Environmental correlates of temporal variation in the diet of Australian fur seals

Kimberley Kliska

43576354

Marine Predator Research Group

Macquarie University, North Ryde, Sydney 2109

kimberley.kliska@students.mq.edu.au

A thesis submitted in partial fulfilment of the requirements for graduation with

MASTER OF RESEARCH

in the

DEPARTMENT OF BIOLOGICAL SCIENCES

FACULTY OF SCIENCE AND ENGINEERING

9 OCTOBER 2015

Word Count: 14158

Supervisor: Professor Robert Harcourt[1].

Co-supervisors: Dr Rebecca McIntosh[2], Dr Ian Jonsen[1]

1. Department of Biological Sciences, Macquarie University, Sydney, Australia.
2. Phillip Island Nature Parks, Victoria, Australia.

Key words: El Nino Southern Oscillation, Southern Annular Mode, sea surface temperature, Australian fur seal, Bass Strait, *Sardinops sagax.*

This thesis is written in the form of a journal article for the International Council for the Exploration of the Sea (ICES) Journal of Marine Science

Declaration

I wish to acknowledge the following assistance in the research detailed in this report:

Dr Roger Kirkwood and Dr Rebecca McIntosh conducted fieldwork supported by Dr Peter Dann from Phillip Island Nature Parks, Victoria.
Fiona Hume from Tasmania was contracted by Phillip Island Nature Parks to process samples and identify specimens, conducting the laboratory work over the past ten years.

Dr Jason Everett from University of New South Wales assisted with obtaining the sea surface temperature data used in the final analysis.

All other research described in this thesis is my own original work.

Kimberley Kliska
9th October 2015.

Personal acknowledgements

I would like to acknowledge the support of the research department at Phillip Island Nature Parks (PINP) that made this project possible. The long-term collection of data has occurred through the vision of Dr Roger Kirkwood (Currently of Wageningen University, The Netherlands) and more recently my supervisor Dr Rebecca McIntosh. The collection of long term data could not occur without the support of the staff, enthusiastic volunteers, PINP, various external funding organizations and support from management, specifically Dr Peter Dann the research manager at PINP.

I would also like to personally acknowledge the support of my supervisors who contributed to my ability to undertake this study. Thank you to Rebecca McIntosh from PINP who is an incredibly supportive mentor and developed my field and laboratory skills and initially encouraged me to take on the project; Thank you to Ian Jonsen who showed great patience guiding me through the modeling process; and thank you to Rob Harcourt for academic advice, guidance and sharing extensive fur seal knowledge.

To the Marine Predator Research Group, thank you for your support, assistance with my sillier questions, providing constructive feedback while sharing the research experience, it was a great being part of a fun, diverse and interesting group of people.

To my family, Mum, Barbara Mitchell and Dad, John Kliska, brother Zac and sister Beck, I could not have done this without your encouragement and support. Your encouragement to ask questions and immerse myself in the natural world has lead me to where I am today and I am extremely grateful. To my partner Marcus, thank you for sharing your seal world with me and inspiring me to take on this study. Your support, along with Taz and Jessie made the challenges easier.

Australian fur seals at Seal Rocks, in Bass Strait, Victoria. Photograph: K Kliska, 2015.

Table of contents

List of Figures

List of tables

Abstract

Long term systematic monitoring of the diet of large marine predators can be an effective approach to detect and understand changes in ecosystems vulnerable to environmental change. This study quantified seasonal and annual changes in the frequency of occurrence (%FO) of prey items in the diet of Australian fur seals (*Arctocephalus pusillus doriferus*) in Bass Strait from 1998 to 2014. Using hard part analysis, 71 prey species were identified, with combinations of 8 main species found in more than 70% of the samples. Otolith measurements suggest Australian fur seals consumed predominantly juvenile fishes. I investigated correlations between environmental variables and %FO using generalised additive models. Southern Oscillation Index (SOI) correlated with the %FO of red cod *Pseudophycis bachus*, pilchard *Sardinops sagax* and jack mackerel *Trachurus declivis*. Positive correlations relating to El Niño conditions were found for both red cod and pilchard and correlation with neutral SOI was found for jack mackerel. Correlations identified between long-term environmental change and prey of marine predators suggests large-scale processes can influence prey assemblages at various trophic levels in Bass Strait.

Introduction

The marine coastal environment is experiencing accelerating change (IPCC, 2014). Environmental change is altering species assemblages within ecosystems and ecosystem function (Last, et al., 2011). To understand the effects of these changes on ecosystem function, we need to understand how species will respond to changes in their environment (Otto, et al., 2014, Schmidt, et al., 2015). One approach to detecting changes in the prey species is to systematically monitor the diet of high trophic level predators over time (Boyd and Murray, 2001, Hindell, et al., 2003). Marine predators are ecologically important and as high trophic level consumers, they can be indicators of changes in prey availability and ecosystem health (Boyd and Murray, 2001, Hindell, et al., 2003, Trathan, et al., 2007, Hobday, et al., 2015). Prey presence and prey size are likely to vary over time and this variation can be linked to environmental and oceanographic processes (Croxall, et al., 1992). Monitoring diet provides an indication of the availability of certain prey cohorts within the foraging range of marine predators moderated by animal preference (Lea, et al., 2006). Therefore, by monitoring the diet of a known generalist predator, for example, the Australian fur seal, we may gain an indication of prey available to that predator within an ecosystem.

There are many approaches to the quantification of the diet of marine predators (Bowen and Iverson, 2013). One of the most cost-effective, relatively non-invasive methods that can be used in long term monitoring programs is hard part analysis (Bowen and Iverson, 2013, Tollit, et al., 2015). This method involves the collection of fresh scat and regurgitate and the recovery and identification of undigested prey remains within the collected samples (Kirkwood and Goldsworthy, 2013). Hard part analysis is particularly applicable to marine predators, such as fur seals, that forage in the marine environment but return to terrestrial areas to breed and rest (Renouf, 1991, Bowen and Iverson, 2013).

Australian fur seals are generalist feeders that forage benthically, i.e. on species on or near the sea floor (Arnould and Hindell, 2001, Arnould and Kirkwood, 2008). The largest breeding colony of Australian fur seals is located at Seal Rocks in northern Bass Strait (McIntosh, et al., 2014). This population was exploited during the 1800s and early 1900s (Kirkwood and Goldsworthy, 2013). However, since the cessation of commercial harvesting and government protection of the species in 1975, population numbers have recovered and are now considered

secure (Kirkwood and Goldsworthy, 2013, McIntosh, et al., 2014). Ongoing research efforts at Seal Rocks has provided an opportunity to collect scats and regurgitates for diet analysis since 1997. The aim has been to provide an indication of fish and cephalopod assemblages in the Bass Strait marine ecosystem available to the seals over this period.

The marine environment in South-eastern Australia is one of the fastest changing marine regions in the world (Last, et al., 2011, Hobday and Pecl, 2014, Chambers, et al., 2015). In the south-east of Australia sea temperature is warming four times faster than the global average (IPCC, 2014). Large-scale environmental processes such as El Niño-Southern Oscillation (ENSO) and the Southern Annular Mode (SAM) are intensifying (Marshall, 2003). This intensification of large-scale processes is driving local increases in SST (Berlincourt and Arnould, 2015, Descamps, et al., 2015) However, little is known about the effect of such large-scale environmental processes or the effects of wind strength and direction on prey of high trophic marine predators in Bass Strait.

The diet of Australian fur seals has historically shown temporal and spatial variation (Gales and Pemberton, 1994, Hume, et al., 2004, Littnan, et al., 2007, Kirkwood, et al., 2008, Arnould, et al., 2011). Previous studies have recorded a range of species in the diet including barracouta *Thyrsites atun*, cephalopods and Southern rock lobster *Jasus edwardsii* (McNally and Lynch, 1954); redbait *Emmelichthys nitidus*, jack mackerel, leatherjacket species from the family Monocanthidae, arrow squid *Nototodarus gouldi*, red cod and gurnard species from the family Trigilidae (Kirkwood, et al., 2008); as well as cartilaginous species (Deagle, et al., 2009). The present study aims to improve our understanding of seasonal and annual variability in the diet of Australian fur seals by correlating presence and absence of prey with environmental variables in the Bass Strait marine ecosystem. Specifically, this study aims to: 1) quantify any temporal and seasonal variation in the diet of Australian fur seals; 2) determine prey size class(es) for Australian fur seals; and 3) determine if environmental variables are correlated with any observed changes in the diet of Australian fur seals from Seal Rocks in Victoria, Australia.

Methods

Fieldwork

Fresh scat and regurgitate samples were collected, roughly every two months, between December 1997 and December 2014 from Seal Rocks in Victoria, Australia (38°30'S, 145°10'E). Staff of Phillip Island Nature Parks and trained volunteers performed sample collection. As per methods in Kirkwood, et al. (2008), the individual scats and regurgitates were collected and stored in separate plastic bags and either processed within the next 48 hours or stored frozen until processing at Phillip Island Nature Parks research laboratory. Each year, an experienced contractor (Fiona Hume) processed the samples and identified prey items from otoliths, cephalopod beaks and other identifiable hard parts. The following laboratory methods are summarised from Kirkwood, et al. (2008).

Laboratory methods

Individual scats were soaked in warm water with 2ml of biodegradable detergent for at least two hours before processing. After soaking, each scat was sieved through three tiers of nested sieves 600µm, 500µm and 212µm where all diagnostic fish parts (otoliths, mouth parts, body plates and spines) cephalopod beaks and crustacean remains were collected using small tweezers. These hard parts were then placed onto a petri dish to dry. Once dry, all hard parts were stored in individually labelled plastic containers for analyses.

Hard parts were identified to species level, assigned to a family group or recorded as unidentified (see Kirkwood et al. 2008). Sagittal otoliths were identified to species level where possible, using a stereo microscope (Olympus SZ61), and comparison to reference collections and the atlas *Otoliths of Common Australian Temperate Fish: A photographic guide*, by Furlani, et al. (2007). Counts of left and right otoliths provided estimates of the minimum number of fish present in each sample. The presence of teeth, mouthparts, spines and distinctive vertebrae of leatherjacket species were recorded as one individual per sample, except where multiple leatherjacket spines were present, in which case each spine was counted as one fish. Cephalopod species were counted by the presence of upper and lower beaks and identified by comparing lower beaks with reference collections and the atlas *Cephalopod beak identification and biomass estimation techniques: tools for dietary studies of Southern Australian finfishes,*

by Lu and Ickeringill (2002). As per Hume, et al. (2004), *Octopus berrima* and *O. pallidus* could not be distinguished and so were recorded as *O. berrima/O. pallidus*.

Prey species Monocanthidae (leatherjackets), Neosebastidae (gurnard perches), Sebastidae (sea perches), Triglidae (gurnards), Macrouridae (whiptail), Ostracontidae (cowfish), Myctophidae (myctophids) and Bothidae (flounder) were identified to family level. All otoliths identified as *Pseudophycis* species were identified as red cod to remain consistent with previous studies (Kirkwood, et al., 2008). Gempylidae otoliths were identified as the abundant barracouta species *Thyrsites atun*; all eroded gempylid otoliths were assumed to be this species, rather than the less common gemfish *Rexea solandri.* Otoliths that were unable to be identified were recorded as unidentified.

