Bowen, W. (1996). Grey seal predation on the eastern Scotian Shelf: modelling the impact on Atlantic cod. Canadian Journal of Fisheries and Aquatic Sciences, 53(12): 2722-2738.

Montevecchi, W. A. (2002). Interactions between fisheries and seabirds. In: Schreiber, E. A. and Burger, J. (Eds). Biology of marine birds. CRC Press, Boca Raton, Florida, USA, pp. 527-557.

Morissette, L., Christensen, V. and Pauly, D. (2012). Marine mammal impacts in exploited ecosystems: would large scale culling benefit fisheries? PLoS One, 7(9): e43966.

Nolan, C. P., Liddle, G. M. and Elliot, J. (2000). Interactions between killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) with a longline fishing vessel. Marine Mammal Science, 16(3): 658-664.

Northridge, S. P. and Hofman, R. J. (1999). Marine mammal interactions with fisheries. In: Twiss, J. R. and Reeves, R. R. (Eds). Conservation and management of marine mammals. Smithsonian Institution Press, Washington D.C., USA, pp. 99-119.

Noss, R. F., Quigley, H. B., Hornocker, M. G., Merrill, T. and Paquet, P. C. (1996). Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology, 10(4): 949-963.

Nursey-Bray, M. and Magnusson, M. (2016). Assessment of the Impacts of Seal Populations on the Seafood Industry and Marine Stakeholders in South Australia. Report to the South Australian Research and Development Institute.

O'Sullivan, D. and Cullen, J. (1983). Food of the squid *Nototodarus gouldi* in Bass Strait. Marine and Freshwater Research, 34(2): 261-285.

O'Rorke, R., Lavery, S. and Jeffs, A. (2012). PCR enrichment techniques to identify the diet of predators. Molecular Ecology Resources, 12(1): 5-17.

Olsen, M. T., Galatius, A. and Härkönen, T. (2018). The history and effects of seal-fishery conflicts in Denmark. Marine Ecology Progress Series, 595: 233-243.

Özgül, A. and Angel, D. (2013). Wild fish aggregations around fish farms in the Gulf of Aqaba, Red Sea: implications for fisheries management and conservation. Aquaculture Environment Interactions, 4(2): 135-145.

Page, B., McKenzie, J. and Goldsworthy, S. D. (2005a). Dietary resource partitioning among sympatric New Zealand and Australian fur seals. Marine Ecology Progress Series, 293: 283-302.

Page, B., McKenzie, J. and Goldsworthy, S. D. (2005b). Inter-sexual differences in New Zealand fur seal diving behaviour. Marine Ecology Progress Series, 304: 249-264.

Page, B., McKenzie, J., Sumner, M. D., Coyne, M. and Goldsworthy, S. D. (2006). Spatial separation of foraging habitats among New Zealand fur seals. Marine Ecology-Progress Series, 323: 263-279.

Panasci, M., Ballard, W. B., Breck, S., Rodriguez, D., Densmore III, L. D., Wester, D. B. and Baker, R. J. (2011). Evaluation of fecal DNA preservation techniques and effects of sample age and diet on genotyping success. The Journal of wildlife management, 75(7): 1616-1624.

Patterson, T. A., Basson, M., Bravington, M. V. and Gunn, J. S. (2009). Classifying movement behaviour in relation to environmental conditions using hidden Markov models. Journal of Animal Ecology, 78(6): 1113-1123.

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology Evolution, 10(10): 430.

Peters, K. J., Ophelkeller, K., Bott, N. J., Deagle, B. E., Jarman, S. N. and Goldsworthy, S. D. (2014). Fine-scale diet of the Australian sea lion (*Neophoca cinerea*) using DNA-based analysis of faeces. Marine Ecology, 36(3): 347-367.

Phillips, W. and Muller, K. (2006). Ecological character of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance. Department for Environment and Heritage, Adelaide.

Piatkowski, U., Vergani, D. F. and Stanganelli, Z. B. (2002). Changes in the cephalopod diet of southern elephant seal females at King George Island, during El Nino-La Nina events. Journal of the Marine Biological Association of the United Kingdom, 82(5): 913-916.

Pienkowski, M. W., Watkinson, A. R., Kerby, G., Clarke, K. R. and Warwick, R. M. (1998). A taxonomic distinctness index and its statistical properties. J Appl Ecol, 35: 523-531.