Prey species size classes

For prey size class estimates, only otoliths from fish species were measured, as cephalopod beaks were preserved by drying and may have shrunk providing a false estimation of prey size. To obtain prey size, the diameter of 2084 otoliths from the posterior to anterior margin was measured using stereomicroscopy at either 1x (larger otoliths) or 2x (smaller otoliths) magnification. Individual otoliths were placed under a microscope camera. Each otolith was photographed (Olympus DP22-CU, DP2-SAL) and then measured using the MOTIC software program, calibrated to 1000mm scale. Measurements of otolith length were taken of pristine (class 4) and almost pristine (class 3) otoliths as previously defined by Kirkwood et al. (2008) to obtain species-specific fish lengths. For class 3 otoliths, fish length was tested for realistic variation, i.e. would they accord with an unrealistic size estimate on back calculation, therefore prey size classes could be estimated with confidence. Fish length was then calculated using equations from Furlani, et al. (2007). Juvenile fish were defined as sexually immature fish, with maturity size estimates for red cod from Kemp, et al. (2012); jack mackerel from Marshall, et al. (1993); redbait and pilchard Ward, et al. (2012). A precision estimate was obtained to quantify the precision of observer otolith length measurements. This was calculated by taking measurements of otoliths from each of the four main prey species. The measurements were repeated twenty times in the same order and recorded on different sheets to avoid observer bias. The standard error of the mean otolith measurement values for all samples was 0.05mm. For individual fish species the precision estimate for redbait was 0.2mm (n=7 x 20 repeat measurements); red cod 0.3mm (n=3 x 20 repeat measurements); jack mackerel 0.3mm (n=7 x 20 repeat measurements); and pilchard 0.1mm (n=3 x 20 repeat measurements). The precision

estimates for fish length overall were low <0.3mm, resulting in small error that would not influence size class estimates of fish.

Environmental data

Environmental data was obtained to explore potential correlates of variation in the seal diet. All datasets were subsetted to match the time series of the study beginning on the 1st of January 1998 and ending on the 30th of December 2014. Environmental data was standardised by taking the value of a covariate and subtracting the mean of the dataset for that covariate. To ensure independence between the environmental data each covariate was checked for collinearity prior to analysis (Zuur, et al., 2010). Daily L3S gridded Advanced Very High Resolution Radiometer (AVHRR) skin (surface) sea surface temperature (SST) was obtained from the Integrated Marine Observing System (IMOS) Data Portal (http://imos.aodn.org.au/imos/) at 0.02-degree resolution for the region of Bass Strait (39-41°S, 144-148°E). Annual SST values were calculated by averaging the monthly values from each year. Average monthly values of SST were calculated as the arithmetic mean of the daily SST across the whole region for a calendar month. Seasonal SST values were calculated by averaging the monthly mean values in each season.

Local wind speed and direction were obtained from the coastal weather station located at the Laverton Royal Australian Air force (RAAF) base (GPS coordinates: S37.860, E144.761) monitored by the Bureau of Meteorology, Australia. The RAAF base is located approximately 100km northwest of Seal Rocks. A long-term time series was obtained with 8 daily measurements at 3-hour intervals. Due to gaps in sampling effort, a subset of the daily measurements that were consistently sampled throughout the time series was taken from 0:00; 09:00 and 15:00 hours. From this subset, mean seasonal values on an annual basis were calculated. Direction values were derived based on circular mean values from cardinal compass bearings. Preliminary analysis showed that wind speed varied depending on direction of the cardinal compass defined as: north, south, east and west. Both wind speed and the interaction between speed and direction were then included in the analysis.

To determine if broad scale oceanographic processes are linked to variation in prey presence or absence, datasets for both Southern Annular Mode (SAM) and Southern Oscillation Index (SOI) were obtained. The SAM index indicates the variation in westerly winds oscillating around Antarctica. Where the SAM index is negative, the band increases around Antarctica and

results in low-pressure weather systems over Australia and stronger westerly winds. SAM anomaly data were obtained from the British Antarctic Service (BAS) in two different datasets. Annual records were obtained from the BAS website (http://www.antarctica.ac.uk/bas_research/data) and monthly records were obtained from the BAS Natural Environment Research Council website (http://www.nerc-bas.ac.uk/icd/gjma/sam.html). The monthly dataset was pre-standardised as outlined in Marshall (2003), therefore the data was not standardised again. SOI data were obtained from the NOAA Climate Prediction Centre as monthly anomaly values. These data are based on centred 30-year periods of Oceanic Niño Index and provide a measure of the El Niño-Southern Oscillation (ENSO). In this index El Niño conditions are defined as five consecutive months above the set threshold of 0.5 and La Niña conditions are defined as five consecutive months below the set threshold of -0.5. The SOI data were provided as anomalies, therefore the dataset was not further standardised.

Data analysis

Frequency of occurrence

The frequency of each prey species, *i*, was calculated as per the equation: $F_i = n_i/(n-e)$ where n_i is the number of samples containing species *i* in a sampling period (month, season or year), n and e are the total number of samples and empty samples collected in a sampling period, respectively. When calculating %FO 'empty' samples were defined as all samples without hard parts or with only unidentifiable remains and unclassifiable remains. The %FO was calculated at seasonal and annual time scales by aggregating all samples within that time period. Seasons were defined as per the austral calendar beginning on the first day of a defined month: December for summer; March for autumn; June for winter; and September for spring. Main prey was defined as accounting for >10% %FO in any year or >5% of %FO across all years. For modelling purposes a second dataset was created from %FO, identified as presence (number of scats with species *i* present) and absence (number of scats with species *i* absent) of the main nine prey species at a seasonal timescale. The %FO of a species from this second dataset was the response variable included in all models.

Modelling

I applied both Generalised Additive Models (GAM) and Generalised Additive Mixed Models (GAMM) to determine if environmental variation was correlated with the presence of prey in

the seal diet. GAMs can accommodate multiple complex relationships between the covariates and response variables (Wood, 2006). They can also be applied to data with binomial errors (Hastie, 1990). Model selection by Akaike Information Criterion (AIC) values can be applied to GAMs with a non-gaussian distribution (Burnham and Anderson, 2004). However, GAMs cannot account for serial dependence in time series data and can overfit the data (Phillips, 2011). GAMMs build on the GAM structure by allowing the specification of both random effects and correlation structures. The latter can be used to account for serial dependence typically present in time-series data (Wood, 2006). GAMMS with non-gaussian errors cannot rely on AIC or likelihood ratio tests because they are fit using penalised quasi-likelihood (Venables and Ripley, 2002). Therefore GAMs were fit first to identify the model best supported by the data via AIC and GAMMs were then used to fit this best supported model, accounting for serial dependence in the response variable.

In this study, preliminary analyses suggested the degree of serial dependence was relatively low for most species (-0.007 to 0.058). GAMMs with binomial errors and a logit link were fitted to the data to investigate if the presence of prey was correlated with time on a seasonal timescale.

All combinations of covariates (single, double, triple and all) were fitted as GAMs (binomial distribution, logit link function) resulting in 16 candidate models. To investigate the effect of wind direction it was modelled as an interaction with wind speed. The model with the lowest AIC value was then fitted as a GAMM (binomial distribution, logit link function) with a AR(1) correlation structure applied to a combined season/year variable to account for serial dependence (Zuur, et al., 2009). Dropping non-significant terms then reduced the model further. The adjusted R-Squared value from the GAMM summary was used as an indication of variance explained by the final model. All analyses were completed using the R statistical framework version 3.1.2 (R Core Development team, 2015) with models fitted to the data with the “mgcv” package in R - statistical program (Wood, 2006).

Results

Variation in seal diet

Over 17 years and 105 sampling days, 3028 samples (scats and regurgitate) were collected. Fish otoliths from 63 species were identified accounting for ~ 90% of the items in the diet (n=10934) and cephalopods beaks from 8 species were identified accounting for just under 10% of the items in the diet (n=1115). To calculate the importance of each species in the diet, the frequency of occurrence (%FO) of each species within a sample was calculated at seasonal and annual timescales.

The %FO of species in the seal diet varied over time annually (Figure 1; Figure 2) with 8 species found in more than 70% of the samples (mean %FO >10% per year). There were notable shifts in the main species during the earlier part of the study: red cod in 1998 and 1999, leatherjackets in 2000 and 2001, and redbait from 2002 to 2005 (Figure 1). From 2006 jack mackerel and leatherjacket both dominated the diet. The prevalence of pilchard increased from 2012 to 2014 with a maximum %FO of 14% in 2012. The %FO of barracouta %FO was highest in 1999 and 2000 at 22% and 23% respectively and gurnard %FO highest from 2012-2014 at 16%, 25% and 23% respectively. The most dominant cephalopod species was arrow squid contributing 5% %FO. Other squids, predominantly the cuttlefish *Sepia apama* contributed 4.7% of %FO.

The %FO of species also varied seasonally (Figure 2). Leatherjacket was consistent with %FO above 10% in all sampled winter and summer seasons and 80% of all autumn seasons. In the beginning of the time series barracouta %FO was higher in summer and spring with a maximum %FO of 37% in the summer of 1998, and at 31% and 34% in the following summers of 1999 and 2000 respectively. In the four years redbait dominated the diet from 2002 to 2005 the %FO was above 20% in autumn and winter and peaked at 55% in autumn of 2005, however %FO was still above 10% in both spring and summer except in 2004 where %FO was at 9% in spring and no sampling was done in summer. From 2006 when jack mackerel dominated the diet %FO was high in both summer and autumn seasons at 36% and 15% respectively and continued in this pattern through to 2014 where the %FO was at 19% in summer and 14% in autumn. Pilchard was more prevalent in summer and autumn with %FO highest at 25% and 14% in 2014 respectively. In the years 2012-14 when gurnard %FO was highest in the diet, it was most prevalent in winter with a maximum %FO of 36% in winter 2014, and at 31% and 23% in the

winters of 2013 and 2012 respectively. Cephalopod presence was seasonal with %FO highest during autumn 2007 at 25% and above 10% in autumns from 2006-08.

Prey size classes

Of the 2084 otoliths in pristine condition, 1319 were from main prey species. From this selection prey size classes were determined for red cod, pilchard, jack mackerel and redbait species (Table 3). Measurements are presented here as the mean value plus or minus the standard deviation. All pilchard were <84mm indicating that only juveniles of these this species were found in the diet. The size of red cod ranged from 14-347mm (mean=152±8mm, n=127) with 3% of red cod found to be of adult size >315mm (n=4). The size of jack mackerel ranged from 84-352mm (mean=196±4mm, n=500), with 0.6% of jack mackerel of adult size >315mm (n=3). The size of redbait ranged from 91-268mm (mean=141±3, n=564) with 5% of adult size >157 mm (n=30).

Environmental variation over time

Five environmental covariates were investigated as predictors for the diet of the Australian fur seal over time. Mean annual sea surface temperature (SST) ranged from 14.8-16°C (mean 15.5± 0.1°C) and showed a gradual increase throughout the time series (Figure 3a.). In 1999 SSTs were notably low on average with a mean value of 14.8°C compared to the overall mean of 15.5°C (range=14.8-16°C). SST was highest in 2012 with a mean value of 15.9°C (range=12.6-19.3°C) and remained above the overall mean in 2013 and 2014. SOI varied with both El Niño and La Niña events occurring during the time series (Figure 3b). El Niño events occurred in 1998, 2002/2003, 2006, and in 2009/2010 (Bureau of Meteorology, 2015). La Niña events occurred in 1998 until 2001; 2007/2008; and in 2010, 2011 and 2012 (Bureau of Meteorology, 2015). The SAM index was highly variable with the strongest positive index (3) recorded in 2000 (Figure 3c). The strongest negative SAM index was recorded in 2002 at -2. In 2010 the SAM index was strongly positive with two seasons (winter and spring) above the mean at 2.35. The mean overall wind strength was 17 kmh^{-1} (range: 14-20 kilometres/hour (kmh^{-1})). Wind strength was most variable in year 2002 with strong winds from a southerly direction (Figure 3d). Wind strength varied upon direction, with stronger wind on average from the south (Figure 4).

Environmental effects on prey

GAMs were fitted to the %FO of each of the main prey species identified in the seal diet with all possible combinations of covariates (see red cod example: Table 4 and supplementary material). The GAM with the lowest AIC value for redbait, jack mackerel, squid, leatherjacket and pilchard species included all the covariates; for barracouta and red cod the best model included SST, SOI and wind; for gurnard the best model included SOI, SAM and wind; and for arrow squid the best model included SST, SAM and wind (Table 5).

Southern Oscillation Index

The GAMM results showed that SOI correlated to %FO of three main prey species (Table 6). A positive SOI (El Niño conditions) was significantly correlated with the presence of red cod (p=<0.001) (Figure 5a) with the model explaining 14% of the variation (Table 6). The 1997/1998 El Niño was one of the strongest on record at 1.6 SOI compared to the mean for the entire time series at 1.2 and longest at 13 months compared to the mean duration for the entire time series at 11.7 months. The presence of red cod was highest in 1998 with a %FO of 53% (Figure 5b). In autumn 2002 and autumn and winter in 2006 El Niño conditions were present again and red cod %FO was 22% and 24% respectively (Figure 5b). The presence of pilchard was also positively correlated with SOI (p=<0.001) (Figure 5c) however the model was weak, explaining -3% of the variation present, with none of the predictors explaining the variability in %FO (Table 6). Pilchard recently reappeared in the seal diet on average contributing 23% %FO in 2014 (Figure 5d). This coincided with a drawn out transition phase from La Niña to El Niño (Bureau of Meteorology, 2015). The presence of jack mackerel was also correlated with SOI (p=<0.001) (Figure 5e). The GAMM model showed that SOI events explained 16% of the variation of jack mackerel in the diet (Table 6). The %FO of jack mackerel peaked when the SOI was relatively neutral. In 2004 and 2013 the SOI was neutral and the annual %FO of jack mackerel was 27.9% and 49.7% respectively. %FO of jack mackerel in spring was >50% in both these years (Figure 5f). In 2008 a weak La Niña event occurred and jack mackerel %FO was also high at 30.5% (Figure 5f).

Other environmental predictors

Following the model selection process I found no correlation between sea surface temperature, wind speed and direction or SAM in predicting %FO of main prey items of Australian fur seals.

Discussion

Large-scale environmental processes drive biological changes at various temporal scales. This study showed temporal variation in the diet of Australian fur seals at Seal Rocks, Bass Strait, from 1998-2014. Large-scale environmental processes, such as the El Niño Southern Oscillation (ENSO), are known to drive physical and biological processes within marine ecosystems (Fogt and Bromwich, 2006, Dann and Chambers, 2013, Sebille, et al., 2014) and were therefore expected to influence prey assemblages within Bass Strait. The seal diet dataset spanned multiple El Niño Southern Oscillation (ENSO) events, and %FO of three species in the seal diet was correlated with the Southern Oscillation Index (SOI) as a measure of ENSO.

This study confirms variation in the diet of Australian fur seals exists at both annual and seasonal time scales, suggesting temporal variation of prey species exists within the Bass Strait marine ecosystem. The prey species identified in this study were comparable to previous studies on the diet of Australian fur seals (Hume, et al., 2004, Littnan, et al., 2007, Kirkwood, et al., 2008), however they were not over a time series of this length. Similar to previous studies (Hume, et al., 2004, Littnan, et al., 2007, Kirkwood, et al., 2008) a high number of prey species were identified, however only eight of these species were found in more than 70% of the samples. The hard part analysis used in this study is limited to identifying remains of prey species that survive passing through the digestive tract (Tollit, et al., 1997). Other techniques such as pyro-sequencing DNA have found cartilaginous species in the diet of Australian fur seals (Deagle, et al., 2009). A recent review of diet analysis techniques of marine mammals, demonstrated that systematic sampling of diet using hard part analysis provides an indication of diet composition over time and is a valid technique for detecting large scale changes in the diet of pinnipeds (Bowen and Iverson, 2013). By applying this technique, prey identified in this study did not vary from those identified by Kirkwood, et al. (2008), which used the same dataset until 2006, with the exception of pilchard.

The fluctuation of pilchard abundance in South Australian and Bass Strait marine ecosystems has been previously documented in the diet of seabirds and seals (Page, et al., 2005, Kirkwood, et al., 2008, Chiaradia, et al., 2010). However, until now it has not been documented as a main prey item of Australian fur seals. From 2012, pilchard made up >10% of the diet of Australian fur seal each year. The pilchard population within Bass Strait underwent a mass mortality, the largest ever recorded for one species of marine fish, in 1995 and a second smaller mortality

event in 1998 (Whittington, et al., 2008, Chiaradia, et al., 2010). This population decrease altered the trophic structure of the marine ecosystem in Bass Strait (Kirkwood, et al., 2008). Pilchards may have been present in the diet of Australian fur seals pre-1998, however the appearance of pilchard as a main prey item from 2012 onwards suggests the pilchard population has increased, which has also been documented in commercial fisheries. Pilchards are a commercially valuable species, caught in the Small Pelagic Fishery off southern Australia (Ward, et al., 2012). The findings from this present study could be applied in ecosystem based modelling (e.g. Atlantis) for fisheries management within Bass Strait to further develop the sustainable practices of the Small Pelagic Fishery. The appearance of pilchard in the seal diet was also significantly linked to large-scale environmental variation - the SOI.

The present study showed that SOI is significantly correlated with prey-specific variation in Australian fur seal diet. However, the relationship is weak for three of the main prey species identified. These findings are consistent with previous research by Ward and Staunton-Smith (2002), with the presence of pilchards in this study correlated with El Niño events. El Niño events influence the Bonney upwelling system off the coast of South Australia, and therefore the productivity of the area (Middleton, et al., 2007). The correlation identified with La Niña and jack mackerel is consistent with previous research by Jordan, et al. (1995) who identified the spawning of this species occurring in summer during times of high SST and La Niña events. The results of the present study suggest that large-scale environmental processes influence presence of prey in the diet of Australian fur seals in Bass Strait, supporting previous research by Knox, et al. (2014). Knox, et al. (2014) identified positive correlations with SOI and body growth in Australian fur seals, inferring that SOI drives prey availability to seals. Hoskins and Arnould (2014) also determined SOI has an impact on dive effort of female Australian fur seals from Kanowna Island, Bass Strait. However, research by Gibbens and Arnould (2009) at Kanowna Island found no correlation between SOI and biological variables (pup production; timing and synchrony of breeding and female body condition). They therefore hypothesised that prey availability in the Bass Strait continental shelf region is temporally stable. The work by Gibbens and Arnould (2009) was performed over 10 years (1997-2007), whereas the present study identifies correlations with SOI and the %FO of prey over 17 years, covering an additional 2 El Niño events. Other fine scale environmental parameters such as SST may influence prey presence in Bass Strait (Middleton, et al., 2007).

Increases in SST are already driving changes in the coastal marine environment in south-eastern Australia (Last, et al., 2011, Lough and Hobday, 2011). SST has been previously observed to alter prey of high trophic level predators within the Bass Strait marine ecosystem (Gibbs, 1992, Kirkwood, et al., 2008). Increases in SST have also been predicted to affect availability and distribution of prey for marine mammals (Schumann, et al., 2012) The present study did not identify a correlation between SST and %FO of prey in the seal diet. In a previous analysis performed by Kirkwood, et al. (2008), using the same dataset up until 2006, a trend between SST and redbait was apparent. This difference between the present study and that by Kirkwood et al. (2008) is presumably due to the increase in the length of the time series in this study and the application of contemporary modelling techniques. The coarse scale of the data may explain the lack of correlation, or that SST only provides surface values and not temperature changes occurring in the water column. In addition to SST, other fine scale environmental parameters such as wind, driven by larger scale processes of SAM may also influence prey movement in Bass Strait and the diet of Australian fur seals.

The SAM influences westerly winds in southern Australia (Lovenduski and Gruber, 2005). Westerly winds drive nutrient rich upwelling water from the Bonney upwelling system into western Bass Strait and influence the flow of currents through Bass Strait (Middleton, et al., 2007, Sandery and Kämpf, 2007). Upwelling changes primary productivity within entire ecosystems, influencing the prey available to higher trophic level predators (Armbrecht, et al., 2014). The Bonney upwelling has been previously linked to foraging and breeding success of top predators, including the Australian fur seal in Bass Strait (Gibbens and Arnould, 2009, Berlincourt and Arnould, 2015). Zonal wind strength has been correlated with foraging effort in Australian fur seals at other breeding colonies in Bass Strait (Hoskins and Arnould, 2014). Modelling predicts that SAM will influence the strengthening of the East Australian Current occurring between latitudes 44S & 55S, including Bass Strait (Cai, et al., 2005). In the present study no correlation was found between prey presence in the Australian fur seal diet and the SAM index or wind speed and direction. This may be due to the large scale on which SAM operates or that other large scale processes, as shown in this study (ENSO), influence prey presence. However, Fogt and Bromwich (2006) showed that SAM and ENSO are coupled, thereby the influences of SAM and wind on the ecology of prey within Bass Strait requires further investigation. It is not only the presence of and the driving forces of prey in the diet of the Australian fur seal that is interesting, but also the size of the prey.

Very little variation was found with prey size in this study, with predominantly juvenile fish of redbait, red cod, jack mackerel and all pilchard fish of juvenile size observed in the diet. As pilchards, as previously motioned, mass mortality in southeast Australia in both 1995 and 1998 (Chiaradia, et al., 2010) and juveniles of this species may be highly abundant, however, it is interesting that they may be targeting juvenile fish of multiple main preys. Perhaps juveniles are easier to catch and manipulate or are higher in abundance than larger fish. Due to this lack of variation, I did not model the results, and further information is required before pursuing further research into the size of prey the seals are eating. Firstly, the estimation of prey size in this study was limited as no regression equations or correction factors are available to calibrate for the otolith erosion caused by digestion. To account for this we only measured otoliths considered in pristine condition, with limited erosion. Secondly, larger sized fish may be broken up prior to ingestion, by shaking at the surface, as shown in captive feeding trials by Hocking, et al. (2014), biasing the measuring of otoliths to smaller individuals who could be swallowed whole. Therefore, interpretation of the prey size classes in this study requires validation through application of regression equations or experimentally derived correction factors (Tollit, et al., 2003). With neither available for these fish species more research is needed to better understand the biology and behaviour of the prey species. Perhaps fisheries data could provide some insight into the availability of these species and their relative size classes in Bass Strait.

Other factors such as physiology, foraging behaviour and individual specialisation may also influence the selection of prey by different cohorts of Australian fur seals, and therefore prey the observed diet (Arnould, et al., 2011). Physiology of seals varies between age, gender and life cycle of seals affecting their ability to dive and obtain certain prey items (Renouf, 1991). Australian fur seals also use various prey capture techniques (Hocking et al. 2014) that may result in individual variation within diet. This study is limited as the sex, age and breeding status of the samples collected for hard part analysis was unknown, therefore the study is limited to investigating the diet of the general population from Seal Rocks.

The study was also limited in some seasons by sampling effort. To obtain faecal samples that will accurately provide data on the diet of a marine mammal >60 samples per time period is recommended (Trites and Joy, 2005). On an annual timescale this study exceeds the recommendations (Table 1.), however not all seasons have been sampled adequately, with two summer seasons and five spring seasons lower than recommended and six summer seasons and one spring season lacking data altogether (Table 2.). Therefore, interpretation of the seasonal

variation in the diet requires some consideration. For example, redbait does not appear in the diet in summer 2004, however no sampling was completed in that season.