Pinkas, L. M., Oliphant, M. S. and Iverson, I. L. (1971). Food habits of albacore, bluefin tuna and bonito in Californian waters. Fish Bulletin, 152(10): 1-105.

Pompanon, F., Deagle, B. E., Symondson, W. O., Brown, D. S., Jarman, S. N. and Taberlet, P. (2012). Who is eating what: diet assessment using next generation sequencing. Molecular ecology, 21(8): 1931-1950.

Preti, A., Smith, S. E. and Ramon, D. A. (2004). Diet differences in the thresher shark (*Alopias vulpinus*) during transition from a warm-water regime to a cool-water regime off California-Oregon, 1998-2000. California Cooperative Oceanic Fisheries Investigations Report, 45: 118-125.

Punt, A. and Butterworth, D. (1995). The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 4. Modelling the biological interaction between Cape fur seals *Arctocephalus* *pusillus pusillus* and the Cape hakes *Merluccius capensis* and *M. paradoxus*. South African Journal of Marine Science, 16(1): 255-285.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Randall, B., Randall, R. and Compagno, L. (1988). Injuries to jackass penguins (*Spheniscus demersus*): evidence for shark involvement. Journal of Zoology, 214(4): 589-599.

Read, A. J. (2008). The looming crisis: interactions between marine mammals and fisheries. Journal of Mammalogy, 89(3): 541-548.

Reddy, P. A., Bhavanishankar, M., Bhagavatula, J., Harika, K., Mahla, R. S. and Shivaji, S. (2012). Improved methods of carnivore faecal sample preservation, DNA extraction and quantification for accurate genotyping of wild tigers. PLoS One, 7(10): e46732.

Reed, J., Tollit, D., Thompson, P. and Amos, W. (1997). Molecular scatology: the use of molecular genetic analysis to assign species, sex and individual identity to seal faeces. Molecular ecology, 6(3): 225-234.

Reid, K., Sims, M., White, R. W. and Gillon, K. W. (2004). Spatial distribution of predator/prey interactions in the Scotia Sea: implications for measuring predator/fisheries overlap. Deep Sea Research Part II: Topical Studies in Oceanography, 51(12-13): 1383-1396.

Reijnders, P. (1983). The effect of seal hunting in Germany on the further existence of a harbour seal population in the Dutch Wadden Sea. Zeitschrift fuer Saeugetierkunde, 48(1): 50-54.

Rey, A. R., Samaniego, R. S. and Petracci, P. F. (2012). New records of South American sea lion *Otaria flavescens* predation on southern rockhopper penguins *Eudyptes chrysocome* at Staten Island, Argentina. Polar Biology, 35(2): 319-322.

Rittel, H. W. and Webber, M. M. (1973). Dilemmas in a general theory of planning. Policy Sciences, 4(2): 155-169.

Roberts, J., Chick, A., Oswald, L. and Thompson, P. (1995). Effect of carp, *Cyprinus carpio* L., an exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. Marine and Freshwater Research, 46(8): 1171-1180.

Robertson, A., Healey, M. and King, A. (1997). Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs. II. Impacts on benthic properties and processes. Marine and Freshwater Research, 48(5): 445-454.

Robinson, S., Gales, R., Terauds, A. and Greenwood, M. (2008a). Movements of fur seals following relocation from fish farms. Aquatic Conservation-Marine and Freshwater Ecosystems, 18(7): 1189-1199.

Robinson, S., Terauds, A., Gales, R. and Greenwood, M. (2008b). Mitigating fur seal interactions: relocation from Tasmanian aquaculture farms. Aquatic Conservation-Marine and Freshwater Ecosystems, 18(7): 1180-1188.

Roche, C., Guinet, C., Gasco, N. and Duhamel, G. (2007). Marine mammals and demersal longline fishery interactions in Crozet and Kerguelen Exclusive Economic Zones: an assessment of depredation levels. CCAMLR Science, 14: 67-82.

Rocklin, D., Santoni, M.-C., Culioli, J.-M., Tomasini, J.-A., Pelletier, D. and Mouillot, D. (2009). Changes in the catch composition of artisanal fisheries attributable to dolphin depredation in a Mediterranean marine reserve. ICES Journal of Marine Science, 66(4): 699-707.

Roman, J., Dunphy-Daly, M. M., Johnston, D. W. and Read, A. J. (2015). Lifting baselines to address the consequences of conservation success. Trends in Ecology & Evolution., 30(6): 299-302.