In addition to the correlations identified, the lack of correlations for the other five main species is also of interest. Other main fish species such as gurnard and redbait did not appear to be influenced by the environmental predictors investigated in this study. However, previous work by Kirkwood, et al. (2008), identified SST influences redbait presence in the seal diet. SST influences the reproduction of Cephalopod species, such as squid species identified in the diet, however no correlation was identified in this study. Previous studies identified that arrow squid demonstrate extreme plasticity to environmental conditions (Jackson, et al., 2003). The lack of correlation found in this study may be due to either high adaptability of these prey species in Bass Strait or the environmental predictors investigated. As previously discussed environmental predictors can vary geographically; therefore the findings of this study are also restricted to Australian fur seals in central Bass Strait.

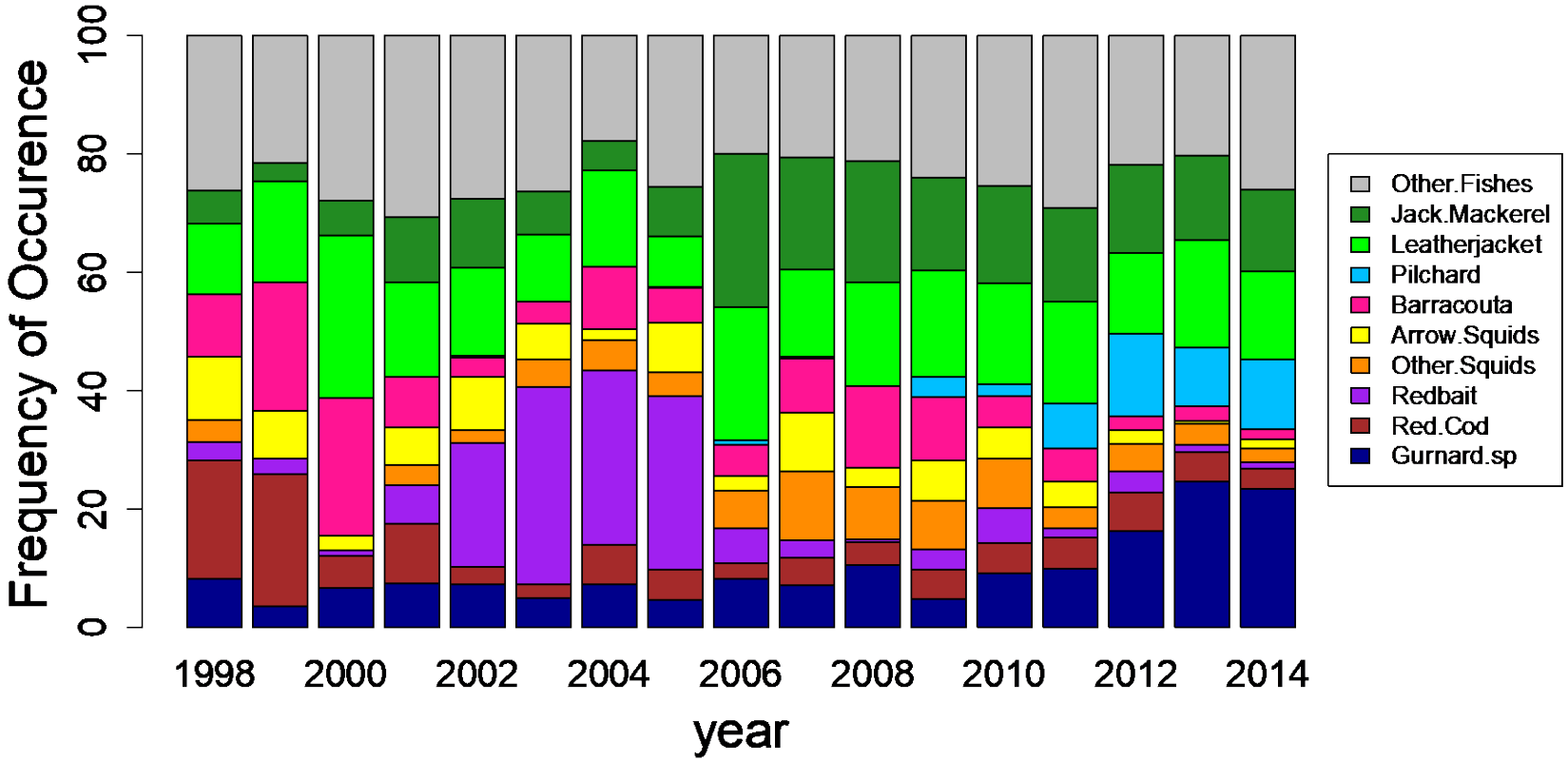
Diet can vary at different colonies across the range of Australian fur seals. The samples from this study are from Seal Rocks located in northern Bass Strait. Seal Rocks is approximately 200kms from the edge of the continental shelf. Other Australian fur seal colonies to the west and east in Bass Strait are closer to the continental shelf slope and diet can vary with proximity to the shelf slope (Littnan, et al., 2007). Additionally tracking studies have identified that there is small overlap in foraging areas between larger breeding colonies (Arnould and Kirkwood, 2008, Kirkwood and Arnould, 2012), that may influence the diet of seals at those sites. Geographical location changes the extent to which environmental parameters influence productivity in an area, for example: areas closer to upwelling are generally more productive than those in northern Bass Strait. Therefore environmental parameters may correlate differently to seal diet in other areas, due to differences in local ocean oceanography and biological production. Other environmental parameters (e.g. chlorophyll A) that were not explored in this study, because they are not available for this time series, may influence the diet of Australian fur seals in those areas. Extending the regular collection of long-term data to several Australian fur seal colonies across their range and considering other environmental variables (e.g. chlorophyll A) could further develop our understanding of how environmental factors influence the diet of Australian fur seals. However, this is difficult due to the remote location of sites, expense of work, and the weather-dependent nature of boat work. In addition

to geographical location of the study site the impact of fisheries on prey assemblages should be considered.

The impact of commercial fisheries on prey species for top predators can range from direct harvest to indirect cascade effects and the removal of species at various trophic levels (Daskalov, et al., 2007). Historically, commercial fishing in the form of trawling was more active in this region. However, due to a buyback scheme in 2005/2006, trawling activity has reduced (Minnegal and Dwyer, 2008). Fishing pressure in this area has decreased with quota restrictions based on ecosystem-based modelling and there is a low level of spatial overlap between the Australian fur seals and three of the Bass Strait fisheries: gillnet; Danish seine and otter trawl (Arnould and Kirkwood, 2008). The impact on fisheries catch on the diet of Australian fur seals has not been investigated during this study, and previous work by Kirkwood, et al. (2008) did not find any correlations between prey assemblages and catch per unit effort. However the reduction in trawling activity coincided with notable shifts in the main species in the Australian fur seal's diet during 2006 (this study). Therefore, further investigation is recommended.

In summary, this study has demonstrated that the diet of Australian fur seals changes temporally and is influenced by large-scale processes. The results from this study further develop our understanding of how large-scale environmental processes influence ecological changes in the Bass Strait marine ecosystem. I applied contemporary modelling techniques to long-term diet data to identify correlations between prey assemblages and identify the influence of long-term environmental change on prey assemblages. This approach has potential to be applied into the future to monitor the ecological changes occurring in marine coastal environments.

Figures and tables:



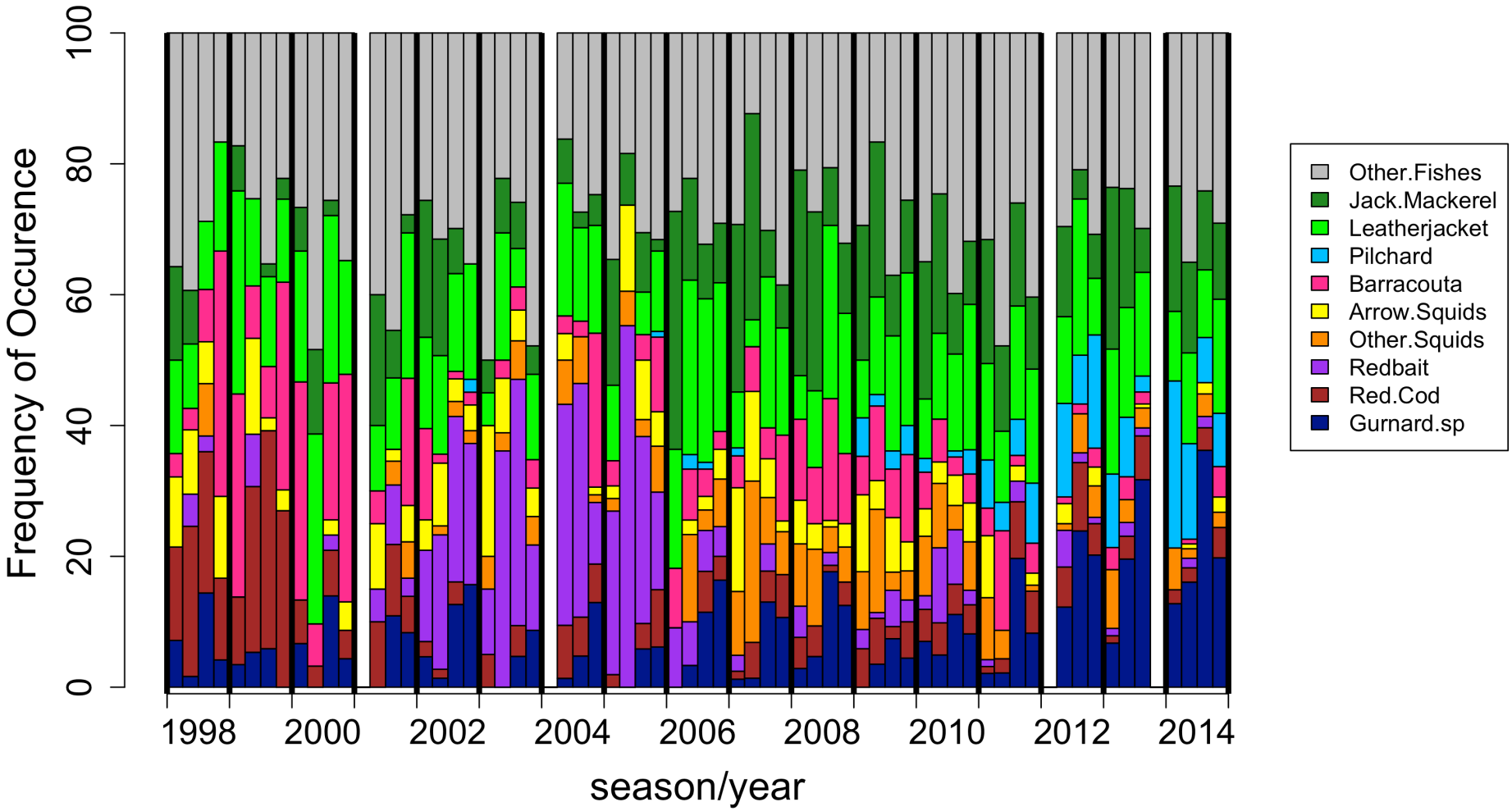

Frequency of Occurence
0
20
40
60
80
100
1998
2000
2002
2004
2006
2008
2010
2012
2014
season/year
Other.Fishes
Jack.Mackerel
Leatherjacket
Pilchard
Barracouta
Arrow.Squids
Other.Squids
Redbait
Red.Cod
Gurnard.sp

Table 1. Annual sample sizes of scat and regurgitate collected for hard part analysis.

	Year																
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Sample size	347	323	145	153	358	193	301	442	366	588	421	441	530	482	496	546	349

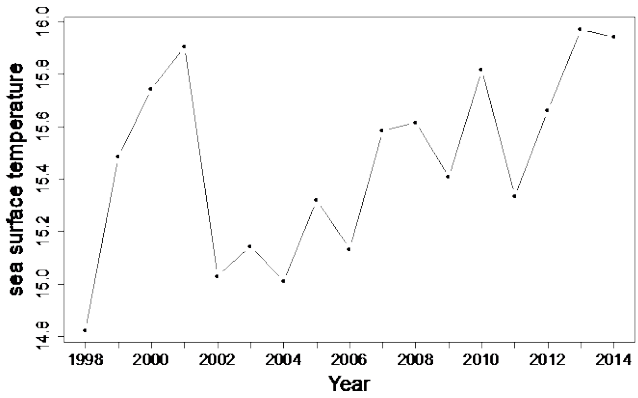
Table 2. Seasonal sample sizes of scat and regurgitate collected for hard part analysis.

	Year																
Seasonal sample size	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Summer	101	46	0	0	61	0	0	70	17	110	78	50	174	122	0	70	0
Autumn	88	109	43	29	101	45	99	47	108	81	163	145	72	57	241	178	176
Winter	180	61	63	73	115	109	105	180	115	198	118	125	131	160	82	236	70
Spring	29	81	39	51	58	39	97	145	126	148	62	121	153	143	130	0	103

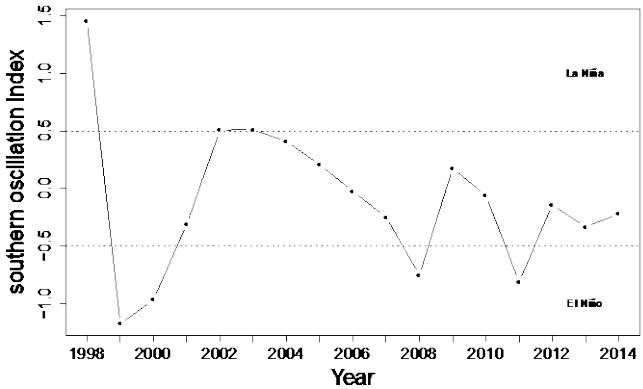
Table 3: Prey size classes for prey consumed by Australian fur seals at Seal Rocks from 1998-2014. All equations are from Furlani, et al. (2007). Class JUV refers to juveniles; remaining percentage represents adults i.e. a fish of sexually mature size class.

Species	Length	n	Mean ± SD (mm)	Sexual maturity (mm)	Range mm	Equation
Red cod	Total	127	152± 8	315	14-347	6.33OL^1.62
Pilchard	Standard	99	66± 3	146	43-84	32.07OL^1.35
Jack Mackerel	Fork	500	196±4	315	84-352	16.796OL^1.3992
Redbait	Fork	564	141± 3	157	91-268	20.125OL^1.2238

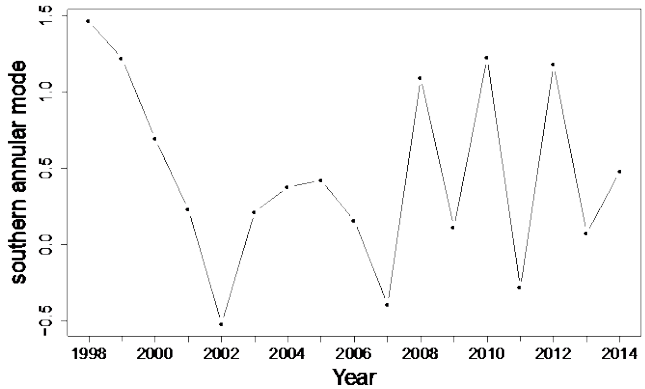
a)



b)



c)



d)

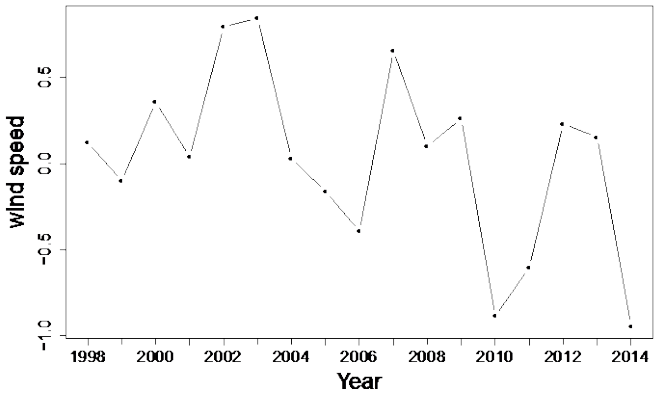


Figure 3. Environmental variation throughout the time series: a) SST; b) SOI; c) SAM and d) Wind speed.

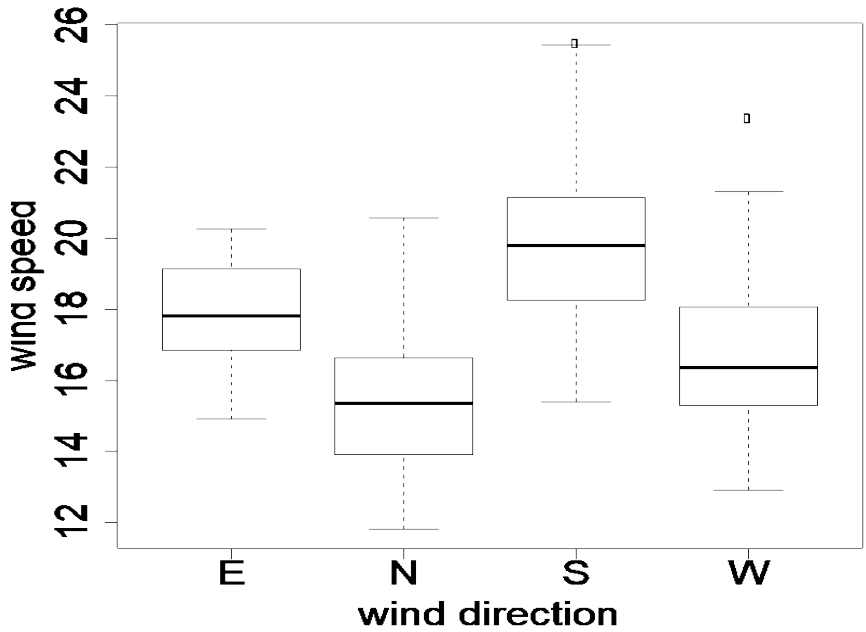


Figure 4. Boxplot showing the mean seasonal wind speed and direction throughout the time series. Direction was measured by the cardinal compass: E=East, N=North, S=South and W=West, outliers are shown for S and W.

Table 4: Generalised additive models results for red cod, an example of the model selection process in descending order. Covariates are the same as those listed in Table 5 (for all other species see Supplementary material).

Covariates	AIC	Δ AIC	RL	W	rSq	D.exp
SST+SOI+wind*wind direction	336.98	0.00	1.00	0.93	0.31	52.10
SST+SOI+SAM+wind*wind direction	342.19	5.20	0.07	0.07	0.27	49.41
SOI+SAM+wind*wind direction	351.18	14.20	0.00	0.00	0.23	44.57
SOI+wind*wind direction	352.82	15.84	0.00	0.00	0.21	42.96
SST+wind*wind direction	366.48	29.50	0.00	0.00	0.10	37.57
SAM+wind*wind direction	374.54	37.56	0.00	0.00	0.17	25.11
SST+SAM	376.33	39.35	0.00	0.00	0.16	25.17
SST+SOI+SAM	376.33	39.35	0.00	0.00	0.16	25.17
SST+SOI	381.02	44.04	0.00	0.00	0.04	29.84
wind*wind direction	381.02	44.04	0.00	0.00	0.04	29.84
SOI	381.44	44.46	0.00	0.00	0.14	20.33
SOI+SAM	382.27	45.28	0.00	0.00	0.14	21.06
SST	387.20	50.22	0.00	0.00	0.03	26.10
Null model	424.60	87.61	0.00	0.00	0.00	0.00
SAM	425.06	88.07	0.00	0.00	-0.02	1.68

AIC= Akaike Information Criterion; Δ AIC = the difference in AIC from that of the best fitting model; RL=Relative likelihood; W=weight; rSq=R Squared; and D.exp=Deviance explained.

Table 5: The best generalised additive models, selected using AIC for all main prey identified in the diet of Australian fur seals. All covariates are seasonal values by year; SST refers to sea surface temperature; SOI refers to Southern Oscillation Index; SAM refers to the Southern annular mode and wind is local wind speed and direction.

Species	Model	AIC	R Squared	Deviance explained
Red cod	SST+SOI+ wind*wind direction	336.98	0.31	52.10
Redbait	SST+SOI+SAM+wind*wind direction	343.86	0.77	80.70
Pilchard	SST+SOI+SAM+wind*wind direction	177.78	0.89	91.31
Jack Mackerel	SST+ SOI+SAM+wind* wind direction	395.45	0.27	52.56
Barracouta	SST+SOI +wind* wind direction	335.66	0.34	59.15
Gurnard sp.	SOI+SAM+wind*wind direction	398.29	0.39	55.00
Squid sp.	SST+SOI+SAM+wind*wind direction	276.06	0.41	61.88
Arrow Squid	SST+SAM+wind*wind direction	399.68	0.14	33.89
Leatherjacket	SST+SAM+SOI+wind*wind direction	395.45	0.27	52.56

Table 6: Generalised additive mixed model results. The p-values show the significant correlations for Southern Oscillation Index with R-squared adjusted showing the degree of variance explained by the model.

Species	Covariates	P values (SOI)	R-squared (adj)
Red cod	SOI	<0.00	0.14
Pilchard	SOI	<0.01	-0.03
Jack Mackerel	SOI	<0.01	0.16