Romero Jr, A. (2001). Past and present utilization of marine mammals in Grenada, WI. Journal of Cetacean Research and Management, 2: 223-226.

Russell, D. J. F., Brasseur, S. M. J. M., Thompson, D., Hastie, G. D., Janik, V. M., Aarts, G., McClintock, B. T., Matthiopoulos, J., Moss, S. E. W. and McConnell, B. (2014). Marine mammals trace anthropogenic structures at sea. Current Biology, 24(14): R638-R639.

Šálek, M., Drahníková, L. and Tkadlec, E. (2015). Changes in home range sizes and population densities of carnivore species along the natural to urban habitat gradient. Mammal Review, 45(1): 1-14.

Sepúlveda, M., Newsome, S. D., Pavez, G., Oliva, D., Costa, D. P. and Hückstädt, L. A. (2015). Using satellite tracking and isotopic information to characterize the impact of South American sea lions on Salmonid aquaculture in Southern Chile. PLoS One, 10(8): e0134926.

Shaughnessy, P., Kirkwood, R., Cawthorn, M., Kemper, C. and Pemberton, D. (2003). Pinnipeds, cetaceans and fisheries in Australia: a review of operational interactions. In: Gales, N. J., Hindell, M. A. and Kirkwood, R. (Eds). Marine Mammals: fisheries, tourism and management issues. CSIRO Publishing, Melbourne, pp. 136-152.

Shaughnessy, P. D., Bossley, M. and Nicholls, A. (2018). Fur seals and sea lions (family Otariidae) on the breakwaters at Adelaide’s Outer Harbor, South Australia. Australian Mammalogy, 40: 157-161.

Shaughnessy, P. D., Goldsworthy, S. D. and Mackay, A. I. (2015). The long-nosed fur seal in South Australia in 2013-14; abundance, status and trends. Australian Journal of Zoology, 63: 101-110.

Shokralla, S., Spall, J. L., Gibson, J. F. and Hajibabaei, M. (2012). Next-generation sequencing technologies for environmental DNA research. Molecular ecology, 21(8): 1794-1805.

Simenstad, C. A., Estes, J. A. and Kenyon, K. W. (1978). Aleuts, sea otters, and alternate stable-state communities. Science, 200(4340): 403-411.

Smale, M. J. (1995). Otolith atlas of southern African marine fishes. JLB Smith Institute of Ichthyology, Grahamstown. 253 pp.

Smith, T. D. (1995). Interactions between marine mammals and fisheries: an unresolved problem for fisheries research. In: Developments in Marine Biology. Elsevier, vol. 4, pp. 527-536.

Stagličić, N., Šegvić-Bubić, T., Ugarković, P., Talijančić, I., Žužul, I., Tičina, V. and Grubišić, L. (2017). Ecological role of bluefin tuna (*Thunnus thynnus*) fish farms for associated wild fish assemblages in the Mediterranean Sea. Marine environmental research, 132: 79-93.

Stark, K. E. (2008). Ecology of the Arrow Squid (*Nototodarus gouldi*) in Southeastern Australian Waters: A Multi-Scale Investigation of Spatial and Temporal Variability. PhD. University of Tasmania. 145 pp.

Steer, M. A., McGarvey, R., Carroll, A. J., Burch, P., Jackson, W. B., Lloyd, M. T. and Feenstra, J. E. (2016). Southern Garfish (*Hyporhamphus melanochir*) Fishery, South Australian Research and Development Institute (Aquatic Sciences), Publication No. F2007/000720-4 (SARDI).

Steer, M. A., McGarvey, R., Fowler, A. J., Burch, P., Feenstra, J., Jackson, W. B. and Lloyd, M. T. (2012). Southern Garfish (*Hyporhamphus melanochir*) Fishery. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Publication No. F2007/000720-3 (SARDI).

Stewart, B. S. (1997). Ontogeny of differential migration and sexual segregation in northern elephant seals. Journal of Mammalogy, 78(4): 1101-1116.

Stock, D., Gibbons, J. and Whitt, G. (1991). Strengths and limitations of molecular sequence comparisons for inferring the phylogeny of the major groups of fishes. Journal of fish Biology, 39: 225-236.

Street, R. J. (1964). Feeding habits of the New Zealand fur seal. New Zealand Marine Department Fisheries Technical Report No. 9.