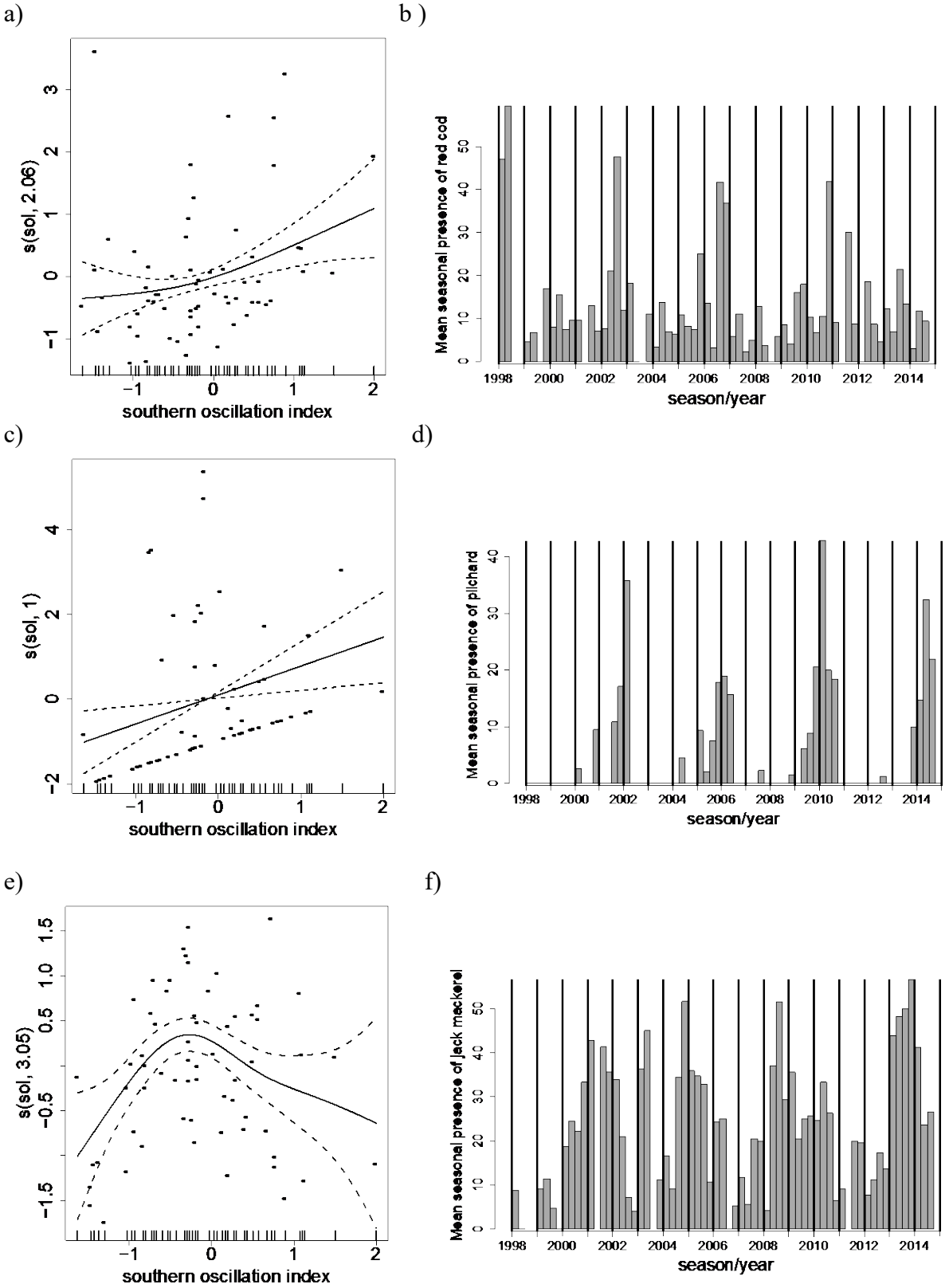


Figure 5: GAM plots from the generalised additive mixed models for significant relationships between frequency of occurrence of prey and the Southern Oscillation Index, the dotted line indicates 95% confidence intervals for model prediction. Mean seasonal %FO of species throughout the time series the black line indicates years, each bar a season. : a and b) red cod; c and d)pilchard; e and f) jack mackerel.

Supplementary information:

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Acknowledgements:

The Phillip Island Nature Park Animal Ethics Committee approved all sampling for this study. Sampling was conducted under Wildlife Permits from the Department of Environment, Land, Water and Planning. I acknowledge the contribution of all staff and volunteers who collected samples and Fiona Hume who was contracted to process samples in the laboratory and identify the thousands of otoliths that make up this time series. I also thank Dr Jason Everett for assistance in obtaining the SST dataset.

References

Armbrecht, L.H., Roughan, M., Rossi, V., Schaeffer, A. Davies, P.L. Waite, A. M., and Armand, L. K. 2014. Phytoplankton composition under contrasting oceanographic conditions: Upwelling and downwelling (Eastern Australia). Continental Shelf Research, 75: 54-67.

Arnould J. P.Y., and Hindell, M. A. 2001. Dive behaviour, foraging locations, and maternal-attendance patterns of Australian fur seals (Arctocephalus pusillus doriferus). Canadian Journal of Zoology, 79: 35-48.

Arnould, J. P. Y., Cherel, Y, Gibbens, J., White J. G., and Littnan, C. L. 2011. Stable isotopes reveal inter-annual and inter-individual variation in the diet of female Australian fur seals. Marine Ecology Progress Series, 422: 291-302.

Arnould, J. P. Y., and Kirkwood, R. 2008. Habitat selection by female Australian fur seals (*Arctocephalus pusillus doriferus)* Aquatic conservation: marine and freshwater ecosystems, 17: S53-S67.

Berlincourt, M. and Arnould, J. P. Y. 2015. Influence of environmental conditions on foraging behaviour and its consequences on reproductive performance in little penguins. Marine Biology: 1-17.

Bowen, W. D., and Iverson, S. J. 2013. Methods of estimating diets: A review of validation experiments and source of bias and uncertainty. Marine Mammal Science, 29: 719-754.

Boyd, I., and Murray, A. 2001. Monitoring a marine ecosystem using responses of upper trophic level predators. Journal of Animal Ecology, 70: 747-760.

Bureau of Meteorology 2015. ENSO Wrap-Up: Current state of the Pacific and Indian Ocean

Cai, W., Shi, G., Cowan, T., Bi, D., and Ribbe, J. 2005. The response of the Southern Annular Mode, the East Australian Current, and the southern mid‐latitude ocean circulation to global warming. Geophysical Research Letters, 32.

Chambers, L. E., Patterson, T., Hobday, A. J., Arnould, J. P. Y., Tuck, G. N., Wilcox, C., and Dann, P. 2015. Determining trends and environmental drivers from long-term marine mammal and seabird data: examples from Southern Australia. Regional Environmental Change, 15: 197-209.

Chiaradia, A., Forero, M. G., Hobson, K. A., and Cullen, M. 2010. Changes in diet and trophic position of a top predator 10 years after a mass mortality of a key prey. ICES Journal of Marine Science: Journal de Conseil, 67: 1710-1720.

Croxall, J., Callaghan, T., Cervellati, R., and Walton, D. 1992. Southern Ocean environmental changes: effects on seabird, seal and whale populations [and discussion]. Philosophical Transactions of the Royal Society B: Biological Sciences, 338: 319-328.

Dann, P. and Chambers, L. 2013. Ecological effects of climate change on Little Penguins Eudyptula minor and the potential economic impact on tourism. Climate Ressearch, 58: 67-79.

Daskalov, G.M., Grishin, A. N., Rodionov, S., and Mihneva, V. 2007. Trophic cascades triggered by overfishing reveal possible mechanisms of ecosystem regime shifts. Proceedings of the National Academy of Sciences, 104: 10518-10523.

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.

Descamps, S., Tarroux, A., Lorentsen, S.-H., Love, O. P., Varpe, Ø., and Yoccoz, N. G. 2015. Large-scale oceanographic fluctuations drive Antarctic petrel survival and reproduction. Ecography: In press.

Fogt, R. L., and Bromwich, D. H. 2006. Decadal variability of the ENSO teleconnection to the high-latitude South Pacific governed by coupling with the Southern Annular Mode*. Journal of Climate, 19: 979-997.

Furlani, D., Gales, R. and Pemberton, D. 2007. Otoliths of common temperate Australian fish: a photographic guide. CSIRO Publishing, Melbourne.

Gales, R., and Pemberton, D. 1994. Diet of the Australian fur seal in Tasmania. Marine and freshwater research, 45: 653-664.

Gibbens, J. R., and Arnould, J. P. Y. 2009. Interannual variation in pup production and the timing of breeding in benthic foraging Australian fur seals. Marine Mammal Science, 25: 573-587.

Gibbs, C. F. 1992. Oceanography of Bass Strait: implications for the food supply of little penguins *Eudyptula minor*. Emu, 91: 395-401.

Hastie, T. J., and Tibshirani, R. J. 1990. Generalized Additive Models. Chapman and Hall, London.

Hindell, M., Bradshaw, C., Harcourt, R., and Guinet, C. 2003. Ecosystem monitoring: Are seals a potential tool for monitoring change in marine systems? Books Online, 2006: 330-343.

Hobday, A. J., Arrizabalaga, H., Evans, K., Nicol, S., Young, J. W., and Weng, K. C. 2015. Impacts of climate change on marine top predators: Advances and future challenges. Deep Sea Research Part II: Topical Studies in Oceanography, 113: 1-8.

Hobday, A. J., and Pecl, G. T. 2014. Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. Reviews in Fish Biology and Fisheries, 24: 415-425.

Hocking, D. P., Salverson, M., Fitzgerald, E. M., and Evans, A. R. 2014. Australian fur seals (*Arctocephalus pusillus doriferus*) use raptorial biting and suction feeding when targeting prey in different foraging scenarios. PloS one, 9.

Hoskins, A. J., and Arnould, J. P.Y. 2014. Relationship between long-term environmental fluctuations and diving effort of female Australian fur seals. Marine Ecology Progress Series, 511: 285-295.

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: 407-415.

IPCC 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)] IPCC, Geneva, Switerland, 151pp. in IPCC AR5 Synthesis Report website. .

Jackson, G. D., McGrath Steer, B., Wotherspoon, S., and Hobday, A. J. 2003. Variation in age, growth and maturity in the Australian arrow squid *Nototodarus gouldi* over time and space-what is the pattern? Marine Ecology Progress Series, 264: 57-71.

A. Jordan, G. Pullen, J.-a. Marshall and H. Williams 1995. Temporal and spatial patterns of spawning in jack mackerel, *Trachurus declivis* (Pisces: Carangidae), during 1988-91 in eastern Tasmanian waters. Marine and freshwater research, 46: 831-842.

Kemp, J., Jenkins, G. P., and Swearer, S. E. 2012. The reproductive strategy of red cod, *Pseudophycis bachus*, a key prey species for high trophic-level predators. Fisheries Research, 125: 161-172.

Kirkwood, R., and Arnould, J. P.Y. 2012. Foraging trip strategies and habitat use during late pup rearing by lactating Australian fur seals. Australian Journal of Zoology, 59: 216-226.

Kirkwood, R., and Goldsworthy, S. 2013. Fur seals and sea lions. CSIRO Publishing, Melbourne.

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.

Knox, T. C., Stuart-Williams, H. Warneke, R. M., Hoskins, A. J., and Arnould, J. P. Y. 2014. Analysis of growth and stable isotopes in teeth of male Australian fur seals reveals interannual variation in prey resources. Marine Mammal Science, 30: 763-781.

Last, P. R., White, W. T., Gledhill, D. C., Hobday, A. J., Brown, R., Edgar, G. J., and Pecl, G. 2011. Long‐term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography, 20: 58-72.

Lea, M.A., Guinet, C., Cherel, Y., Duhamel, G., Dubroca, L., Pruvost, P., and Hindell, M. 2006. Impacts of climatic anomalies on provisioning strategies of a Southern Ocean predator. Marine Ecology Progress Series, 310: 77-94.

Littnan, C. I., Arnould, J. P. Y., and Harcourt, R. 2007. Effect of proximity to the shelf edge on the diet of female Australian fur seals. Marine Ecology Progress Series, 338: 257-267.

Lough, J. M., and Hobday, A. J. 2011. Observed climate change in Australian marine and freshwater environments. Marine and freshwater research, 62: 984-999.

Lovenduski, N. S., and Gruber, N. 2005. Impact of the Southern Annular Mode on Southern Ocean circulation and biology. Geophysical Research Letters, 32.

Lu, C. C., and Ickeringill, R. 2002. Cephalopod beak identification and biomass estimation techniques: tools for dietary studies of southern Australian finfishes. Museum Victoria Scientific Report 6:1–65.

Marshall, G. J. 2003. Trends in the Southern Annular Mode from observations and reanalyses. Journal of Climate, 16: 4134-4143.

Marshall, J., Pullen, G., and Jordan, A. 1993. Reproductive biology and sexual maturity of female jack mackerel, *Trachurus declivis (Jenyns)*, in eastern Tasmanian waters. Marine and freshwater research, 44: 799-809.

McIntosh, R., Sutherland, D., Dann, P., Kirkwood, R., Thalman, S. Alderman, R. Arnould, J. P. Y. et al. 2014. Pup estimates for Australian and New Zealand fur seals in Victoria, Tasmania and New South Wales between 2007 and 2013. Phillip Island Nature Parks; Department of the Environment, Australian Government.

McNally, J., and Lynch, D. D. 1954. Notes on the food of Victorian seals. Office of the Director of Fisheries and Game, Melbourne.

Middleton, J. F., Arthur, C., Van Ruth, P. Ward, T. M., McClean, J. L., Maltrud, M. E., Gill,P. et al. 2007. El Niño effects and upwelling off South Australia. Journal of Physical Oceanography, 37: 2458-2477.

Minnegal, M. and Dwyer, P. D. 2008. Mixed messages: Buying back Australia's fishing industry. Marine Policy, 32: 1063-1071.

Otto, S. A., Kornilovs, G., Llope, M., and Möllmann, C. 2014 498, 73-U408. Interactions among density, climate, and food web effects determine long-term life cycle dynamics of a key copepod. Marine Ecology Progress Series, 498: 73-84.

Page, B. McKenzie, J., and Goldsworthy, S. D. 2005. Dietary resource partitioning among sympatric New Zealand and Australian fur seals. Marine Ecology Progress Series, 293: 283-302.

Phillips, A. J. 2011. Long term albacore (*Thunnus alalunga)* spatio-temporal association with environmental variability in the Northeastern Pacific. MS thesis. Oregon State University, Corvallis, Oregon.

R Core Development team 2015. A Language and Environment for Statistical Computing. R foundation for statistical computing. Vienna, Austria.

Renouf, D. 1991. Behaviour of pinnipeds. Chapman and Hall, London.

Sandery, P. A., and Kämpf, J. 2007. Transport timescales for identifying seasonal variation in Bass Strait, south-eastern Australia. Estuarine, Coastal and Shelf Science, 74: 684-696.

Schmidt, A.E., Dybala, K. E., Botsford, L. W., Eadie, J. M., Bradley, R. W., and Jahncke, J. 2015. Shifting Effects of Ocean Conditions on Survival and Breeding Probability of a Long-Lived Seabird. PloS one, 10: e0132372.

Schumann, N., Arnould, J. P. Y., Gales, N., and Harcourt, R. 2012. Marine mammals. Marine climate change impacts and adaptation report card for Australia: 353-378.

Sebille, E., Sprintall, J. Schwarzkopf, F. U., Sen Gupta, A., Santoso, A., England, M. H., Biastoch, A., et al. 2014. Pacific‐to‐Indian Ocean connectivity: Tasman leakage, Indonesian Throughflow, and the role of ENSO. Journal of Geophysical Research: Oceans, 119: 1365-1382.

Tollit, D. J., Steward, M. J., Thompson, P. M., Pierce, G. J., Santos, M. B., 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: 105-119.

Tollit, D. J., Wong, M., and Trites, A. W. 2015. Diet composition of Steller sea lions (*Eumetopias jubatus*) in Frederick Sound, southeast Alaska: a comparison of quantification methods using scats to describe temporal and spatial variabilities. Canadian Journal of Zoology, 93: 361-376.

Tollit, D. J., Wong, M., Winship, A. J., Rosen D. A., and Trites, A. W. 2003. Qauntifying 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: 724-744.

Trathan, P. N., Forcada, J., and Murphy, E. J. 2007. Environmental forcing and Southern Ocean marine predator populations: effects of climate change and variability. Philosophical Transactions of the Royal Society B: Biological Sciences, 362: 2351-2365.

Trites, A. W., and Joy, R. 2005. Dietary analysis from fecal samples: How many scats are enough? . Journal of Mammalogy, 86: 704-712.

Venables, W. N., and Ripley, B. D. 2002. Modern Applied Statistics with S. Fourth edition. . Springer-Verlag New York, Inc.

Ward, T., and Staunton-Smith, J. 2002. Comparison of the spawning patterns and fisheries biology of the sardine, *Sardinops sagax*, in temperate South Australia and sub-tropical southern Queensland. Fisheries Research, 56: 37-49.

Ward, T. M., Lyle, J., Keane, J. P., Begg, G. A., Hobsbawn, P., Ivey, A. R., Sakabe, R., et al. 2012. Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2011. SARDI Aquatic Sciences, Adelaide.

Whittington, R., Crockford, M., Jordan, D., and Jones, B. 2008. Herpesvirus that caused epizootic mortality in 1995 and 1998 in pilchard, *Sardinops sagax neopilchardus* (Steindachner), in Australia is now endemic. Journal of fish diseases, 31: 97-105.

Wood, S. 2006. Generalized Additive Models: An Introduction with R. Chapman Hall／CRC, Boca Raton, Florida.

Zuur, A.F., Ieno, E. N., and Elphick, C. S. 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution, 1: 3-14.

Zuur, A. F. , Ieno, E. N., Walker, N. J. , Saveliev, A. A., and Smith, G. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer, New York.

Supplementary material

Additional tables:

Table 1: Generalised additive model results for pilchard. The model selection is listed in descending order. All covariates are seasonal values by year; SST refers to sea surface temperature; SOI refers to southern oscillation index; SAM refers to the southern annular mode and wind is local speed and direction.

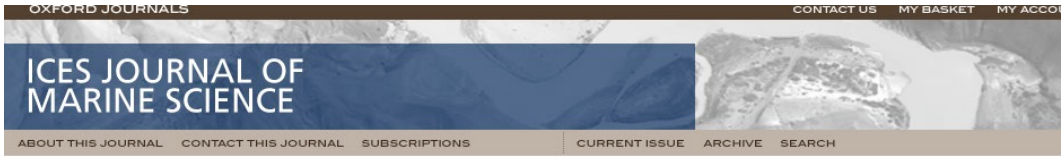
Covariates	AIC	Δ AIC	RL	W	rSq	D.exp
SOI+SAM+SST+ wind*wind direction	177.78	0.00	1.00	0.99	0.89	91.31
SOI+SAM+ wind*wind direction	188.12	17.57	0.01	0.01	0.84	86.68
SOI+wind*wind direction	208.41	41.54	0.00	0.00	0.78	79.07
SST+ wind*wind direction	244.43	55.34	0.00	0.00	0.53	68.55
SAM+ wind*wind direction	244.43	59.72	0.00	0.00	0.53	68.55
SAM+SST+ wind*wind direction	247.81	59.72	0.00	0.00	0.52	66.43
Wind*wind direction	280.22	69.17	0.00	0.00	0.56	56.93
SOI+SST+ wind*wind direction	309.87	124.13	0.00	0.00	0.50	46.84
SAM+SOI+SST	316.83	125.24	0.00	0.00	0.38	47.56
SOI+SAM	323.29	154.94	0.00	0.00	0.41	43.43
SST+SOI	366.50	168.49	0.00	0.00	0.31	29.85
SOI	380.23	211.55	0.00	0.00	0.28	28.30
SAM+SST	416.83	238.13	0.00	0.00	0.01	16.99
SST	450.64	261.68	0.00	0.00	-0.01	8.15
SAM	473.39	295.32	0.00	0.00	0.00	0.00
Null model	1120.87	317.92	0.00	0.00	-1.54	70.67

\

Table 2: Generalised additive model results for jack mackerel. The model selection is listed in descending order. All covariates are the same as Table 5.

Covariates	AIC	Δ AIC	R L	W	rSq	D.exp
SOI+SAM+SST+ wind*wind direction	395.45	0.00	1.00	0.50	0.27	52.56
SOI+SST+ wind*wind direction	397.21	1.76	0.42	0.21	0.27	50.34
SOI + wind*wind direction	397.56	2.10	0.35	0.18	0.28	50.33
SOI+SAM+ wind*wind direction	398.50	3.05	0.22	0.11	0.28	48.40
SOI+SAM+SST	415.97	20.52	0.00	0.00	0.20	39.11
SOI+SST	428.94	33.49	0.00	0.00	0.18	31.12
SOI+SAM	429.01	33.56	0.00	0.00	0.21	31.36
SST+ wind*wind direction	441.88	46.42	0.00	0.00	0.20	23.32
SOI	457.56	62.11	0.00	0.00	-0.04	29.60
SAM+ wind*wind direction	458.14	62.69	0.00	0.00	-0.06	29.91
SAM+SST+ wind*wind direction	458.14	62.69	0.00	0.00	-0.06	29.91
Wind*wind direction	464.76	69.30	0.00	0.00	-0.04	25.12
SAM+SST	480.95	85.50	0.00	0.00	0.03	10.20
SAM	481.78	86.32	0.00	0.00	0.00	12.00
SST	500.42	104.96	0.00	0.00	-0.04	3.04
Null model	500.93	105.48	0.00	0.00	0.00	0.00

Journal instructions



Oxford Journals › Science & Mathematics › ICES Journal of Marine Science › For Authors › Instructions to Authors

CATEGORIES OF PAPERS

The *ICES Journal of Marine Science* publishes papers in each of the following categories:

Original articles: traditional research papers. Generally 5-12 printed pages (approximately 3000- 7000 words) inclusive of text, appropriate references (target 50-60), figures, and tables.

Comment/Reply articles: comments on, or replies to, papers published in the *ICES Journal of Marine Science*; Generally 4 printed pages (approximately 2000 words).

Review articles: comprehensive and synthetic reviews on topics of wide general interest or on hot topics, sometimes solicited by the editorial board. Authors considering submitting a review article for consideration are advised to contact the Editor-in-Chief regarding topic and proposed length.

Food for Thought articles: articles on topical issues, preferably provocative or innovative in nature, solicited or offered to stimulate dialogue, research, and ideas generally.

Quo Vadimus articles: describing the future landscape/potential of a topic, issue, discipline or technology.

GUIDELINES FOR AUTHORS

The following instructions and guidelines will assist authors preparing to submit manuscripts to the *ICES Journal of Marine Science*.

Submissions to regular journal issues should be made online - full instructions are available **here**.

For additional guidance from the editorial office on how to ensure your paper is best suited to the journal see our How to get published in ICES Journal of Marine Science page.

For details of the article types accepted please see our 'about the journal' page.

For queries relating to submission please email Lulu Stader. Additionally, contact details for the Journal's editors may be found on the editorial board page.

Authors are urged to provide a written justification as to why they believe that the content of the paper is relevant to the Journal, highlighting the primary scientific contribution and significance of the work reported.

Authors are expected to comply with the Council of Science Editors authorship criteria guidelines

Authors are requested to identify the editor(s) and reviewers who they think would be appropriate to handle their manuscript. Authors should have no conflicts of interest with that editor or any reviewers whom they recommend. Please note that we cannot guarantee that their preferred editor or reviewers will be assigned.

Format

Manuscripts should usually be submitted as a Word document. The document should be double-spaced throughout with a left-hand margin of 3cm or more, and the page and line numbers function switched

on.

The manuscript should contain the following information: title; author(s); author addresses, plus email address, phone and fax numbers of the corresponding author; abstract; key words; core text; tables and figures.

Maximum word count for abstracts: 300 words

Style
Please use British spelling throughout. Dates should appear in the day-month-year format. Measurements should be metric and use the SI conventions for units and abbreviations.

References
Cite references in the text in the 'name, date' format. If there are two authors, give both names. If there are three or more authors: Smith *et al*. (1988) or (Smith *et al*., 1988). For unpublished material such as personal communications, give the author's first initial(s): (F. Fry, pers. comm.).

The reference list at the end of the article should be restricted to work already published, or definitely accepted for publication (in press). Unpublished material, including work submitted to a journal but not yet formally accepted, should not be included. List entries alphabetically by the first author's surname, followed by initials. In cases of multiple authorship: Fry, F., Plie, I. I., and Soglia, I. Give the names of all authors, unless there are more than seven, in which case, list the first seven authors followed by *et al*. Spell out names of journals in full.

Examples:

1. *Material published in a journal:*
Pares, P., and Britain, B. 1965. Predator–prey behaviour of herring (*Clupea harengus albertus*). International Journal of Applied Biology, 24: 132–135.

2. *Material published in a book:*
Havfrue, D. L. 1990. Ecological implications of genetic mutation. *In* Studies in Parthenogenesis, 2nd edn, pp. 282–289. Ed. by F. Ray, and O. Lith. Thalassa Press, London. 331 pp.

Endnote style files for ICES Journal of Marine Science references can now be downloaded from **here**

Ordering references:
1. In-text citations: please list references by date rather than alphabetically.
2. Reference list: please list references alphabetically by first author, then by date.
Instructions for citing online references – please give url and access date.