Svane, I. and Barnett, J. (2008). The occurrence of benthic scavengers and their consumption at tuna farms off Port Lincoln, South Australia. Journal of Experimental Marine Biology and Ecology, 363(1-2): 110-117.

Tang, C. Q., Leasi, F., Obertegger, U., Kieneke, A., Barraclough, T. G. and Fontaneto, D. (2012). The widely used small subunit 18S rDNA molecule greatly underestimates true diversity in biodiversity surveys of the meiofauna. Proceedings of the National Academy of Sciences, 109(40): 16208-16212.

Tanner, J. E. and Fernandes, M. (2010). Environmental effects of yellowtail kingfish aquaculture in South Australia. Aquaculture Environment Interactions, 1(2): 155-165.

Tate, M. L. (1981). The autumn-winter diet of the New Zealand fur seal *Arctocephalus forsteri* (Lesson) with special reference to its cephlapod prey. Dip. Sci. thesis, University of Otago, Dunedin, N.Z. 52 pp.

Thomas, A. C., Deagle, B. E., Eveson, J. P., Harsch, C. H. and Trites, A. W. (2015). Quantitative DNA metabarcoding: improved estimates of species proportional biomass using correction factors derived from control material. Molecular Ecology Resources, 16(3): 714-726.

Thomas, A. C., Jarman, S. N., Haman, K. H., Trites, A. W. and Deagle, B. E. (2014). Improving accuracy of DNA diet estimates using food tissue control materials and an evaluation of proxies for digestion bias. Molecular ecology, 23(15): 3706-3718.

Thwaites, L. A., Fleer, D. and Smith, B. B. (2010). Estimating the biomass of adult common carp in Lake Albert, South Australia: a progress report for Biosecurity SA. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication Number F2010/000681-1. SARDI Research Report Series, (490).

Tilzey, R., Goldsworthy, S., Cawthorn, M., Clavert, N., Hamer, D., Russel, S., Shaughnessy, P., Wise, B. and Stewarsdson, C. (2006). Assessment of seal-fishery interactions in the winter blue grenadier fishery off west Tamania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers. Final report to the Fisheries Research and Development Corporation. Project no. 2001/008.

Tollit, D., Heaslip, S., Barrick, R. and Trites, A. (2007). Impact of diet-index selection and the digestion of prey hard remains on determining the diet of the Steller sea lion (*Eumetopias jubatus*). Canadian Journal of Zoology, 85(1): 1-15.

Tollit, D., Heaslip, S., Deagle, B., Iverson, S., Joy, R., Rosen, D. and Trites, A. (2006). Estimating diet composition in sea lions: which technique to choose. Sea lions of the world, 1: 293-306.

Tollit, D., Steward, M., Thompson, P., Pierce, G. J., Santos, M. and Hughes, S. (1997). Species and size differences in the digestion of otoliths and beaks: implications for estimates of pinniped diet composition. Canadian Journal of Fisheries and Aquatic Sciences, 54(1): 105-119.

Tollit, D. J., Schulze, A. D., Trites, A. W., Olesiuk, P. F., Crockford, S. J., Gelatt, T. S., Ream, R. R. and Miller, K. M. (2009). Development and application of DNA techniques for validating and improving pinniped diet estimates. Ecological Applications, 19(4): 889-905.

Tollit, D. J., Wong, M., Winship, A. J., Rosen, D. A. and Trites, A. W. (2003). Quantifying errors associated with using prey skeletal structures from fecal samples to determine the diet of Steller's sea lion (*Eumetopias jubatus*). Marine Mammal Science, 19(4): 724-744.

Trillmich, F. (1996). Parental investment in pinnipeds. Advances in the Study of Behavior, 25: 533-577.

Trillmich, F., Ono, K. A., Costa, D. P., DeLong, R. L., Feldkamp, S. D., Francis, J. M., Gentry, R. L., Heath, C. B., LeBoeuf, B. J. and Majluf, P. (1991). The effects of El Nino on pinniped populations in the eastern Pacific. In: Trillmich, F. and Ono, K. A. (Eds). Pinnipeds and El Niño. Springer, Springer-Verlag, Berlin, Germany, pp. 247-270.

Trites, A. W., Christensen, V. and Pauly, D. (1997). Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. Journal of Northwest Atlantic Fishery Science, 22: 173-187.

Tuck, G. N., Polacheck, T. and Bulman, C. M. (2003). Spatio-temporal trends of longline fishing effort in the Southern Ocean and implications for seabird bycatch. Biological Conservation, 114(1): 1-27.

Turvey, S. T., Pitman, R. L., Taylor, B. L., Barlow, J., Akamatsu, T., Barrett, L. A., Zhao, X., Reeves, R. R., Stewart, B. S. and Wang, K. (2007). First human-caused extinction of a cetacean species? Biology letters, 3(5): 537-540.

Venter, A., Oosthuizen, W., Bester, M. and Johnson, R. (2006). Seabird predation by white shark, *Carcharodon carcharias*, and Cape fur seal, *Arctocephalus pusillus pusillus*, at Dyer Island. South African Journal of Wildlife Research, 36(1): 23-32.

Vestheim, H. and Jarman, S. N. (2008). Blocking primers to enhance PCR amplification of rare sequences in mixed samples–a case study on prey DNA in Antarctic krill stomachs. Frontiers in Zoology, 5(1): 12.

Virtue, P., Green, C., Pethybridge, H., Moltschaniwskyj, N., Wotherspoon, S. and Jackson, G. (2011). Arrow squid: stock variability, fishing techniques, trophic linkages-facing the challenges. FRDC Report 2006/012.

Vlčková, K., Mrázek, J., Kopečný, J. and Petrželková, K. J. (2012). Evaluation of different storage methods to characterize the fecal bacterial communities of captive western lowland gorillas (*Gorilla gorilla gorilla*). Journal of Microbiological Methods, 91(1): 45-51.

Ward, T. M., Smart, J. and Ivey, A. (2017). Stock assessment of Australian Sardine (*Sardinops sagax*) off South Australia 2017. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000765-6. SARDI Research Report Series No. 971. 107pp.

Warwick, R. and Clarke, K. (1995). New 'biodiversity' measures reveal a decrease in taxonomic distinctness with increasing stress. Mar Ecol Prog Ser, 129: 301-305.

Watanabe, H., Kawaguchi, K. and Hayashi, A. (2002). Feeding habits of juvenile surface-migratory myctophid fishes (family Myctophidae) in the Kuroshio region of the western North Pacific. Marine Ecology Progress Series, 236: 263-272.

Weise, M. J. and Harvey, J. T. (2008). Temporal variability in ocean climate and California sea lion diet and biomass consumption: implications for fisheries management. Marine Ecology-Progress Series, 373: 157-172.

Wickens, P. A., Japp, D. W., Shelton, P. A., Kriel, F., Goosen, P. C., Rose, B., Augustyn, C. J., Bross, C. A. R., Penney, A. J. and Krohn, R. G. (1992). Seals and fisheries in South Africa – competition and conflict. South African Journal of Marine Science, 12: 773-789.

Wiebkin, A. (2011). Conservation management priorities for little penguin populations in Gulf St Vincent. Report to Adelaide and Mount Lofty Ranges Natural Resources Management Board. South Australian Research and Development Institute (Aquatic Sciences), Publication No. F2011/000188-1 (SARDI).

Wirsing, A. J., Heithaus, M. R. and Dill, L. M. (2007). Can measures of prey availability improve our ability to predict the abundance of large marine predators? Oecologia, 153(3): 563-568.

Wright, D. L. (2014). Variability in foraging by humpback whales (*Megaptera novaenangliae*) on the Kodiak, AK, feeding ground. MSc. University of Alaska. 153 pp.

Yoda, K., Tomita, N., Mizutani, Y., Narita, A. and Niizuma, Y. (2012). Spatio-temporal responses of black-tailed gulls to natural and anthropogenic food resources. Marine Ecology Progress Series, 466: 249-259.

Yodzis, P. (1998). Local trophodynamics and the interaction of marine mammals and fisheries in the Benguela ecosystem. Journal of Animal Ecology, 67(4): 635-658.

Yodzis, P. (2001). Must top predators be culled for the sake of fisheries? Trends in Ecology & Evolution., 16(2): 78-84.

Zhou, J., Wu, L., Deng, Y., Zhi, X., Jiang, Y.-H., Tu, Q., Xie, J., Van Nostrand, J. D., He, Z. and Yang, Y. (2011). Reproducibility and quantitation of amplicon sequencing-based detection. The ISME journal, 5(8): 1303.