If you use EndNote and/or Reference Manager to facilitate referencing citations (not required for submission), this journal's style is available for use here

Language Editing
OUP offers pre-submission language editing through Oxford Language Editing, a service for researchers all over the world. Language editing, particularly if English is not your first language, can be used to ensure that the academic content of your paper is fully understood by the journal editors and reviewers. Visit
www.oxfordlanguageediting.com to find out more about the freelance editors available and the different services offered. Please note that edited manuscripts will still need to undergo peer-review by the journal.

Submission of LATEX files
For submission of TeX manuscripts, ICES Journal of Marine Science strongly recommends the use of its TeX template (click here). All TeX related files should be submitted to the journal, such as the .bib, .sty, and .bst files. No additional styles should be used unless necessary (e.g., to include figure files, to set diagrams, etc.). The use of private macros is discouraged. Only macros used in the manuscript should be supplied with the article (i.e, whole macro libraries from authors' sites should not be submitted).

References should be supplied in standard ICES Journal format using \bibitem and thebibliography environment. No private programs or counters should be used to generate the style of citations and references.

Authors are asked to use the LaTeX tags like \ref, \cite, etc., for the automatic referencing to figures, tables, reference citations, etc. If these are not used, the manuscript will be held up in acceptance and pre-production stages.

For more information please see the OUP Journals FAQ.

FIGURES AND ILLUSTRATIONS

All illustrations should be referred to as figures and should be numbered in a single sequence in the order in which they are mentioned in the text.

Electronically submitted figures should be in high resolution and in one of the following formats: tiff, bitmap (.bmp), jpeg (.jpg), portable data format (.pdf) or postscript (.ps or .eps). The minimum resolution for greyscale and colour images required for publication is 300-500 dpi. For line art the resolution should be at least 1200 dpi. Please be sure to embed the fonts correctly in your eps and pdf files to ensure that they convert to pdf.

For useful information on preparing your figures for publication, go to http://cpc.cadmus.com/da

For any figures that have been previously published, permission must be sought from the previous publisher to reproduce them. It is the authors' responsibility to secure any required permissions prior to submission. Articles cannot be published before permission is secured. Permission must be granted for both print and online publication in perpetuity. These rules apply even if the original figure has been modified. For further advice, please see this page.

Use of colour

We encourage authors to produce all of their figures in colour to enhance the online HTML and PDF versions of their articles. However, colours should be adopted that will reproduce with clarity in grayscale in the printed version of the journal. At the discretion of the Editor, one colour figure will be provided in the print version of the journal free of charge, provided that colour improves on the information content of the figure. Authors will be charged £350/US$600/EUR525 for print reproduction of each additional colour figure in their article. (Orders from the UK will be subject to the current UK VAT charge. For orders from elsewhere in the EU you or your institution should account for VAT by way of a reverse charge. Please provide us with your or your institution's VAT number.) Colour figures must have a resolution of at least 300 dots per inch at their final size.

IMPORTANT: authors should size their figures to fit either into one column (85 mm wide) or double column/page width (170 mm wide), but preferably not in between. Remember to assess how much space your figure legend will take.

Supplementary material for online-only publication

Supplementary information and/or data, which are preferred to Appendices, may be submitted for online-only publication if it adds value to the manuscript. However, it should not contain material crucial to the understanding of the manuscript, which must be able to stand alone. The availability of online supplementary material should be indicated at the appropriate point in the text and in a section entitled "Supplementary material", placed immediately before the Acknowledgements section. The section should begin with a statement such as, "The following supplementary material is available at ICESJMS online", and should include a brief description of the supplementary material. The citation of references within the supplementary section is discouraged because the references are not hyperlinked as they are in the main text. If such a citation is necessary, however, the full reference(s) should be included at the end of the supplementary material.
Supplementary materials should be submitted as separate files.
Please note that Supplementary materials will not be edited or amended in any way by the editors or the publisher. Authors are responsible for ensuring that they are rendered correctly.

ETHICAL CONDUCT

ICESJMS expects that authors will observe the highest standards with respect to publication ethics. For example, the following practices are unacceptable: (1) falsification or fabrication of data, (2) plagiarism, including duplicate publication of the authors' own work in whole or in part, (3) misappropriation of the work of others such as omission of qualified authors, (4) withholding information of relevance to assess possible conflicts of interest (e.g. financial support), etc. Allegations of unethical conduct will be discussed initially with the corresponding author. In the event of an unresolved dispute, the matter may be referred to the author's institution and funding agencies for investigation and adjudication.

ICESJMS applies plagiarism detection software (iThenticate) to submitted manuscripts. The Journal reserves the right to decline submissions suspected of plagiarism at any point during the assessment process and will retract articles found to violate plagiarism guidelines after publication. In addition, the Journal reserves the right to report any suspicion of plagiarism to the senior author's institution.

Oxford University Press, publisher of the *ICESJMS*, is a member of the Committee on Publication Ethics (COPE), the Journal adheres to the COPE code of conduct and guidelines.

ANIMAL ETHICS AND WELFARE

Authors must adhere to international guidelines and standards for the ethical use of animals in research (see also the Fisheries Society of the British Isles Briefing Paper on fish welfare), the legal requirements of the country in which the work was carried out, and any institutional guidelines. Authors should state

(within the Methods section) the name of the local and/or national body that grants approval for the use of animals in research and the reference number for animal ethics approval of the protocols applied in the work.

If ethical considerations arose in the course of the study, the author should describe in the manuscript how those considerations were addressed. In exceptional cases, where unresolved ethical questions remain, the manuscript may be sent to appropriate experts in the ethical use of animals in research for additional refereeing. In such cases, the decision as to whether the manuscript is accepted for publication remains with the journal Handling Editor or, in the final instance, the Editor-in-Chief.

CONFLICT OF INTEREST

At the point of submission, the journal's policy requires that each author reveal any financial interests or connections, direct or indirect, or other situations that might raise the question of bias in the work reported or the conclusions, implications, or opinions stated - including pertinent commercial or other sources of funding for the individual author(s) or for the associated department(s) or organization(s), personal relationships, or direct academic competition. When considering whether you should declare a conflicting interest or connection please consider answering the following question: Is there any arrangement that would embarrass you or any of your co-authors if it was to emerge after publication and you had not declared it?

As an integral part of the online submission process, Corresponding Authors are required to confirm whether they or their co-authors have any conflicts of interest to declare, and to provide details of these. If the Corresponding Author is unable to confirm this information on behalf of all co-authors, the authors in question will then be required to submit a completed Conflict of Interest form to the Editorial Office. It is the Corresponding Author's responsibility to ensure that all authors adhere to this policy.

If the manuscript is published, Conflict of Interest information will be communicated in a statement in the published paper.

If you think that you require a Conflict of interest form email: emily.hill@oup.com

GENERAL POLICIES

Proofs

Page proofs are sent to authors as a PDF file by e-mail. To avoid delays in publication, proofs should be checked immediately for typographical errors and returned as instructed in the proof e-mail. Essential changes of an extensive nature may be made only by insertion of a Note Added in Proof.
Page charges will not be levied. Authors will, however, be charged for extensive changes made in proof and for special items such as colour that appear in the printed Journal (but see below under 'Illustrations' for inclusion of colour online without charge).

OPEN ACCESS OPTION FOR AUTHORS

ICES Journal of Marine Science authors have the option to publish their paper under the Oxford Open initiative; whereby, for a charge, their paper will be made freely available online immediately upon publication. After your manuscript is accepted the corresponding author will be required to accept a mandatory assignment of copyright agreement. As part of the assignment process you will be asked to indicate whether or not you wish to pay for open access. If you do not select the open access option, your paper will be published with standard subscription-based access and you will not be charged.

Oxford Open articles are published under Creative Commons licences. Authors publishing in ICES Journal of Marine Science can use the following Creative Commons licences for their articles:

• Creative Commons Attribution licence (CC-BY)

Please click here for more information about the Creative Commons licences.

You can pay Open Access charges using our Author Services site. This will enable you to pay online with a credit/debit card, or request an invoice by email or post. The open access charges applicable are:

Regular charge - £1750/ $2800 / €2275
List B Developing country charge* - £875 / $1400 / €1138
List A Developing country charge* - £0 /$0 / €0
*Visit our Developing Countries page for a list of qualifying countries

Please note that these charges are in addition to any colour/page charges that may apply.

Orders from the UK will be subject to the current UK VAT charge. For orders from the rest of the European Union, OUP will assume that the service is provided for business purposes. Please provide a VAT number for yourself or your institution, and ensure you account for your own local VAT correctly.

ASSIGNMENT OF COPYRIGHT

It is a condition of publication that authors grant an assignment of copyright to Oxford Journals or the society of ownership. This ensures that requests from third parties to reproduce articles are handled efficiently and consistently, and will also allow the article to be as widely disseminated as possible. In assigning copyright, authors may use their own material in other publications, provided that the journal is acknowledged as the original place of publication, and Oxford Journals is notified in writing and in advance. Work submitted for publication must be original, previously unpublished, and not under consideration for publication elsewhere. If previously published figures, tables, or parts of text are to be included, the copyright-holder's permission must have been obtained prior to submission. The author bears the responsibility for checking whether material submitted is subject to copyright or ownership rights, e.g. photographs, illustrations, trade literature and data. Where use is so restricted, the Editors and the Publisher must be informed with the submission of the material.

Upon receipt of accepted manuscripts at Oxford Journals authors will be invited to complete an online copyright assignment form.

Please note that by submitting an article for publication you confirm that you are the corresponding/submitting author and that Oxford University Press ("OUP") may retain your email address for the purpose of communicating with you about the article. You agree to notify OUP immediately if your details change. If your article is accepted for publication OUP will contact you using the email address you have used in the registration process. Please note that OUP does not retain copies of rejected articles.

DATA ARCHIVING AND SOFTWARE CODE ACCESSIBILITY

To promote the preservation and fuller use of data, the ICES Journal of Marine Science encourages data and software code archiving in appropriate public data libraries.

ICES has a well-established Data Centre, which manages a number of large dataset collections related to the marine environment. By maximizing the availability of data to the community at large, ICES promotes the use of these data, thereby ensuring that their maximum value can be realized. Authors are encouraged to read the ICES data submission guidelines and policy.

Alternately, PANGAEA® is a data archive that is certified by the International Council for Science (ICSU) World Data System (WDS). Data can be submitted in any format in accordance with PANGAEA's general data submission guidelines. There are many alternative archives that may suit a particular data set, including theDryad repository for ecological and evolutionary biology data. For gene sequence data and phylogenetic trees, deposition in GenBank or TreeBASE, respectively, is often appropriate.

Accession numbers for GenBank, TreeBASE, and Dryad should be included in accepted manuscripts.

For primary biodiversity data authors are encouraged to place all species distribution records in a publicly accessible database such as the national Global Biodiversity Information Facility (GBIF) nodes or data centres endorsed by GBIF, including BioFresh for freshwater data.

Additionally, for papers published in ICESJMS, supplementary material (including data) can be submitted as online Supplementary Material.

- About the journal
- Rights & Permissions
- This journal is a member of the Committee on Publication Ethics (COPE)
- We are mobile – find out more

Published on behalf of

- ICES/CIEM International Council for the Exploration of the Sea/Conseil International pour l'Exploration de la Mer

Editor-in-Chief

Dr Howard I. Browman

- View full editorial board

Impact factor: 2.525

5-Yr impact factor: 2.595

Eigenfactor®: 0.01588

- Instructions to authors
- Submit Now!
- Online Submission Instructions

- Author Self Archiving Policy

Open access options for authors - visit Oxford Open

- This journal is compliant with the Research Councils UK Policy on Access to Research Outputs
- What we offer
- Advertising sales
- Reprints
- Supplements
- Email table of contents
- Email Advance Access
- CiteTrack
- XML RSS feed

Online ISSN 1095-9289 - Print ISSN 1054-3139